AN EUCALYPT AND BHABAR GRASS PLANTATION SYSTEM TO OPTIMIZE RESOURCE USE FOR BIOMASS PRODUCTION IN THE FOOTHILLS OF SUB-TROPICAL NORTH INDIA

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GREWAL, S. 1995. An eucalypt and bhabar grass plantation system to optimize resource use for biomass production in the foothills of sub-tropical north India. In a replicated field study conducted for eight years (1984-91) on an eroded alluvial soil of semi-arid tropics (Udic Ustocrept), bhabar, a commercial grass (*Eulaliopsis binata*) was uniformly intercropped under *Eucalyptus tereticornis* planted at 2500 ha^{-1} for pole wood in a north-south oriented paired rows system allowing better canopy adjustment and light conditions. The response to six eucalypt planting treatments, usual pits of 0.3 m^3 (T1), shallow augerhole SAH (6 x 60 cm) (T2), deep augerhole DAH (6 x 120 cm) (T3), DAH filled with 1 kg farm yard manure (FYM) (T4), DAH filled with 1 kg of rice husk (RH) (T5), and DAH+FYM+RH (T6), was studied to find out the best practice that promotes tree growth and minimizes competition for moisture. After seven years, the best and the worst treatments of DAH + FYM (T4), and pit planting (T1) recorded a survival of 84 and 53%, DBH of 9.7 and 8.6 cm, pole biomass of 67.1 and 28.5 air-dry tonnes, marketable number of poles 2109 and 1328 and annual net returns from trees and grass Rs 10 659 and Rs 6239 ha^{-1} y^{-1} respectively against Rs 700 ha^{-1} y^{-1} from rainfed field crops. DAH without FYM (T3) and SAH (T2) followed the best treatment. Rice husk (high CN ratio) seriously depressed tree growth. FYM filled in DAH helped in the development of a vigorous deep root system to exploit moisture from lower soil layers and hence alleviated the effect of droughts. The grass yield under tree planting treatments was almost uniform, and varied from 11 t ha^{-1} in good to 2 t ha^{-1} in poor rainfall years with annual mean of 4.07 t ha^{-1} from the November and 0.99 t ha^{-1} from the June cuts. The plantation improved infiltrability of the soil and hence ensured less runoff and efficient use of rainwater resource for biomass production.

Key words: Plantation - eucalypt - bhabar grass - treatments - biomass

GREWAL, S. 1995. Sistem ladang rumput eucalyptus dan bhabar untuk mengoptimumkan penggunaan sumber bagi pengeluaran biojisim di kaki bukit-kaki bukit sub-topika di India utara. Satu kajian lapang semula yang dijalankan selama lapan tahun (1984-91) di atas tanah aluvium yang terhakis di tanah separa-gersang (Udic Ustocrept), bhabar, sejenis rumput komersil *(Eulaliopsis binata)* telah ditanamselang secara seragam di bawah *Eucalyptus tereticornis;* ditanam pada 2500 ha^{-1} bagi kayu jarak pada satu sistem barisan berkembar berunsurkan utara-selatan membenarkan penyelarasan sudur dan keadaan cahaya yang lebih baik. Tindak balas ke atas rawatan enam tanaman Eucalypt, lubang yang biasa iaitu 0.3m^3 (T1), lubang penggerek yang cetek SAH (6 x 60 cm) (T2), lubang penggerek yang dalam DAH (6 x 120 cm) (T3), DAH yang diisi dengan 1 kg baja dari reban (FYM) (T4), DAH yang diisi dengan 1 kg sekam padi (RH) (T5) dan DAH + FYM + RH (T6) telah dikaji untuk mendapatkan cara yang paling baik untuk menggalakkan pertumbuhan pokok dan meminimumkan persaingan untuk lembapan. Selepas tujuh tahun, rawatan DAH + FYM (T4) yang paling baik dan penanaman lubang (T1) yang paling teruk, mencatatkan kemandirian bagi 84 dan 53%, DBH bagi 9.7 dan 8.6 cm, biojisim kayu jaras bagi 67.1 dan

28.5 tan angin-kering, bilangan kayu jaras yang boleh dijual 2109 dan 1328 dan pulangan bersih tahunan daripada pokok-pokok dan rumput masing-masing Rs 10659 dan 6239 bertentangan dengan Rs 700 ha^{-1} y^{-1} daripada tanaman ladang "rainfed". DAH tanpa FYM (T3) dan SAH (T2) mengikuti rawatan yang paling baik. Sekam padi (kadar CN yang tinggi) menyebabkan kemerosotan dalam pertumbuhan pokok. FYM yang diisi dengan DAH membantu pertumbuhan sistem akar dalam yang bertenaga bagi mengeksploit lembapan daripada lapisan tanah yang lebih rendah dan dengan ini mengurangkan kesan disebabkan oleh kemarau. Hasil rumput dengan rawatan penanaman pokok hampir-hampir seragam, dan berbagai bentuk daripada 11 hingga 2 tan ha^{-1} di dalam tahun-tahun hujan lebat dan hujan kurang, masing-masing dengan min tahunan 4.07 daripada tebangan bulan November dan 0.99 tan ha^{-1} daripada tebangan bulan Jun. Ladang tersebut membaiki penyusupan tanah. Dengan ini memastikan sumber-sumber air hujan kurang larian dan digunakan dengan efisien untuk pengeluaran biojisim.

Introduction

Most degraded tropical forest ecosystems are typically characterized by the lack of adequate vegetation cover, soil erosion, fertility depletion, diminished biological productivity and diversity and hydrologic instability (Parrotta 1992). Plantations of suitable trees and grasses may provide much needed protective cover to the degraded lands, initiate the process of ecosystem rehabilitation (Lugo 1988, Montagnine & Sacho 1990), take off pressure from natural forests and hence resolve impending energy crisis in the developing countries of the tropics (NAS 1980).

Eucalyptus are preferred for plantation forestry because of their multiple use, fast growth, coppicing ability and capacity to grow under diverse soil and climate conditions (Gosh *et al.* 1979, NAS 1980, Srivastava 1981, Gogate 1983, Pearce 1983). Farmers in India planted 8550 million trees on private lands between 1981 and 1988 and the share of eucalypt alone in these plantations was above 87% (NWDB 1989). Some studies conducted in north India have shown that eucalypt decreases crop yields of associated grain crops like wheat and rice (Dhillon *et al.* 1982, Kohli *et al.* 1987, Ahmed 1989). The studies evaluating the effect of *Eucalyptus* on forage and commercial grasses are, however, limited. The major interest in grasses lies in foliage production (not grain) where the source-sink relationships are different from crops and the chances of tolerating competition may be better (Grewal *et al.* 1992). The need for intensive research on such plantations has already been indicated (Debroy & Pathak 1974, Harsh & Kathuja 1987, Nair 1989, Young 1989, Grewal *et al.* 1992).

Bhabar grass (*Eulaliopsis binata*) is the predominant commercial grass species of the degraded natural forest habitats of foothill north India called 'Shiwaliks' (Dabadghao & Shankaranarayana 1973, Shankaranarayana & Sharma 1984). It has high profitability because of its extensive use for good quality paper pulp, forage, and rope making, which is an important cottage industry of this region. Incidently, this sod forming perennial grass grows mainly during the rainy season and hence provides dense protective cover to the erosion prone land. In view of the great demand of *Eucalyptus* wood for poles, paper pulp and furniture and sod forming perennial grasses for erosion control and biomass production for forage and commercial use, both of these plants were integrated in a suitably designed plantation system.

This paper reports the long term growth, biomass production and economic returns from this system and compares the results with a usual rainfed cropping system.

Materials and methods

Site description

The field study was conducted for eight years (1984-91) at the Research Farm of the Central Soil and Water Conservation Research and Training Centre, Chandigarh (70° 45'E, 30° 45'N, 370 m a.s.l.) on a light textured and heavily eroded foothill soil classified as typic, measic, hyperthermic Udic Ustocrept. As per land capability classification, the site is Class IIIe (Verma *et al.* 1965). The soil is well drained, slightly alkaline (pH 7.4 - 8.0), non-calcareous with slope varying from 1-2%. In the 0-240 cm deep soil profile, the clay content varies from 9 - 16%, silt from 12 - 17%, fine sand from 42 - 58% and coarse sand from 21- 32%. The available water holding capacity of the soil is quite low (18 cm per 100 cm soil depth). The soil texture is relatively light (loamy sand) at the surface layers and becomes progressively heavier in the lower layers (sandy loam). The available plant nutrients are in the low range. The available N in each 30 cm soil layer varies from 80-162, P from 12-20 and K from 75-93 kg ha^{-1}. In a typical semi-arid climate, the area receives on an average 1100 mm of annual rainfall, out of which about 80% comes during the three monsoon months. The mean monthly daily temperature varies from a maximum of 38.2 °C in June to a minimum of 6.9 °C in January. The mean annual pan evaporation is 2300 mm and the mean monthly pan evaporation exceeds the mean monthly rainfall in all except the three monsoon months. Out of the eight study years, 1984 and 1987 received below normal, 1988 and 1990 above normal rainfall (Figure 1). As such, the 8 years mean annual rainfall (1113 mm) was very close to the 33 years mean annual rainfall (1103 mm) indicating that the rainfall was representative during the study period. In the five years preceding this experiment, uniform crops of rainfed sesame in summer and rapeseed in winter were raised at this site without any fertilizer use. Because the ground water is very deep (below 50 metres) and erratic, there are no irrigation wells/tube wells in the areas. Many farmers in the vicinity were growing eucalyptus on similar lands because of frequent crop failures on one hand and attractive price of eucalypt poles on the other.

Experiment design and layout

To reduce tree-grass competition, 2500 seedlings ha^{-1} (planted for poles) were arranged in north-south oriented paired rows (instead of a square system) in order to provide more light for understorey grass. The trees in the paired rows were staggered for better space adjustment (Figure 2). The soil is relatively light in

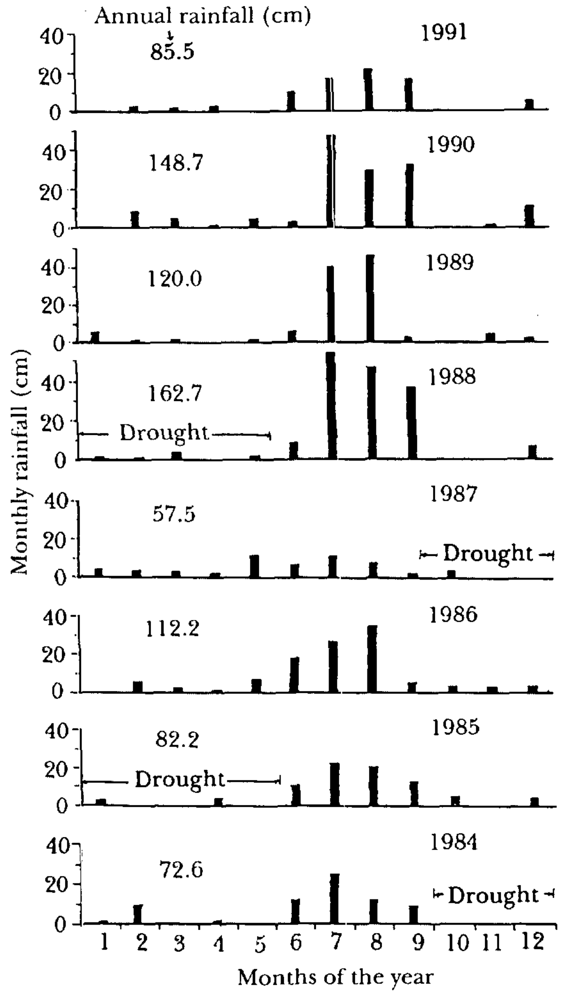

Figure 1. Monthly rainfall distribution from 1984 to 1991 at the study site

texture at the top and heavy down below (preferred by both the associates) and hence allows more water to infiltrate but stores the percolated water for prolonged use (Grewal *et al.* 1990 a,b). For *in situ* rainwater conservation, 20 cm high earthen bunds around each 8 × 4 m plot and 30 cm high peripheral bund all around the field were made. The usual method of planting seedlings in 30 × 30 × 30 cm pits (T1) was compared with planting in shallow augerholes, 6 cm wide and 60 cm deep (SAH, T2), and deep augerholes (6 × 120 cm) (DAH, T3) refilled with the same soil. The boll of earth of polybag seedling was snugly fitted at the top of the refilled augerhole. It was hypothesized that tree roots should go straight down to lower soil layers in the soft soil of the augerholes (AH) and in the process allow grass root development in the surface layers. This system of sharing rhizosphere was further improved by filling one kilogram of farm yard manure (FYM) in deep augerholes (T4) to meet the immediate plant nutrient needs and also improve water retention capacity of the augerhole soil. Since rice husk (RH) was easily available and has no local use, we planned to use it as organic source for filling the deep augerhole in another treatment (T5). We also realized that RH having high CN ratio might depress plant growth initially, so FYM and RH were mixed in yet another treatment (T6). Treatments 2 and 3 compared usual pit (T1) vs. augerhole planting at 2 depths and treatments 4 to 6 compared the effect of filling mixture in the AH. No irrigation or fertilizer was given to the plantation. Seedlings of *Eucalyptus tereticornis* were raised in polybags in the nursery and transplanted in July 1984 at the onset of monsoon. The above six planting treatments were replicated four times in randomized block design (Figure 2). Eight seedlings were planted in each 8 x 4 m plot. Bhabar grass was planted from rooted slips at 50 x 50 cm spacing at the same time. A guard row of *Eucalyptus* was planted all along the plot to take care of the boundary effects.

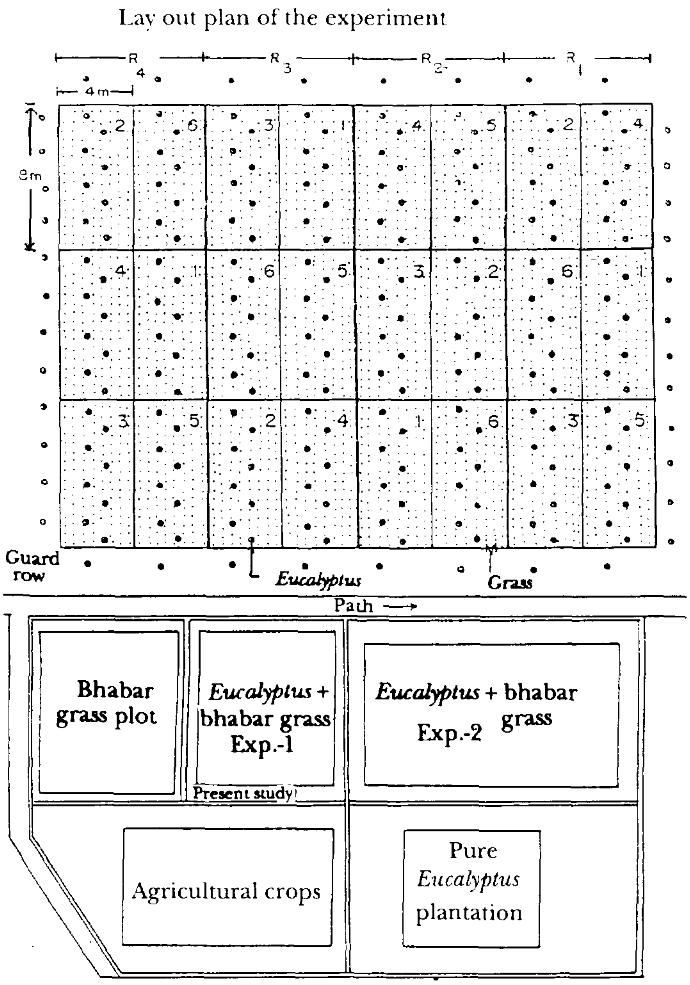

Figure 2. Layout plan of the experiment and site map

Observations

The tree growth differences were recorded by measuring height from immediate ground level to the highest tip of each tree by a graduated staff/pole and the basal diameter (bd) was measured with a vernier caliper 5 cm above the ground level. After 5 y of age, diameter was measured at breast height (dbh). The plant height and diameter were measured every alternate month during the first two years and twice a year thereafter. Although the dead plants were replaced in the next planting season, these were not considered in the growth measurements. The plantation was harvested after 7.5 y of growth in December 1991. Each tree was felled at 5 cm above ground level. The harvested tree biomass was divided into leaves and twigs, branch wood and main pole/stem wood (up to 5 cm diameter at the tapering end) and weighed green and air dry. Bhabar grass was cut row-wise from each of the seven rows in a treatment once in November for paper pulp and once in June for forage according to the local practice. The fresh weight was taken immediately after harvest and air dry weight recorded after sun-drying for about 30 days on site till constant weight. The combined weight of rows was taken as the plot yield and converted to yield per hectare. The annual net returns were calculated by deducting the cost of cultivation from the gross returns obtained by multiplying the production with the uniform market price of 1991.

In one field plot, pure bhabar grass was raised in a 0.3 ha area (Figure 2) adopting all the cultural practices and harvesting schedules of the experimental plots. In another 0.25 ha area of the same field, rainfed agricultural crops of sesame followed by rapeseed were simultaneously raised as per farmers practice without any fertilizer use. It was intended to compare the productivity and net returns from forest farming with that of the traditional agriculture. The pure bhabar grass and agricultural crops were not randomized and replicated but yields were obtained from four randomized plots of 10 × 10 cm each. Another plantation of pure eucalypt raised under identical soil and climatic conditions was used to represent eucalypt without bhabar grass, and to compare some of the soil properties for root study, 12 plants of eucalypt were raised in two separate plots as per treatment T1 and T4. Out of these, 3 representative plants were harvested from each treatment at six months of age and all the growth parameters and biomass recorded. The roots were then excavated up to 180 cm depth by wetting the soil and washing with a spray pump. The excavated roots were cut into 30 cm sections, oven dried at 70 °C to constant weight following which, root dry weight was recorded.

Some of the important physico-chemical properties of the soil were determined from each treatment in two replications at the start of the study by drawing duplicate samples from each 30 cm soil layer up to 180 cm depth of the profile and analysed as per procedure outlined by Richards (1954) and Jackson (1973). At the end of the experiment the soil analysis was repeated. Since the differences in soil properties between the treatments were not very clear at the end of the study, differences between land use systems were presented as these differences were quite marked. The infiltration rates of the three land use systems of pure bhabar grass, pure eucalypt and eucalypt +bhabar grass were also determined by using double ring infiltrometers (Richards 1954). The variation in hydraulic conductivity due to land use change was measured indirectly by recording the rate of recession in the level of water filled uniformly in the dug-out augerholes, depth of soil wetting after 24 h of redistribution and cross sectional area wetted by the percolated water. The undisturbed bulk density core samples in triplicate were drawn from three depths, 0-15, 15-30 and 30-45 cm, from the soil profile of all the three land use systems mentioned above. The soil samples were also analysed for organic carbon and soil pH following Piper (1957). The rainfall of the experimental site was recorded by a standard rain gauge. The meteorological data recorded at the Research Centre were used for the experimental site. The state government fixed rates for the eucalypt poles were used for calculating the economic returns from eucalypt poles. The statistical analysis of the data to find out critical differences was done following Cochran and Cox (1950).

Results and discussion

Eucalypt growth

Initially, the plant height and basal diameter were significantly superior in the 6 x 120 cm AH treatments (T3, T4) over other treatments (Table 1). The addition of rice husk in DAH depressed plant growth. The growth differences between SAH and DAH appeared with the onset of a drought phase experienced in the summer months of 1985 (Figure 3). The growth responses to the application of FYM emerged clearly after the onset of 1985 monsoon. T4 remained the best treatment but statistically T3 and T4 were at par. A severe drought occurred during 1987-88 (Figure 1) which seriously disrupted growth rhythm and caused considerable plant mortality. The growth differences among treatments became non-significant following this drought first in height and then in diameter. As the canopy closed after the 5th year, the treatment differences further narrowed down. When the plants were harvested in 1991 (7th year), the plant growth was best in DAH + FYM treatment. The depressing effect of rice husk was clearly evident.

Plant survival

During the drought phase which occurred from October 1984 to June 1985, pit plants suffered higher mortality as compared to AH plants. The dead plants were replaced in July 1985 and by October 1985, the survival was 84, 91 and 100 percent in pit, SAH and DAH treatments respectively (Figure 4). Plant survival was lower in DAH + RH (88%) compared to DAH + FYM (97%) treatments. The plant mortality remained low in 1986 because of good rainfall. The plant population was again brought to a uniform level by October 1986. During the drought phase of 1987-88, relatively weaker or replaced plants of both pit planted (T1) and RH applied treatments (T5, T6) recorded higher mortality as compared to other three treatments. Though the rainfall in subsequent years was good, plant population gradually started to decrease probably due to the effect of canopy closure. The

Table 1. Periodic height and basal diameter of eucalypt in various treatments

Planting treatment	Mean height (cm) at								Mean bd (cm) at						Mean dbh (cm) at	
	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7 y (age)
(T1) 30×30×30 cm pit	89	245	465	576	712	878	1088	1127	0.58	3.0	5.0	6.5	8.0	9.1	8.0	8.6
(T2) 6×60 cm AH	84	263	474	621	802	975	1100	1153	0.59	3.2	5.9	7.5	9.3	10.7	8.2	8.8
(T3) 6×120 cm AH	89	341	592	695	854	985	1108	1156	0.59	4.6	6.8	8.5	9.7	11.7	8.4	9.1
(T4) 6×120 cm AH+1kg FYM	85	371	601	711	884	1017	1160	1218	0.59	5.1	7.4	8.8	10.6	12.3	8.7	9.7
(T5) 6×120 cm AH+1kg RH	89	220	497	604	769	937	1015	1085	0.57	2.4	5.3	7.9	9.2	9.9	7.3	7.9
(T6) 6×120 cm AH + 1kg FYM+1kg RH	90	283	504	611	769	950	1015	1088	0.59	3.1	5.7	8.0	9.5	10.5	7.9	8.3
Significance		**	*	*						**	*	*	**			
LSD	ns	67	83	74	85	ns	ns	ns	ns	0.41	0.99	1.37	1.23	1.46	ns	ns

AH = Augerhole
FYM = Farm yard manure
RH = Rice husk
bd = Basal diameter
dbh = Diameter at breast height

* Significant at p = 0.05
** Significant at p = 0.01
ns Not significant

rate of population decrease was rather sharp in pit planted and RH applied treatments. The saplings of DAH and DAH + FYM treatments recorded the highest and statistically better survival as compared to pit (control) and RH applied treatments.

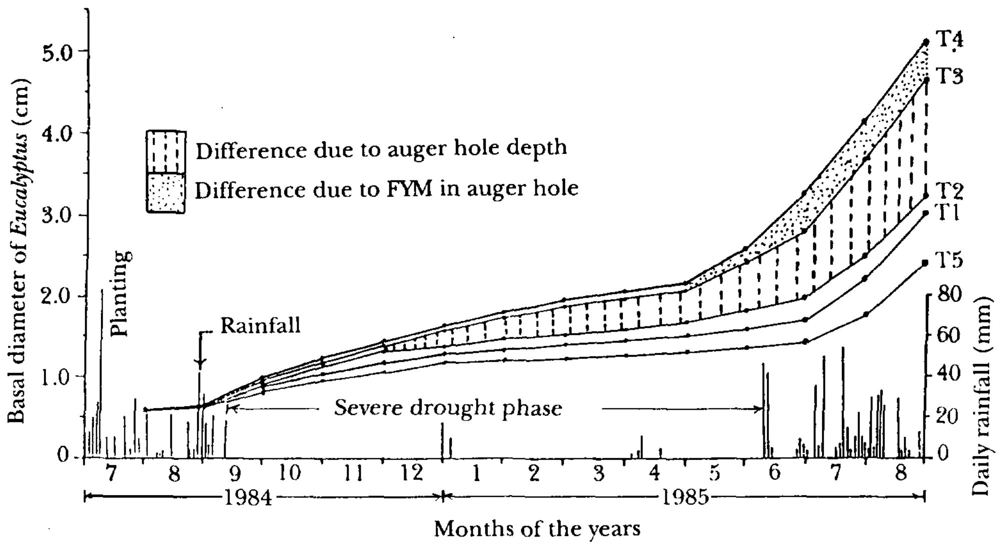

Figure 3. Basal diameter of eucalypt under different treatments and rainfall distribution during the establishment stage

Aerial biomass

The total number of harvested poles was lowest in pit planting (1828), followed by RH applied treatments (1641). The number was above 2100 in other treatments (Table 2). Interestingly, there was an increase of 58.8 and 64.6% in the number of harvestable poles in SAH and DAH treatments respectively over pit planting. The mean stem biomass per plant in SAH plants was 21.1% more than pit plants. The differences in stem biomass per tree between SAH and DAH were not significant but DAH + FYM treatment was significantly better than DAH without FYM. The suppressing effect of RH was also reflected in the stem biomass. As such, DAH + FYM treatment recorded the highest stem, branch and leaf biomass per plant. The harvested stem wood was 93, 113 and 135% higher in SAH, DAH and DAH + FYM treatments respectively over the control. The trend in branch wood, and leaves and twig biomass production was also similar to that of stem wood. The highest total biomass of 80.2 t ha^{-1} and gross returns of Rs 42 695 ha^{-1} (when sold as fuelwood) were recorded in the treatment of DAH + FYM, closely followed by DAH without FYM. The treatment of pit planting recorded the lowest total biomass (33.6 t ha^{-1}) and gross returns (Rs 18 011 hs^{-1}).

Table 2. Air dry harvested aerial biomass of eucalypt from different treatments

Planting treatment	No of harvested plants ha^{-1}	Biomass (kg $plant^{-1}$)			Biomass yield (kg ha^{-1})				Gross returns (Rs ha^{-1})**		
		Stem	Branch	Leaves + twigs	Stem wood	Branch wood	Leaves + twigs	Total	Stem wood	Branch wood	Total
T1	1 328	21.48	2.25	1.56	28 525	2 988	17 115	33 585	17 115	896	18 011
					(-)	(-)					
T2	2 109	26.03	3.00	1.63	54 897	6 327	3 438	64 662	32 938	1 898	31 040
	(58.8)	(21.1)*			(92.5)	(111.7)	(65.9)				
T3	2 186	27.82	3.31	2.10	60 826	7 236	4 591	72 653	36 496	2 171	38 667
	(64.6)	(27.1)			(113.2)	(142.2)	(121.6)				
T4	2 109	31.80	3.88	2.36	67 066	8 183	4 977	80 226	40 240	2 455	42 695
	(58.8)	(48.0)			(135.1)	(28.5)	(140.2)				
T5	1 641	20.01	2.34	1.22	32 836	3 840	2 002	38 678	19 702	1 152	20 854
	(23.6)	(-6.8)			(15.1)	(28.5)	(-3.3)				
T6	1 641	22.35	3.04	1.28	3 667	4 989	2 100	43 765	22 006	1 497	23 503
	(23.6)	(-4.1)			(28.6)	(67.0)	(1.4)				
LSD (p = 0.05)	423	3.57	0.63	0.31	-	-	-	-	-	-	-

* Figures in parentheses indicate % increase over control

** Stem and branch @ Rs 600 and Rs 300 t^{-1}

Rs 30 = One US dollar.

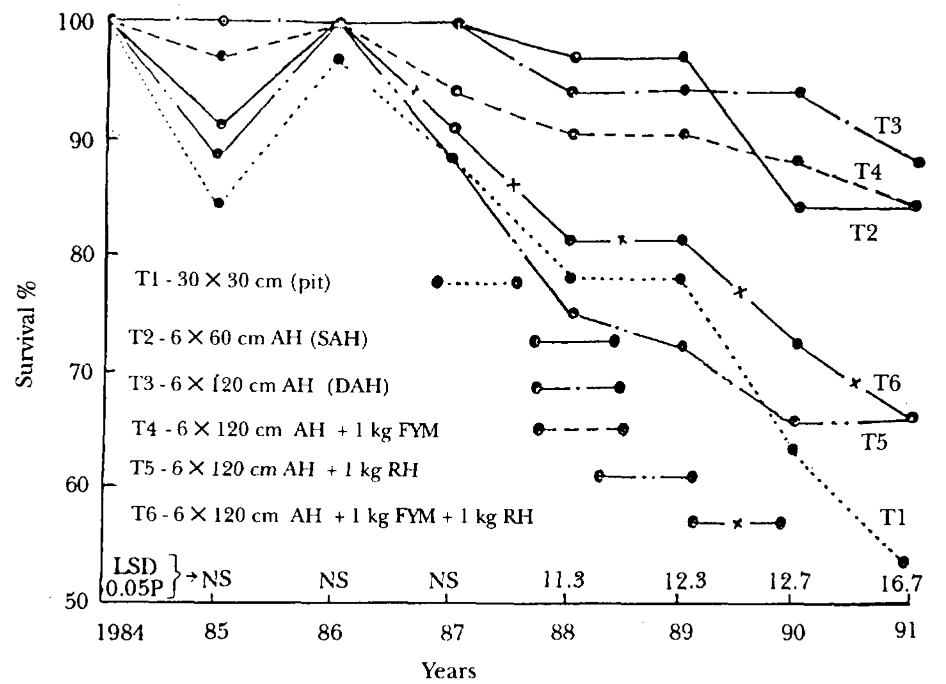

Figure 4. Plant survival percentage under different treatments from planting to harvest year

Pole wood production and monetary returns

The number of bigger size poles (above 40 cm girth) increased from 78 in pit planting to 156 (78 + 78) in SAH, 312 (156 + 156) in DAH and 469 (391 + 78) in DAH + FYM treatments respectively (Table 3), and the corresponding net monetary returns from these poles increased from Rs 3 900 to Rs 11 700 (3 900 + 7 800), Rs 23 400 (7 800 + 15 600) and Rs 27 750 (19 950 + 7 800). The proportion of smaller size poles (less than 20 cm girth) to total number of harvested poles was more in pit planting (T1) and RH applied treatments (T5, T6) which exhibited poor growth performance. The total monetary return of Rs 51 955 ha^{-1} (after 7.5 y) from the best treatment (T4) was 2.6 times more than the worst treatment (T1) of pit planting (Rs 20 315). The treatment of DAH without FYM (T3) was the second best. As the real money spinners were bigger size poles, the treatment of DAH + FYM produced higher proportion of bigger size poles and hence provided better economic returns (Figure 5).

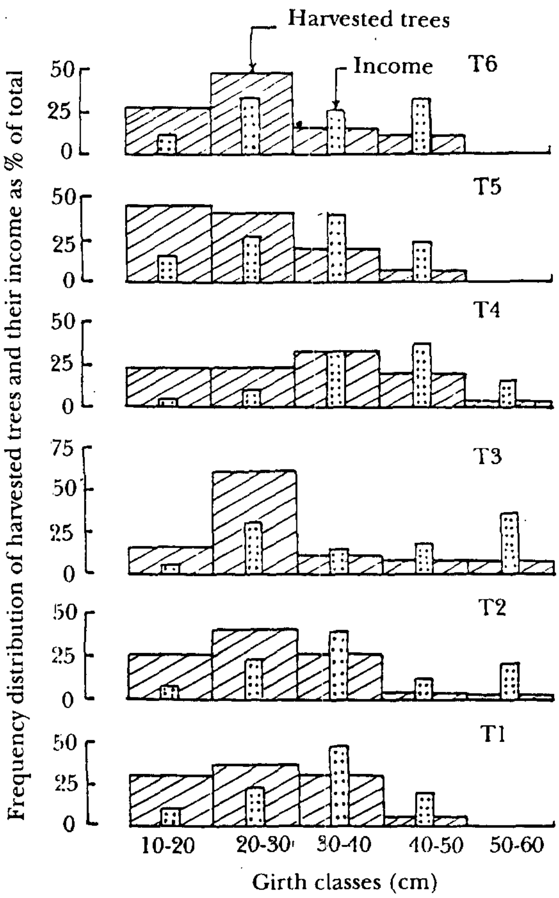

Figure 5. Distribution of harvested trees and income into girth classes

Bhabar grass yield

The bhabar grass yield differences among different eucalypt planting treatments remained non-significant except in the November 1985 and 1990 cuts (Table 4). The eight years mean grass yield varied from the lowest of 3.84 in DAH+FYM+RH treatment to 4.55 t ha^{-1} in the best treatment of DAH+FYM. The overall yield was low (1.1 t ha^{-1}) during the establishment year which gradually increased to 3.70 and 8.31 t ha^{-1} in 1985 and 1986 respectively. The rainfall was adequate and well distributed in 1986 and as a result, the grass yield was the highest. The steep yield decline in 1987 was attributed to extremely low rainfall. The mean grass yield picked up again in 1988 (6.18 t ha^{-1}) because of better rainfall amount and distribution. In the subsequent three years (1989, 1990 and 1991), the grass yield declined perhaps because of gradual canopy closure of the eucalypt trees. The main growing period of grass coincided with the monsoon season and hence better yield in the November as compared to the June cut. Grass obtained from the November cut is considered more suitable for paper pulp. Because of inflorescence and hard main stem, the June cut is not preferred for paper and is best suited for forage. The grass yield of the June cut was similar in all the treatments and varied from 0.44 t ha^{-1} in the establishment year to 2.19 t ha^{-1} in 1986. The overall grass yield was 4 t ha^{-1} from the November and 1 t ha^{-1} from the June cuts against 6.64 and 1.50 t ha^{-1} respectively of pure grass. These results are in general agreement with the data earlier reported by Sud *et al.* (1986).

Table 3. Distribution of harvested poles in various girth classes and income generated

Treatment	No. of poles ha^{-1} in girth class (cm) and income (Rs ha^{-1})					Total no. of poles ha^{-1} and income (Rs ha^{-1})
	10-20 (Rs 5)*	20-30 (Rs 10)	30-40 (Rs 25)	40-50 (Rs 50)	50-60 (Rs 100)	
T1	390	469	391	78		1 328
	(1 950)**	(4 690)	(9 775)	(3 900)		(20 315)
T2	547	859	547	78	78	2 109
	(2 735)	(8 590)	(13 675)	(3 900)	(7 800)	(36 700)
T3	314	1 328	234	156	156	2 188
	(1 570)	(13 280)	(5 850)	(7 800)	(15 600)	(44 100)
T4	468	469	703	391	78	2 109
	(2 340)	(4 690)	(17 575)	(19 950)	(7 800)	(51 955)
T5	703	547	313	78	-	1 641
	(3 515)	(5 470)	(7 825)	(3 900)	-	(20 710)
T6	470	781	234	156	-	1 641
	(2 350)	(7 810)	(5 850)	(7 800)	-	(23 010)

* Price per pole at Government approved rates (support price);
** Figures in parentheses give values of poles at the given rates.

Net returns

The total cost of inputs varied from Rs 26 330 in the pit planting to Rs 35 220 ha^{-1} in the DAH+FYM treatment (Table 5). The gross returns both from trees and grass in the respective treatments were Rs 70 003 and Rs 109 881 ha^{-1} and the total and annual net returns Rs 43 673 and Rs 74 611 and Rs 6 239 and Rs 10 659 ha^{-1}. The remaining treatments were in between these two extremes. The overall cost of inputs was almost equal but bhabar grass provided higher net returns as compared to eucalypt. The net returns from the agricultural crops were only Rs 700 $ha^{-1} y^{-1}$. The net returns in the second rotation may be more because of no establishment costs. The cash flow from bhabar grass started from the very beginning and hence compensated for money locked in raising trees for several years.

Table 4. Air dry bhabar grass yields from the November and June cuts under different treatments

Treatment	Air dry bhabar grass yield (t ha^{-1})								
	1984	1985	1986	1987	1988	1989	1990	1991	Mean
		November cut							
T1 30×30×30 cm pit	1.05	3.16	8.90	1.59	6.33	4.25	3.14	3.66	4.01
T2 6×60 cm AH	1.11	4.06	8.81	1.63	5.70	4.04	3.17	3.32	3.98
T3 6×120 cm AH	1.09	3.92	8.89	1.50	6.17	4.17	3.72	3.43	4.11
T4 6×120 cm AH+1kg FYM	1.31	4.02	9.66	1.95	6.75	5.39	3.76	3.54	4.55
T5 6×120 cm AH+1kg RH	1.01	3.57	8.44	1.45	6.17	4.09	3.26	3.47	3.93
T6 6×120 cm AH+1kg FYM+1kg RH	1.04	3.46	8.13	1.66	5.98	3.79	3.29	3.36	3.84
LSD (p = 0.05)	ns	0.31	ns	ns	ns	ns	0.33	ns	ns
Mean	1.10	3.70	8.81	1.63	6.18	4.29	3.39	3.46	4.07
Seasonal rainfall (mm)	465	686	805	313	1586	934	1269	694	912
		June cut							
T1 30×30×30 cm pit	-	0.35	1.91	0.37	1.32	1.07	0.47	0.52	0.56
T2 6×60 cm AH	-	0.46	2.04	0.42	1.43	1.21	0.58	0.65	0.97
T3 6×120 cm AH	-	0.47	2.39	0.46	1.47	1.24	0.67	0.67	1.05
T4 6×120 cm AH+1kg FYM	-	0.52	2.75	0.52	1.62	1.32	0.73	0.73	1.17
T5 6×120 cm AH+1kg RH	-	0.41	1.81	0.36	1.39	1.12	0.51	0.59	0.88
T6 6×120 cm AH+1kg FYM+1kg RH	-	0.40	2.24	0.45	1.41	1.23	0.57	0.63	0.99
LSD (p = 0.05)		ns	ns	ns	ns	ns	ns	ns	ns
Mean		0.44	2.19	0.43	1.44	1.20	0.59	0.63	0.99
Seasonal rainfall (mm)	262	103	236	270	150	266	278	161	201
Sole grass; November cut	1.21	4.72	10.90	3.03	8.67	8.25	8.76	7.56	6.64
June cut	-	0.75	1.83	1.09	2.34	2.11	2.05	1.82	1.50

Table 5. Cost of inputs, gross and net returns (Rs ha^{-1}) from different treatments calculated at the uniform price level of 1991

Particulars	Treatment					
	T1	T2	T3	T4	T5	T6
Cost of inputs						
(A) **Eucalypt**						
a) Planting cost	4 270	4 270	5 300	6 000	5 850	6 250
b) Annual cost (for 6 y)	2 430	2 430	2 430	2 430	2 430	2 430
c) Harvesting cost	4 956	8 318	9 072	9 518	6 182	6 182
Total	11 656	15 018	16 802	17 948	14 462	14 862
(B) **Bhabar grass**						
a) Planting cost	2 338	2 338	2 338	2 338	2 338	2 338
b) Harvesting cost (for 8 y)						
November cut	11 356	11 271	11 640	12 886	11 130	10 875
June cut	980	1 698	1 838	2 048	1 540	1 732
Total (A+B)	26 330	30 325	32 618	35 220	29 470	29 807
Gross returns						
Eucalypt	2 0315	36 700	44 100	51 955	20 710	23 010
Bhabar grass (8 y)						
November cut	4 8120	47 760	49 320	54 600	47 160	46 080
June cut	1 568	2 716	2 940	3 276	264	2 772
Total	70 003	87 176	96 360	109 831	70 334	7 1862
Net returns						
Total	43 673	56 851	63 742	74 611	40 864	4 2055
Annual	6 239	8 122	9 106	10 659	5 838	6 008

Net returns at 1991 prices from agricultural crops Rs 700 ha^{-1}

Root study

The mean weight of roots at six months of age was 74.5 g plant^{-1} in pit and 239.2 g plant^{-1} in DAH+FYM treatments (Table 6). While the roots could penetrate only up to 90 cm depth in pits, they crossed 180 cm depth in the FYM - filled AH. The 120 cm deep AH was full with a mesh of fine roots proliferating in FYM. Most of the roots remained confined to the augerhole - filled soil mass. In the surface 30 cm depth, the root weight was more than twice in AH as compared to pit. All other growth parameters were far superior in the AH planted seedlings as compared to the pit planted seedlings. The filling of FYM in AH proved extremely useful in facilitating the extension of roots to lower moist soil layers, hence obliterating the adverse effect of moisture stress during droughts.

Table 6. Root and shoot growth and biomass accumulation by eucalypt under two treatments at six months age

Soil depth (cm)	Pit planting (T1)	DAH+FYM (T4)
	Mean oven dry root weight (g $plant^{-1}$)	
0 - 30	62.5	134.2
30 - 60	10.3	54.2
60 - 90	1.7	30.8
90 - 120	-	14.7
120 - 150	-	4.3
150 - 180	-	1.0
Total	74.5	239.2
Plant height (cm)	139	191
Basal stem dia(cm)	1.76	2.07
Oven dry biomass (g $plant^{-1}$)		
Leaves	74.4	148.7
Stem+branch	90.4	196.8
No. of leaves $plant^{-1}$	125	359
Root shoot ratio	0.82	1.22

(Based on triplicate samples)

Hydrological aspects

The peripheral bund remained intact throughout the study period indicating that no amount of rainwater from the plot was converted into runoff. The experimental site was inspected several times after intense rainfall but little ponded water in the plots was observed. The rainwater infiltrated at a very fast rate. In the adjoining agricultural plot, there was always ponded water after heavy rains. The soil moisture samples drawn before the onset of monsoon rains generally indicated less water in the profile of eucalyptus + bhabar grass as compared to agricultural crops. For instance, the soil samples drawn on 8.6.1990 indicated the gravimetric water content in 0-120 cm soil profile as 11.17, 18.16 and 23.78 cm of water under tree + grass, grass alone and agricultural crop. It appears that more depletion of soil water before rains and between rainfall events caused by grass at the surface and trees in the lower layers may be responsible for rapid infiltration of rainwater. The cumulative infiltration of 3 h was 1.6, 3.2 and 7.6 cm under agriculture, grass alone and tree+grass plantation (Table 7). The rate of recession of water in the augerhole, depth of soil wetting and cross-sectional area wetted also followed the same trend. These data show the considerable improvement in the infiltrability and hydraulic conductivity of the soil under tree-grass association. As a result, the chances of rainwater going as runoff were low. As compared to agriculture, the soil pH was slightly decreased and organic carbon increased from 0.16 to 0.21% by eight years of tree + grass land use. The improvement in organic carbon status of the soil is an important consideration in the rehabilitation of degraded land (Gill *et al*, 1987, Sharma & Gupta 1989). The prevention of runoff and soil loss by bhabar grass was also indicated by an earlier study conducted by Sud and Mittal (1987). Jhorar *et al.*, (1992) also observed improvement in the infiltration rate of soil under *Eucalyptus.*

Table 7. Hydrophysical soil properties under three land use systems

Property	Land use systems		
	Agriculture	Bhabar grass	Eucalypt + bhabar grass
Infiltration rate ($cm\ ha^{-1}$)			
1st hourly	0.7	1.5	3.2
2nd hourly	0.6	1.0	2.5
3rd hourly	0.3	0.7	1.9
Total	1.6	3.2	7.6
Rate of recession of water in augerhole (cm)			
5 min	12.3	15.9	19.7
10 min	16.7	19.8	24.1
15 min	21.2	23.7	26.8
20 min	23.1	15.1	27.1
25 min	24.4	26.2	28.8
30 min	26.7	28.0	30.2
Depth of wetting after 24 h of redistribution (cm)	39.2	45.5	46.7
Cross sectional area wetted after redisribution (cm^2)	790	911	979
Surface soil pH (1:2)	7.2	7.1	7.0
Organic carbon (%)	0.16	0.23	0.21
Bulk density ($g\ cm^{-3}$)	1.55	1.57	1.59

The results show that very strong treatment differences developed in height and basal diameter during the first year of the study and remained significant with respect to height up to the 4th, and basal diameter up to the 5th year of study and turned non-significant thereafter. Initially, the DAH (T3) planted seedlings were taking the lead over the pit and SAH planted seedlings obviously because of penetration of roots in DAH to lower moist soil layers and hence better ability to withstand moisture stress caused by the lack of rainfall in the post monsoon months. As the soil moisture availability improved with two good showers in June 1985, the application of FYM in DAH (T4) caused the seedlings to start showing significant growth superiority over those in DAH without FYM. That the FYM induced deep and vigorous root development was indicated by the root study. Such an improvement in initial growth of eucalypt planted in DAH filled with FYM was also observed by Grewal *et al.* (1990 a). The addition of rice husk in the

DAH depressed the plant growth probably due to the immobilisation of nitrogen during the process of decomposition of high CN ratio material.

The number of dead seedlings replaced in the 1984 and 1985 monsoons was relatively high in T1, T5 and T6 and low in T2, T3 and T4 treatments. Most of the replaced seedlings survived but their growth performance remained sub-optimal. As a result, the percentages of smaller size poles in the 10 - 20 cm girth class at harvest were 29.4 and 42.8% in T1 and T5 but only 14.4 and 22.2% in T3 and T4 treatments respectively. Although 1988, 1989 and 1990 were good rainfall years, the replanted seedlings were shaded out upon canopy closure. Data on the remaining relatively healthy plants indicate better height and girth values in T1, T5 and T6 treatments thus making the growth differences with other treatment as non-significant. SAH was statistically not superior to pit planting in the first three years but became so in the 4th year in height and 5th year in DAH perhaps because SAH treatment had the minimum mortality and hence carried the highest plant density up to 1989.

Although the overall treatment differences in eucalypt growth were not significant at harvest, the survival percentage, the number of harvested poles, and the stem and branch biomass per tree were significantly higher in the T2, T3 and the T4 treatments as compared to T1, T5 and T6 treatments. So, the overall biomass production was relatively higher in this set of treatments. Since the income from poles was size dependent and bigger size poles were more in DAH + FYM treatment as compared to SAH and DAH without FYM treatments, the overall net returns were highest in this case. The eucalypt planting treatments failed to create significant differences in grass yield perhaps because the dense plantation caused almost uniform shade conditions to the understorey grass. The deeper rooting of the eucalypt in the T3 and T4 treatments reduced competition with the grass resulting in about 12% more bhabar grass yield in T4, but this was statistically non-significant.

The gradual reduction in overall grass yield could be due to shade, moisture and nutrient competition and allelochemical effects. There are conflicting reports about allelochemical effects of eucalypt on the undergrowth. According to Trenbath (1981) fresh leaves of eucalypt cause a depressing effect but the leaf litter may cause little inhibitory effect. The eucalypt leaves appear to inhibit undergrowth due to immobilization of nutrients by their high CN ratio rather than phytotoxicity (Kimber 1973, Sanginga & Swift 1992). The inhibition of undergrowth because of allelopathic effects of eucalypt as reported by Fisher (1980) has been questioned by Poore and Fries (1985) for its lack of scientific evidence.

In the field study conducted by Sud *et al.* (1986), the average annual grass yield (1975-82) was 5.65 t ha^{-1} (4.5 t ha^{-1} from the November and 0.80 t ha^{-1} from the June cuts). The plantation system provided more economic returns as compared to maize-wheat rotation (Sud *et al.* 1989).

The overall net returns of Rs 10 000 $ha^{-1} y^{-1}$ from the best treatment of this experimental plantation (with coppiced crop of eucalypt and bhabar grass sods present for the next rotation) were several times more than the returns from rainfed field crops raised under comparable conditions. Better returns than rainfed agriculture, organic matter build-up, low chances of runoff and soil loss, permanent protective vegetation cover to the soil, no use of contaminating fertilizers, early cash flow from commercial grass, and low maintenance costs are some of the other ecological and economic benefits of this tree and grass plantation system. In view of the unlimited demand of eucalypt wood for poles and paper pulp, and sod forming grasses for erosion control and biomass production for commercial use, such plantation systems may replace rainfed crops presently raised on erosion prone lands of the semi-arid tropics. Large scale adoption of such carefully planned plantation models may not only use natural resources more efficiently but also reduce human and livestock pressure on fragile natural forest ecosystems.

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