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

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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 11º28′10″ N and longitude 76º37′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 26ºC during April-May and lowest temperature close to 0ºC during December-January have been observed. The detailed analyses of rainfall and watershed characteristics are available in Sikka

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et al (1998).

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

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

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

Year	Watershed A (Control-untreated)		Watershed B (Planted with *Eucalyptus)*	
	Total runoff (mm)	Baseflow (mm)	Total runoff (mm)	Baseflow (mm)
1968	335	290	305	252
1969	210	125	247	161
1970	404	314	451	350
1971	490	386	485	386

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 wighti,* 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 pipe 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 '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

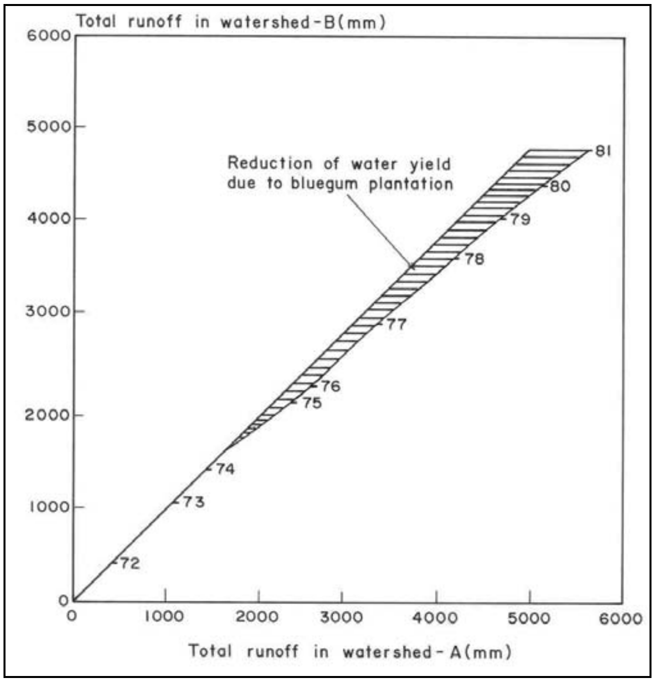

Figure 1. Double mass curve of total runoff from natural grassland (A) and bluegum planted (B) watershed for the first rotation (1972-81).

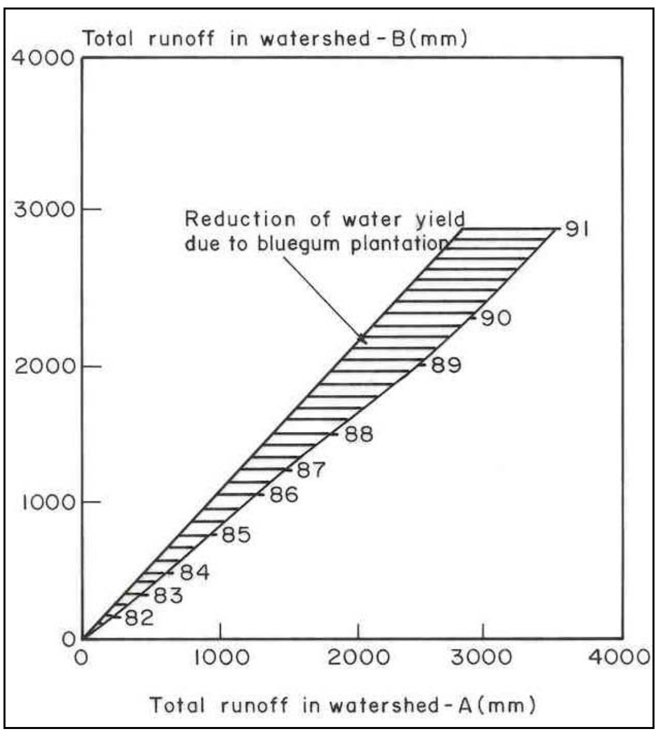

Figure 2. Double mass curve of total runoff from natural grassland (A) and bluegum planted (B) watersheds for the second rotation (1982-91).

annual reduction in water yield (i.e. total runoff) during the second rotation, as a result of bluegum plantation 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

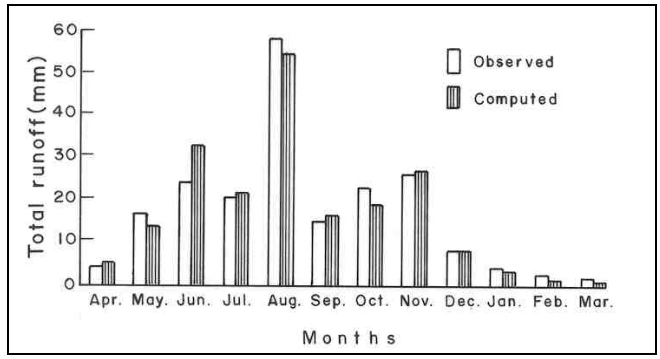

Figure 3. Monthly observed and computed total runoff during 1982 just after clear felling of bluegum (first rotation) indicating hydrological recovery.

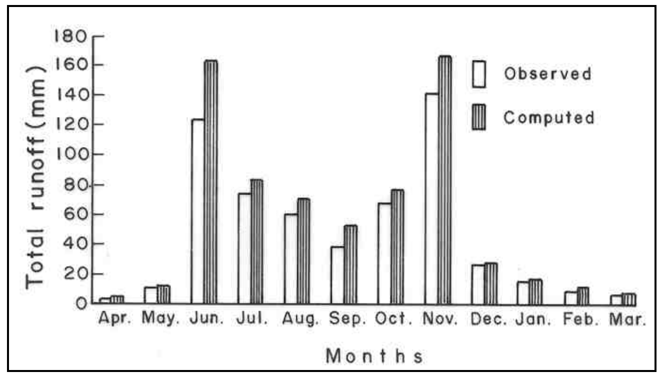

Figure 4. Monthly observed and computed total runoff during 1992 just after clear felling of bluegum (second rotation) indicating hydrological recovery.

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 2^{nd} to 4^{th} year and after 5^{th} year onwards it slowed down contrary to the first rotation, wherein the growth rate of height was maintained steadily right from 2^{nd} 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 pulpwood, 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

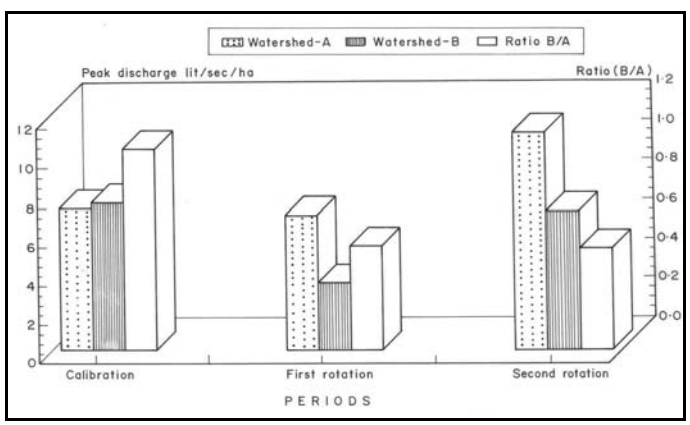

Figure 5. Concurrent peak discharges for all peaks > 0.47 L sec^{-1} ha^{-1} in natural grassland (A) and bluegum planted (B) watersheds.

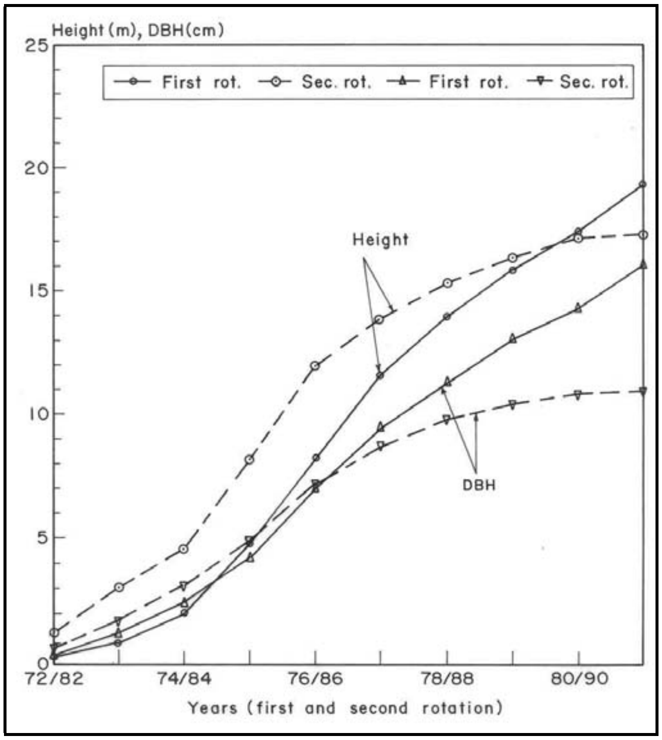

Figure 6. Height and DBH of bluegum plantation during two rotations.

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

Years	Total runoff in mm		Baseflow in mm	
	Observed	Computed	Observed	Computed
First Rotation (1972-73 to 1981-83)				
1972	600	609	431	437
1973	523	541	346	362
1974	432	431	349	360
1975	585	787	438	683
1976	203	259	167	213
1977	479	556	302	397
1978	619	713	392	491
1979	516	697	311	322
1980	301	436	212	272
1981	368	463	258	247
Total	4626	5492	3206	3784
Mean	462.6	549.2	320.6	378.4
% Reduction		15.8		15.3
Second Rotation (1981-82 to 1991-92)				
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 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% over the natural grassland during the second rotation. The rotation worked out as Rs.4560 ha yr^{-1} (at the price level of mean annual reduction in total runoff, surface runoff and base flow by 68, 76 and 56%, respectively due to bluegum growth during the months from July through October suggested that this was directly related to the availability of rain water during the South-West and North-East monsoon seasons. Rapid and vigorous growth of coppice shoots lead to fast hydrological recovery after clear-felling in both the rotations.

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.

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