Hydrological Implications of Planting Bluegum in Natural Shola and Grassland Watersheds of Southern India

J.S. Samra*, A.K. Sikka, and V.N. Sharda

ABSTRACT

The paper presents the results of a long term (1968-92) experimental watershed study conducted by Central Soil & Water Conservation Research & Training Institute, Research Center, Udhagamandalam at Glenmorgan in Nilgiris on the hydrological implications, tree growth and economics of planting Eucalyptus globulus (bluegum) in a natural mixed “Shola” and grassland forest watershed following the paired watershed technique. Grassland area of 18.7 ha (59%) of a watershed was replaced with bluegum in one of the two comparable watersheds of about 32 ha each during 1972, after a calibration period of 4 years (1968-71). Ten years rotation cycle was followed for harvesting and coppice regeneration. Average annual reduction in water yield of the order of 16% and 25.4% was determined from the bluegum watershed over the natural grassland during the first and second rotation, respectively. Maximum reductions in runoff were observed during July to October and this was attributed to greater availability of rainfall and hence its utilization during this period. Appreciable reduction in low flow as a result of decline in base flow could be predicted with Low Flow Index (LFI) decreasing by 2.0 and 3.75 times, in the first and second rotation, respectively. This dry period flow, though small, is very crucial for sustaining water supply to hydroelectric reservoirs. Moderation in peak discharge rates was also observed as a result of bluegum plantation. The biomass and economic returns for the second rotation were also 42 per cent and 40 per cent higher than the first rotation, but at a cost of 60% more reduction in water yield during the second rotation over the first rotation. The coppiced bluegum depleted soil moisture from deeper soil layer whereas during the first rotation, the extraction was mostly confined to the surface layers.

INTRODUCTION

Land use activities and vegetation manipulation that alter the type or extent of vegetative cover on a watershed may affect water budget of a catchment. Forest and grassland watersheds are largely confined to upper catchments of important water resources projects. The Nilgiris (blue mountains), situated in Western Ghat in South India, have unique climatic-climax vegetation called “Shola” forest and vast stretches of grasslands with swampy dots here and there. Large-scale plantations of Eucalyptus globulus (bluegum) were taken up in these catchment areas during sixties and seventies by planting bluegum in grasslands. These areas form catchments to number of important hydro-electric reservoirs constructed in Nilgiris, accounting for about 40% of the total hydro-electric power generated in Tamil Nadu State. Hydrological implications of planting bluegum in these catchments are therefore very crucial to the area.

A number of studies have been conducted on hydrological behavior of planting bluegum in India (Samraj et al., 1988; Sharda et al., 1988; Sikka et al., 1998; Sharda et al., 1998) and elsewhere (Calder et al., 1993; Stoneman, 1993; David et al., 1994). These studies are location specific and not much information is available on the effects of coppiced eucalyptus on hydrological behavior. The focus of this paper is to summarize the results of a long term study (1968-92) conducted by Central Soil and Water Conservation Research and Training Institute, Research Center, Udhagamandalam in this regard and it presents the hydrological behavior, tree growth and economics of planting bluegum in a natural mixed “Shola” and grassland watershed in the Nilgiris, South India.

DESCRIPTION OF STUDY AREA

The study area is located at Glenmorgan (latitude 11°28’10” N and longitude 76°37’14” E), 24 kms away from Udhagamandalam on Udhagamandalam-Mysore road in Wenlock Downs Forest Reserves in the Nilgiris district of Tamil Nadu. The study area consists of two small adjoining watersheds (each about 32 ha) having nearly identical topography, slope, vegetation and soil characteristics. The area is marked by the rugged, undulating topography at an elevation of 2,200 m above mean sea level. The important watershed characteristics of both the watersheds A and B (A - control and B - treated with bluegum plantations) are presented in Table 1. It experiences a montane temperate humid climate with an average annual rainfall of 1379 mm, mostly confined to the southwest monsoon and the northeast monsoon. Maximum temperature of 26°C during April-May and lowest temperature close to 0°C during December-January have been observed. The detailed analyses of rainfall and watershed characteristics are available in Sikka et al (1998).

*J.S. Samra, Indian Council of Agricultural Research, Krishi Bhavan, New Delhi-110 001 India; A.K. Sikka, Central Soil & Water Conservation Research & Training Institute, Research Centre, Udhagamandalam – 643 004, India; and V.N. Sharda, Central Soil & Water Conservation Research & Training Institute, Dehra Dun - 248 195, India. *Corresponding author: cwcrti@icar.delhi.nic.in.
The soils are lateritic and derived from Charnockites with texture varying from sandy loam to sandy clay loam. The field capacity, wilting point and bulk density have reported as 28.6%, 18% and 1.33 g cm\(^{-3}\), respectively (Anonymous, 1987). The “Shola” forests are largely confined to the valleys or folds, while the adjoining hill slopes are covered with grasses. “Shola” is a wet temperate montane evergreen forest with well-developed top canopy, underwood, undergrowth, leaf litter, humus, lianas, epiphytes, parasites, and saprophytes. It is a climatic climax forest of indeterminable age. The humus and thick leaf litter (10-25 cm thick) are responsible for retention of large amount of water and its slow release, thus giving rise to perennial streams. *Rhododendron arboreum*, *Symplocos spicata*, *Meliosma wightii*, and *Litsea arnottiana* are the dominant “Shola” species in the watersheds.

### METHODOLOGY

Paired watershed technique was followed in the two adjacent identical watersheds (A & B) each having about 32 ha size. After a calibration period of 4 years (1968-71), bluegum was planted at a spacing of 2 x 2 m in one of the watersheds (B) during July 1972 above the frost line covering an area of 18.76 ha (59%). The rest of the area (41%) in watershed B and the entire watershed A were kept under natural conditions of grasslands (grazed) and “Shola” forest. The silvicultural management practices consisted of felling and coppicing of the trees at 10 years rotation.

Automatic stage level recorders with 2:1 broad crested triangular weir were installed for recording runoff at the outlet of both the watersheds, A and B, during 1968. A small meteorological laboratory was also established near the ridge, demarcating the boundary of the two watersheds to record various climatological parameters like rainfall, temperature, open pan evaporation, etc. The soil moisture measurements were made at weekly intervals up to 0.5 to 1.0 m sampling depths during both the rotations. The fluctuations in ground water levels were also recorded in the swamps through piezometric wells installed to a depth of 1.25 m and along the slope through piezometric wells installed to a depth of 5 m. The observations on height, growth and tree diameter at breast height (DBH) of bluegum were recorded regularly during the first and second rotation.

Based upon runoff data collected during the calibration period, regression equations were developed for total runoff, surface runoff and base flow in watersheds A and B (Samraj et al., 1988). Table 2 presents the data on total runoff and base flow in the watersheds A and B during the calibration period. The regression equations developed during the calibration period were used to compute the stream flow for bluegum planted watershed B from the observed data of natural grassland watershed A for both the rotations in order to determine changes in water yield. The computed values of runoff for watershed B from known values of watershed A were compared with the observed values of runoff for watershed B during the first and second rotation to quantify net reduction in water yield. The student’s paired ‘t’ test applied to runoff data revealed that the differences in total runoff and base flow were statistically significant at 1% level. Flow duration curves and Low Flow Index (LFI) were used to quantify the effect of bluegum on low flow regime. Effect of bluegum on high flow was investigated using simple ratios.

### RESULTS AND DISCUSSION

#### Effect of bluegum on water yield

Double mass curves for annual total runoff and base flow drawn between the cumulative observed values of Watershed A and Watershed B for the first and second rotations are shown in Figures 1 and 2. It is observed from double mass curves that reduction in runoff for the bluegum planted watershed could be noticed from 1975 onwards during the first rotation after initial bluegum plantation was well established. While during the second rotation (after clear felling of bluegum at the end of first rotation), bluegum planted watershed started yielding less runoff from the next year 1983 onwards due to rapid growth of coppice shoots. Table 1 presents the annual summary of observed and computed values of total flow and base flow for the first and second rotation for bluegum planted watershed. The average annual reduction in water yield (i.e. total runoff) during the second rotation, as a result of bluegum plantation...

### Table 1. Comparison of geomorphological and land use characteristics of the watersheds.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Watershed A (Control)</th>
<th>Watershed B (Treated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ha)</td>
<td>33.18</td>
<td>31.89</td>
</tr>
<tr>
<td>Initial landuse (ha)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area under “shola”</td>
<td>5.20</td>
<td>2.66</td>
</tr>
<tr>
<td>Area under natural grassland</td>
<td>25.48</td>
<td>26.83</td>
</tr>
<tr>
<td>Area under swamps</td>
<td>2.50</td>
<td>2.40</td>
</tr>
<tr>
<td>Shape index</td>
<td>2.22</td>
<td>1.03</td>
</tr>
<tr>
<td>Max. length of stream (m)</td>
<td>450</td>
<td>380</td>
</tr>
<tr>
<td>Stream density (Km/Km(^2))</td>
<td>1.40</td>
<td>1.20</td>
</tr>
<tr>
<td>Average slope (%)</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>Mean elevation (m)</td>
<td>2166</td>
<td>2166</td>
</tr>
<tr>
<td>Watershed Relief (m)</td>
<td>55</td>
<td>61</td>
</tr>
<tr>
<td>Time of concentration (minutes)</td>
<td>10.30</td>
<td>9.10</td>
</tr>
<tr>
<td>Perimeter (m)</td>
<td>2315</td>
<td>2214</td>
</tr>
<tr>
<td>Form factor</td>
<td>0.41</td>
<td>0.49</td>
</tr>
<tr>
<td>Compactness co-efficient</td>
<td>1.13</td>
<td>1.11</td>
</tr>
</tbody>
</table>

### Table 2. Observed values of total runoff and baseflow in watersheds A and B during the calibration period (1968-69 to 1971-72).

<table>
<thead>
<tr>
<th>Year</th>
<th>Watershed A (Control-untreated)</th>
<th>Watershed B (Planted with Eucalyptus)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total runoff (mm)</td>
<td>Baseflow (mm)</td>
</tr>
<tr>
<td>1968</td>
<td>335</td>
<td>290</td>
</tr>
<tr>
<td>1969</td>
<td>210</td>
<td>125</td>
</tr>
<tr>
<td>1970</td>
<td>404</td>
<td>314</td>
</tr>
<tr>
<td>1971</td>
<td>490</td>
<td>386</td>
</tr>
</tbody>
</table>
was found to be 94 mm (25.4%) over the natural grassland and “Shola” forest, as against 87 mm(16%) during the first rotation. The average annual reductions in base flow during the first and second rotations were 15% and 27%, respectively. The greater magnitude of reduction in runoff during the second rotation (i.e., first coppiced growth) is attributed to fast and vigorous sprouting of coppice shoots and higher wood biomass production. Average annual reductions in water yield by 9.6% and 20.4%, respectively during the first four years of first rotation and second rotation also confirm these reductions due to fast and vigorous sprouting of coppice shoots.

From the pooled month-wise analysis of runoff data, it was inferred that 68, 76 and 56% of the mean annual reduction in total runoff, surface runoff and base flow happened due to coppiced bluegum growth during the months from July through October. Since rainfall during this period was about 60% of the annual rainfall, it was inferred that reduction in water yield by bluegum was directly related to the availability of rainwater during the southwest and northeast monsoon seasons.

The bluegum plantation covered only 59% (18.7 ha) of the total watershed area of 31.89 ha. If the entire watershed area had been fully stocked with bluegum trees, the reduction in the magnitude of water yield would have been much higher.

**Hydrological Recovery after clear felling**

In order to quantify this effect, the regression equations developed for annual runoff, between Watershed A and Watershed B for both the rotations were used to compute the
runoff for clear-felled watershed B assuming no felling was
done. This computed runoff was compared with the
observed runoff from watershed B after felling in both the
rotations. Comparisons of observed and predicted monthly
runoff shown in Figures 3 and 4 demonstrated fast
hydrologic recovery after clear-felling of bluegum during
the year 1982 and 1992 at the end of first and second
rotations, respectively. Immediately after clear felling of
bluegum in 1982, there was hydrological recovery since the
computed total runoff (201.8 mm) and observed (201.1 mm)
were almost same. Rapid and vigorous growth of coppice
shoots in the subsequent year (1983) reduced the total runoff
and base flow by 19 and 31%, respectively compared to
natural grassland watershed. A similar trend was observed
during 1992 after the second harvest of coppiced bluegum.
Fast hydrologic recovery is attributed to extremely rapid and
vigorous growth of coppice shoots of bluegum.

**Effect on Low Flow**

Mean monthly flow data revealed that the dry period
(January-April) total flow was reduced by 20% due to
bluegum plantations during the first rotation and by 28.6%
during the second rotation. The base flow went down by
18% during the first rotation, which was further reduced to
24% during the second rotation (i.e., first coppice growth
period).

Low Flow Index (LFI), the 10 days average flow which
is exceeded 95% of the time of the duration of series, was
estimated from 10 days flow duration curves developed for
the calibration, first rotation and second rotation periods
(Sikka et al., 1998). The Low Flow Index registered a
decrease of 3.75 times during the second rotation as
compared to 2 times during the first rotation over the natural
grassland watershed A, thereby indicating higher reduction
in water yield (largely base flow) due to coppiced bluegum.
This dry period flow, though small, is very crucial for
sustaining water supply in hydroelectric reservoirs.

**Effect on High Flow**

The total number of flow events were grouped under
selected runoff depth classes together with total runoff for
the calibration, first and second rotation periods for both the
Watersheds A and B. The number of flow events in the
lowest depth class i.e., up to 2 mm have increased while
there is a decrease in the number of events in the higher
runoff depth class after bluegum plantation, both during the
first and second rotation periods as compared to calibration
period.

The analysis of peak flows for the selected storm events
revealed significant moderation of peakedness (Figure 5).
The average ratio of peak discharge from planted and
natural grassland watershed decreased from 1.03 during the
calibration period to 0.54 during the first rotation and to
0.52 during the second rotation.

**Effect on Soil Moisture**

The analysis of 0.5 m depth has revealed that the
bluegum growth brought in statistically significant (1% level)
reduction in mean monthly soil moisture of 2.35 cm
yr\(^{-1}\) (23.5 cm cumulative difference) during the second
rotation as compared to 1.15 cm yr\(^{-1}\) (or 11.5 cm cumulative)
during the first rotation. At 1 m depth, the reduction in soil
moisture was of the order of 3.0 cm yr\(^{-1}\) during the second
rotation as compared to 1.8 cm/year during the first rotation.
This reduction was significant both at 1 and 5% level during
the second rotation while during the first rotation it was
significant only at 5% level. The coppiced bluegum depleted
soil moisture from deeper soil layer whereas during the first
rotation, the extraction was mostly confined to the surface
layers. Direct contact of the root system with the ground
water table was not observed during the two rotations.

**Effect on Growth & Economics**

The annual growth rate of height during the second rotation
indicated that the growth rate of height during the second
rotation was maximum during the 2nd to 4th year and after 5th
year onwards it slowed down contrary to the first rotation,
wherein the growth rate of height was maintained steadily
right from 2nd year up to harvest (Figure 6). The DBH
(diameter at breast height) also followed a similar trend of
growth in the second and first rotations. The coppice shoots
were allowed to grow naturally and on an average two to
three shoots per tree were recorded. The higher values of
height and DBH during the second rotation increased
biomass production substantially. The total volume of
pulwood, for example, has increased by 42% during the
second rotation (4810.1 m\(^3\)) in comparison to the first
rotation (3391.3 m\(^3\)). The coppiced bluegum plantations
of the second rotation were harvested during July 1992, and
were sold out separately for pulpwood and leaves. The total
income from pulpwood, leaves and rejects for the second
1982-83) as compared with Rs.3250 ha yr\(^{-1}\) in the
first rotation, thereby registering an increase of more than 40%
over the first rotation.

**CONCLUSIONS**

The bluegum planted watershed produced lesser base
flow and total runoff than the natural grassland and “Shola”
watershed and the reduction was more pronounced during
the second rotation. As against 16 and 15% reduction in
total runoff and base flow during the first rotation, the
coppiced bluegum caused higher reduction of 25.4 and 27%
Figure 6. Height and DBH of bluegum plantation during two rotations.

Table 3 Observed and Computed Values of Total Runoff and Baseflow for bluegum planted Watershed-B.

<table>
<thead>
<tr>
<th>Years</th>
<th>Total runoff in mm</th>
<th>Baseflow in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Computed</td>
</tr>
<tr>
<td>First Rotation (1972-73 to 1981-83)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1972</td>
<td>600</td>
<td>609</td>
</tr>
<tr>
<td>1973</td>
<td>523</td>
<td>541</td>
</tr>
<tr>
<td>1974</td>
<td>432</td>
<td>431</td>
</tr>
<tr>
<td>1975</td>
<td>585</td>
<td>787</td>
</tr>
<tr>
<td>1976</td>
<td>203</td>
<td>259</td>
</tr>
<tr>
<td>1977</td>
<td>479</td>
<td>556</td>
</tr>
<tr>
<td>1978</td>
<td>619</td>
<td>713</td>
</tr>
<tr>
<td>1979</td>
<td>516</td>
<td>697</td>
</tr>
<tr>
<td>1980</td>
<td>301</td>
<td>436</td>
</tr>
<tr>
<td>1981</td>
<td>368</td>
<td>463</td>
</tr>
<tr>
<td>Total</td>
<td>4626</td>
<td>5492</td>
</tr>
<tr>
<td>Mean</td>
<td>462.6</td>
<td>549.2</td>
</tr>
<tr>
<td>% Reduction</td>
<td>15.8</td>
<td>15.3</td>
</tr>
</tbody>
</table>

Second Rotation (1981-82 to 1991-92)

|                        | Observed | Computed | Observed | Computed |
| 1982                   | 201      | 202      | 122      | 142      |
| 1983                   | 198      | 245      | 101      | 146      |
| 1984                   | 287      | 421      | 90       | 149      |
| 1985                   | 231      | 283      | 131      | 174      |
| 1986                   | 266      | 327      | 148      | 193      |
| 1987                   | 191      | 292      | 96       | 147      |
| 1988                   | 211      | 326      | 94       | 141      |
| 1989                   | 410      | 563      | 125      | 152      |
| 1990                   | 217      | 281      | 90       | 99       |
| 1991                   | 546      | 757      | 140      | 208      |
| Total                  | 2758     | 3697     | 1137     | 1551     |
| Mean                   | 275.8    | 369.7    | 113.7    | 155.1    |
| % Reduction            | 25.4     | 26.5     |          |          |

The runoff, during the lean flow period (January-April) was reduced by 28.6% due to coppiced bluegum as against 20% during the first rotation as compared to natural grassland. Decreased LFI by 2.0 and 3.75 times for bluegum planted watershed over the natural grassland watershed in the first and second rotation respectively demonstrated the effect of bluegum in affecting the streams low flow regime. This period of low flow is more crucial for sustaining storage levels in the hydroelectric reservoirs. These results clearly demonstrate more pronounced hydrologic implications during the second rotation (i.e., coppiced growth) as compared to first rotation. Moderation in peak discharge rates was also observed as a result of bluegum plantation, during both the rotations.

Increased wood biomass of coppiced bluegum during the second rotation resulted in 40% increased income over the first rotation, but at a cost of 60% more reduction in annual water yield as compared to first rotation. The results tend to suggest adoption of suitable silvicultural practices like planting of such fast growing tree species at wider spacing, following different rotation periods of plantations and having mixed plantations in the catchments of hydroelectric reservoirs in the Nilgiris.

REFERENCES


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