# RAINWATER CONSERVATION AND USE BY AN ENERGY PLANTATION OF *EUCALYPTUS TERETICORNIS* AND RAINFED FIELD CROPS IN NORTH INDIA

**S.S. Grewal, M.L. Juneja & Kehar Singh**

*Central Soil and Water Conservation Research and Training Institute, Research Centre, Sector-27/A, Chandigarh, India*

*Received July 1992*

**GREWAL, S.S., JUNEJA, M.L. & SINGH, KEHAR. 1994. Rainwater conservation and use by an energy plantation of *Eucalyptus tereticornis* and rainfed field crops in north India.** In an attempt to study the prospects of developing alternative bioenergy sources to petroleum products, a short duration, high density (10,000 trees $ha^{-1}$) energy plantation of *Eucalyptus tereticornis* was raised on a typical sandy loam soil at the foot-hill of north India. The efficiency of rainwater conservation and use was compared with sesame - rapeseed crop raised in the other half of the same field with identical site conditions. The 300 *cm* deep soil profile of the agricultural land use system (ALUS) conserved 45, 84 and 181 *mm* and that of the forestry land use system (FLUS) conserved 311, 240 and 445 *mm* of water from the monsoon rainfall of 685, 905 and 1586 *mm* recorded in 1985, 1986 and 1988 respectively. The respective mean gains were 68 and 244 *mm* of water. The exceptional drought of 1987 produced no net gain for either system. The monsoon rainfall recharged the soil profile up to a depth of 150 *cm* in the ALUS but up to 240-300 *cm* depth in the FLUS. The annual water uses were 774, 806, 417 and 816 *mm* for the ALUS, and 976, 1062, 435 and 1141 *mm* for the FLUS in 1985-86, 1986-87, 1987-88 and six months of 1988-89 respectively. The mean annual and total water uses were 801 and 2803 *mm* respectively for the ALUS, and 1033 and 3614 *mm* respectively for the FLUS. The profile water content at the end of the study was the same for both systems. The FLUS used 29% extra water by conserving rainwater which was wasted by the ALUS as runoff. The FLUS increased soil moisture deficits in deeper soil layers before and between the monsoon rainfall events resulting in high infiltration. *Eucalyptus* was a relatively more efficient user of rainwater than field crops.

Keywords: *Eucalyptus tereticornis* - energy plantation - field crops - north India - rainwater conservation - water use - soil moisture

**GREWAL, S.S., JUNEJA, M.L. & SINGH, KEHAR. 1994. Pemuliharaan dan penggunaan air hujan oleh ladang tenaga *Eucalyptus tereticornis* dan tanaman ladang yang bergantung pada air hujan di India utara** . Satu ladang tenaga pokok *Eucalyptus tereticornis* yang kepadatannya tinggi (10,000 pokok $ha^{-1}$) dan berjangkamasa singkat telah didirikan di tanih lom pasir yang tipikal di kawasan kaki bukit di India utara. Ladang ini merupakan satu percubaan untuk mengkaji prospek dalam mengadakan sumber-sumber tenaga bio sebagai alternatif pada keluaran petroleum. Keberkesanan pemuliharan dan penggunaan air hujan di bandingkan dengan tanaman bijan - biji sesawi yang ditanam pada separuh lagi bahagian ladang yang mempunyai keadaan tapak yang serupa. Sistem penggunaan tanih pertanian (ALUS) yang mempunyai profil tanih sedalam 300 sentimeter (*cm*) telah memulihara air hujan sebanyak 45, 84 dan 181 *mm* masing-masing dari air hujan monsun sebanyak 685, 905 dan 1586 *mm* yang masing-masingnya telah dicatitkan pada tahun 1985, 1986 dan 1988. Sistem penggunaan tanih hutan (FLUS) yang mempunyai profil yang serupa dengan ALUS memulihara air hujan sebanyak 311, 240, dan 445 *mm* masing-masing dari air hujan monsun sebanyak 685, 905, dan 1586 *mm* yang masing-masing dicatitkan pada tahun 1985, 1986 dan 1988. Min tambahan air ialah 68 *mm* bagi ALUS dan 244 *mm* bagi FLUS. Kemarau luar biasa pada tahun 1987 tidak menghasilkan tambahan bersih untuk kedua-dua sistem. Hujan monsun telah mengimbuhkan profil tanih sedalam 150 *cm* pada ALUS tetapi sehingga sedalam 240-300 *cm* bagi FLUS. Penggunaan air tahunan ialah sebanyak 774, 806, 417 dan 816 *mm* masing-masing pada tahun 1985-86, 1986-87, 1987-88, dan 6 bulan untuk tahun 1988-89 bagi ALUS. Bagi FLUS pula, penggunaan air tahunan ialah sebanyak 976, 1062, 435 dan 1141 *mm* masing-masing pada tahun 1985-86, 1986-87, 1987-88 dan bagi 6 bulan untuk tahun 1988-89. Min tahunan penggunaan air untuk ALUS ialah 801 *mm* manakala jumlah penggunaan airnya pula ialah 2803 *mm*. Bagi FLUS pula, min tahunan penggunaan air ialah 1033 *mm* dan jumlah penggunaan airnya ialah 3614 *mm*. Profil kandungan air pada akhir kajian ini sama bagi kedua-dua sistem. FLUS telah menggunakan sebanyak 29% air yang lebih dengan memulihara air hujan yang telah terbuang oleh ALUS. FLUS meningkatkan defisit lembapan tanih dalam paras-paras tanih yang lebih dalam sebelum dan antara musim hujan monsun mengakibatkan penyerapan yang tinggi. *Eucalyptus* merupakan pengguna air hujan yang lebih berkesan jika di bandingkan dengan tanaman ladang

## Introduction

The sharp increase in the prices of petrol and petroleum products in recent years has renewed interest all over the world in the use of plant biomass as an alternate source of energy. Several research workers have stressed the need for large scale energy plantations of fast-growing tree species in short rotations for increasing biomass production (Kaul & Mann 1977, Foley & Bernard 1984, Kondas 1985).

Until recently, eucalypts were considered a very favourable tree species for energy plantations because of their fast growth, coppicing ability and capacity to grow under diverse soil and climatic conditions (Gosh *et al.* 1979, Srivastava 1981, Pearce, 1983, Mathur *et al.* 1984). However, eucalypts have recently been criticised on the grounds that they use a lot of water, deplete the soil of its nutrient and water reserves, and render the soil unproductive. A critical review of the research on the negative effects of eucalypts on soil and water was inconclusive (FAO 1985). Due to the lack of quantitative information on nutrient and water use requirements of eucalypts, it was not possible to defend this remarkable plant genera (Bhatia 1984). A short rotation, high density energy plantation of *Eucalyptus tereticornis* was, therefore, raised to investigate its production potential, cash returns, nutrient and water use in comparison to traditional field crops of the area. Data on production and economic aspects have already been reported (Grewal *et al.* 1993). Information on relative efficiency of rainwater conservation and use are presented in this paper.

## Materials and methods

The field study was conducted over four years (1985-88) at the farm of the Central Soil and water Conservation Research and Training Institute, Research

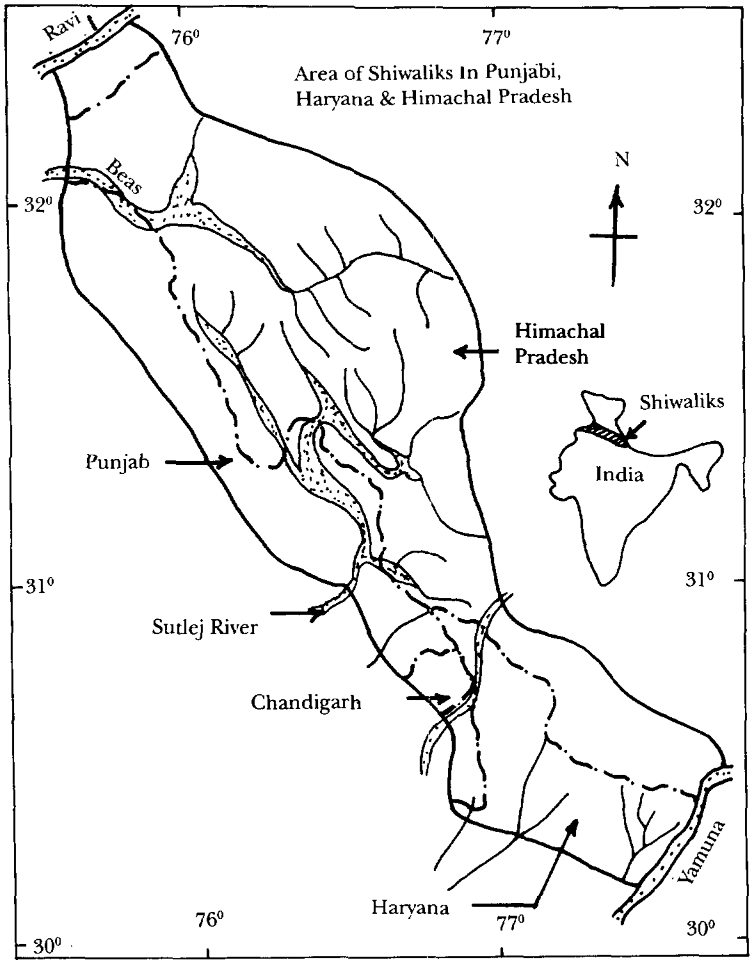


**Figure 1.** Foot hill region of Shiwaliks in north India

Centre, Chandigarh (30° 45'N, 76°15'E ; 350 *m* a.s. l.). This foot-hill region (Figure 1) has a mean annual rainfall of 1100 *mm*, of which about 82% occurs in three monsoonal months (Agnihotri *et al.* 1989) in a typical semi-arid climate (Table 1). Annual rainfalls of 789, 1141,513 and 1736 *mm* were recorded during the study years of 1985, 1986, 1987 and 1988 respectively, out of which 686, 905, 313 and 1586 *mm* were recorded in the three monsoon months of each year. The physical and chemical properties of the soil at experimental site were determined to 300 *cm* depth in 30 *cm* depth intervals following the methods of Piper (1950) and Richards (1954). The soil was light textured sandy loam (Udic Ustocrept) with pH varying from 7.1 to 8.3, electrical conductivity of 1:2 soil-water suspension 0.49 to 2.02 $dSm^{-1}$, clay content 10.3 to 17.6%, silt 12.0 to 18.3%, soil water content 3.2 to 6.1% at 15 *MPa* and 10.6 to 18.0% at 1/3 *MPa* in 30 *cm* layers of 0-300 *cm* deep soil profile (see Grewal *et. al.* 1993 for detail). The available N, P and K were low in all the soil layers as per the norms given by Chopra and Kanwar (1976). The ground water table in the study area was 50*m* below the surface.

**Table 1.** Mean monthy climate parameters (averages 1950-88) as recorded at the meteorology laboratory of the Research Centre

| Month | Rainfall (*mm*) | Rainy days | Pan evaporation (*mm day*$^{-1}$) | Mean temp(C°) | | Wind velocity (*km h*$^{-1}$) | Relative humidity (%) | | Sunshine (*h*) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Max. | Min. | | Morning 0800 *h* | Evening 1400 *h* | |
| Jan. | 43 | 3 | 2.3 | 20.4 | 6.9 | 3.8 | 79 | 57 | 6.6 |
| Feb. | 39 | 2 | 3.3 | 22.9 | 8.7 | 4.6 | 76 | 49 | 7.6 |
| Mar. | 39 | 3 | 5.6 | 29.1 | 13.6 | 5.7 | 64 | 41 | 7.8 |
| Apr. | 15 | 1 | 9.1 | 34.8 | 19.5 | 6.2 | 52 | 32 | 9.5 |
| May. | 36 | 2 | 11.5 | 38.2 | 23.2 | 6.8 | 45 | 31 | 9.5 |
| Jun. | 118 | 6 | 10.8 | 38.0 | 25.6 | 6.4 | 59 | 42 | 7.9 |
| Jul. | 314 | 11 | 5.6 | 33.6 | 25.1 | 4.8 | 82 | 68 | 6.1 |
| Aug. | 308 | 12 | 4.2 | 32.7 | 24.4 | 3.5 | 86 | 72 | 6.2 |
| Sep. | 133 | 6 | 5.1 | 33.2 | 22.2 | 3.3 | 82 | 59 | 8.3 |
| Oct. | 19 | 1 | 5.1 | 31.9 | 18.0 | 4.3 | 67 | 44 | 8.9 |
| Nov. | 11 | 1 | 3.8 | 27.2 | 12.4 | 4.4 | 66 | 43 | 8.3 |
| Dec. | 26 | 2 | 2.3 | 22.2 | 8.1 | 3.8 | 74 | 49 | 7.2 |
| Total/ Mean | 1101 | 51 | 5.7 | 30.4 | 17.3 | 4.8 | 69 | 49 | 7.8 |

Source: Agnihotri *et al.* 1989.

Grewal *et al.* (1993) studied the response of three levels of N, *viz.* 0, 25 and 50*g* per plant applied from two source, prilled urea $(NH_4)_2SO_4$, (PU, 48%) and super granules (SG, 1*g* of urea briquettes, 46 %N, a slow release source) on *Eucalyptus tereticornis* raised under rainfed conditions for fuelwood at 1 × 1 *m* spacing. The nursery raised plants in poly bags of 60 *cm* height and six months of age were planted in July 1985 in 6 *cm* wide and 120 *cm* deep augerholes filled with fertilised soil as per treatment. A basal dose of 25*g* phosphorus from single superphosphate and 10 *g* zinc sulphate per plant was added. Around each 4 × 4 *m* treatment plot having 16 plants, 20*cm* high earthen embankments were made for *in-situ* conservation of rainfall. All the five treatments, *i.e.*, 0-N, 25N-PU, 25N-SG and 50N-SG were randomised in each of five replications. A further row of *Eucalyptus tereticornis* was also planted along the periphery of the plot. The experiment covered an area of 20 × 20 *m* and was laid in one half of a 0.6 *ha* field. In the second half, a block measuring 20 × 20*m* was located 8 *m* away from the first block. The field crops of sesame followed by rapeseed were grown in this block in all the years as a standard farmer's practice of the region. The nature and properties of the soil, slope (1%) and other site conditions including the previous cropping history (rapeseed - sesame for four previous years) were identical in both the plots. The conservation of rainfall and evapotranspiration by the agricultural land use system (ALUS) and the forestry land use system (FLUS) were compared. In order to determine the soil water storage and use, soil samples were collected in duplicate sets from beneath the two crops four times a year (middle of March, June, September and December). Samples were collected at 30*cm* intervals to 300*cm* depth using a Belgian type auger. The soil water was determined gravimetrically. The June and September samples indicated the soil water status of the profile before (Isw) and after the monsoon (Fsw) and the difference indicated the net gain (+) or loss(-). Subsequent depletion of soil water was indicated by the sampling done in middle of December and March. The soil bulk density of each of the 30*cm* layers from both land use systems and infiltration rate of the soil before and after the study using double ring infiltrometers were determined following Richards (1954).

Evapotranspiration (ET) were computed from the seasonal water balance following Hillel (1971) and Riedl and Zachar (1984). Each study year was divided into four seasons, *i.e.*, monsoon (July to Septmber), post monsoon (October to December), winter (January to March) and summer (April to June). For each season, ET was computed by the following relationship:

ET = R - (1+RO)+(Isw-Fsw), where
ET = Seasonal evapotranspiration
R = Rainfall
I = Interception
RO = Runoff
Isw = Initial soil water content
Fsw = Final soil water content

Rainfall of each storm was measured with a non-reconding rain gauge ($200 cm^2$, area, manufactured by Ram Kala and Sons, Pune as per Indian Meteorological Department, Pune specifications installed at the site). Interception and runoff by *Eucalyptus* had been measured near the site under identical conditions by Grewal (1988a) and the same data were used. These interception data were in agreement with those reported by George (1978). Runoff from the field crops had been measured for these years at the same site by Grewal (l988b) and Mittal *et al.* (1988). An average interception of 8% of rainfall was assumed for field crops during the growth period. This estimate was based upon the review of literature by Riedl and Zachar (1984) for similar crop, climate and growth conditions. Deep percolation losses beyond 300 *cm* soil depth were considered negligible because of low soil water content of 270-300 *cm* layer at most of the study period except September, 1985 and 1988. The soil water content in 210 to 300 *cm* soil depth after the monsoon of 1985 and 1988 was lower than the field capacity water content of the soil (Figure 2) thus indicating the limited chances of gravitational water movement (Hillel 1971). Some deep percolation occurred in September, 1988 before the date of soil sampling from FLUS because unusually heavy rainfall may have been compensated for by upward water fluxes from lower layers and hence accounted for. The hydraulic conductivity of such a light textured soil was expected to be very low at low moisture content (Elrick 1968). Hence the chances of appreciable deep percolation losses at soil water content below field capacity were ruled out.

**Table 2.** Gravimetric water content in the soil profile before (BM) and after (AM) monsoon rain and change in soil storage in four years under two crops

| Crop | Gravimetric water content on 0-300 cm soil profile (*mm*) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1985 | | | 1986 | | | 1987 | | | 1988 | | | Mean change in soil water storage |
| | BM | AM | Change in soil water storage | BM | AM | Change in soil water storage | BM | AM | Change in soil water storage | BM | AM | Change in soil water storage | |
| Agriculture | 231 | 276 | 45 (+) | 209 | 293 | 84 (+) | 211 | 172 | 39 (-) | 148 | 329 | 181 (+) | 68 (+) |
| Forest | 230 | 541 | 311 (+) | 178 | 418 | 240 (+) | 150 | 129 | 21 (-) | 119 | 564 | 445 (+) | 244 (+) |
| Seasonal rainfall (*mm*) | | 685 (below normal) | | | 905 (normal) | | | 313 (low) | | | 1586 (high) | | 872 |
| Mean tree height (*cm*) | | 60 | | | 387 | | | 634 | | | 764 | | |

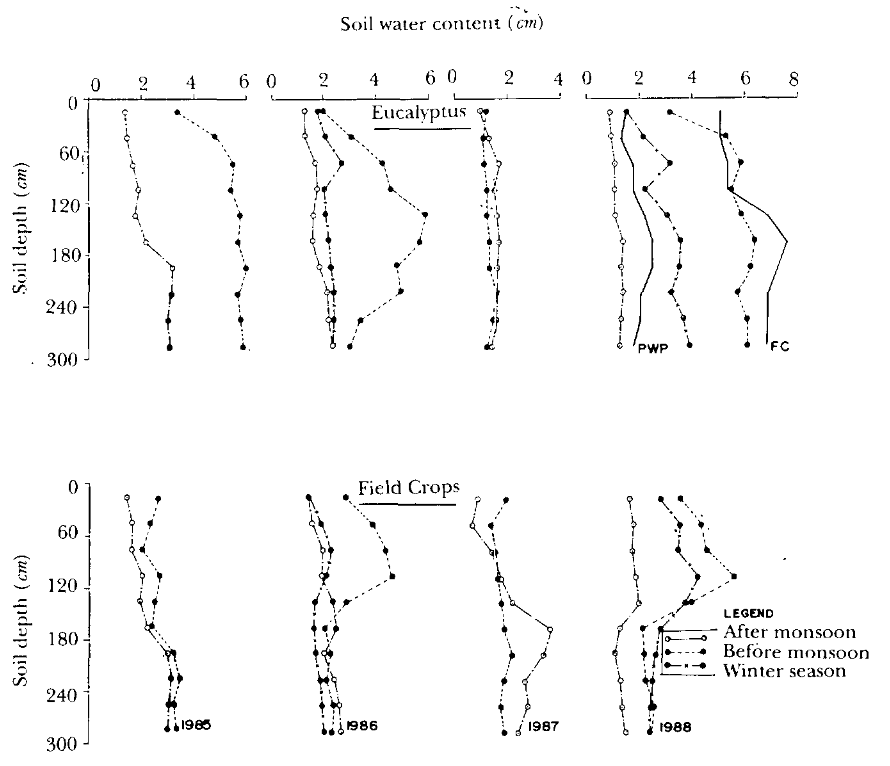


**Figure 2.** Volumetric soil water content in the profiles of FLUS and ALUS before and after the monsoon of four study years

## Results and discussion

### *Rainwater conservation*

Out of the monsoon rainfalls of 685, 905 and 1586 *mm* of 1985, 1986 and 1988, soil water storage increased beneath the agricultural crop by 45, 84 and 181 *mm* compared to 311, 240 and 445 *mm* respectively beneath the forestry crop (Table 2). During the drought year of 1987, the soil water content beneath both crops showed net decrease because plant water use was greater than recharge from rainfall. The mean seasonal increase of soil water storage was 68 *mm* by the agricultural crop and 244 *mm* by the forest crop. The soil water content was low before the monsoon and high after the monsoon in all the years beneath forest crop as compared to the agricultural crop except in the drought year of 1987 (Figure 3).

In the ALUS, the soil water recharge with the monsoon rains was mainly limited to 150 *cm* depth even in good rainfall year but in the case of the FLUS, the recharge was greater and wetting front extended beyond 300 *cm* depth in all the years except 1987 (Figure 2). During the drought year of 1987, enough water was lying below 150 *cm* soil depth in the agricultural crop, which, however, could not use this water and hence failed. But in the case of *Eucalyptus*, the entire moisture of the 0-300 *cm* soil depth was fully exploited and its contents were lowered down nearly to wilting point in all the layers.

**Table 3.** Seasonal water balance components and evapotranspiration (ET) computed for *Eucalyptus* and field crops for four years (*mm*)

| Particulars | 1985-86 | | | | | 1986-87 | | | | | 1987-88 | | | | | 1988 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J-S | O-D | J-M | A-J | Total | O-J | O-D | J-M | A-J | Total | J-S | O-D | J-M | A-J | Total | J-S | O-D | Total | G.Total |
| | | | | | | | | | *Eucalyptus* | | | | | | | | | | |
| 1. Rainfall | 528 | 109 | 83 | 252 | 972 | 698 | 108 | 133 | 206 | 1145 | 225 | 29 | 67 | 118 | 439 | 1487 | 64 | 1551 | 4107 |
| 2. Interception | 26 | 6 | 4 | 12 | 48 | 49 | 8 | 9 | 15 | 81 | 18 | 2 | 5 | 10 | 35 | 149 | 6 | 155 | 319 |
| 3. Runoff | 0 | 0 | 0 | 0 | 0 | 30 | 0 | 0 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 74 | 0 | 74 | 104 |
| 4. Soil recharge 1-(2+3) | 502 | 103 | 79 | 240 | 924 | 619 | 100 | 124 | 191 | 1034 | 207 | 27 | 62 | 108 | 404 | 1264 | 58 | 1322 | 3684 |
| 5. Initial in the profile | 230 | 541 | 430 | 280 | 230 | 178 | 418 | 223 | 191 | 178 | 150 | 129 | 153 | 191 | 150 | 119 | 564 | 119 | 230 |
| 6. Total (4+5) | 732 | 644 | 509 | 520 | 1154 | 797 | 518 | 347 | 382 | 1212 | 357 | 156 | 215 | 299 | 554 | 1383 | 622 | 1441 | 3914 |
| 7. Residual left in the profile | 541 | 430 | 280 | 178 | 178 | 418 | 223 | 191 | 150 | 150 | 129 | 153 | 191 | 119 | 119 | 564 | 300 | 300 | 300 |
| 8. ET (6-7) | 191 | 214 | 229 | 342 | 976 | 379 | 295 | 156 | 232 | 1062 | 228 | 3 | 24 | 180 | 435 | 819 | 322 | 1141 | 3614 |
| 9. ET/Month | 64 | 71 | 76 | 114 | 81 | 126 | 98 | 52 | 77 | 89 | 76 | 1 | 8 | 60 | 36 | 273 | 107 | 190 | 86 |
| | | | | | | | | | Agricultural Crops | | | | | | | | | | |
| 1. Rainfall | 528 | 109 | 83 | 252 | 972 | 698 | 108 | 133 | 206 | 1145 | 225 | 29 | 67 | 118 | 439 | 1487 | 64 | 1551 | 4107 |
| 2. Interception | 42 | 0 | 3 | 0 | 45 | 56 | 0 | 10 | 0 | 66 | 18 | 0 | 5 | 0 | 23 | 119 | 0 | 119 | 253 |
| 3. Runoff | 99 | 0 | 0 | 76 | 175 | 208 | 0 | 0 | 63 | 271 | 29 | 0 | 12 | 31 | 72 | 461 | 0 | 461 | 979 |
| 4. Soil recharge 1-(2+3) | 387 | 109 | 80 | 176 | 752 | 434 | 108 | 123 | 143 | 808 | 178 | 29 | 50 | 87 | 344 | 907 | 64 | 971 | 2875 |
| 5. Initial in the profile | 231 | 276 | 240 | 265 | 231 | 209 | 293 | 195 | 247 | 209 | 211 | 172 | 176 | 205 | 211 | 148 | 329 | 477 | 231 |
| 6. Total (4+5) | 618 | 385 | 320 | 441 | 983 | 643 | 401 | 318 | 390 | 1017 | 389 | 201 | 226 | 292 | 555 | 1055 | 393 | 1448 | 3106 |
| 7. Residual left in the profile | 267 | 240 | 265 | 209 | 209 | 293 | 195 | 247 | 211 | 211 | 172 | 172 | 205 | 148 | 148 | 329 | 303 | 632 | 303 |
| 8. ET (6-7) | 342 | 145 | 55 | 232 | 774 | 350 | 206 | 71 | 179 | 806 | 217 | 25 | 21 | 144 | 417 | 726 | 90 | 816 | 2803 |
| 9. ET/Month | 114 | 48 | 18 | 77 | 65 | 117 | 69 | 24 | 60 | 67 | 72 | 8 | 7 | 48 | 34 | 242 | 30 | 136 | 67 |

* Interception of *Eucalyptus* @ 5,6,7,8 and 10% of rainfall in 1985,1986,1987 and 1988 respectively;
** Interception by field crops @ 8% of rainfall;
J-S: July to September, O-D: October to December, J-M: January to March, A-J: April to June.

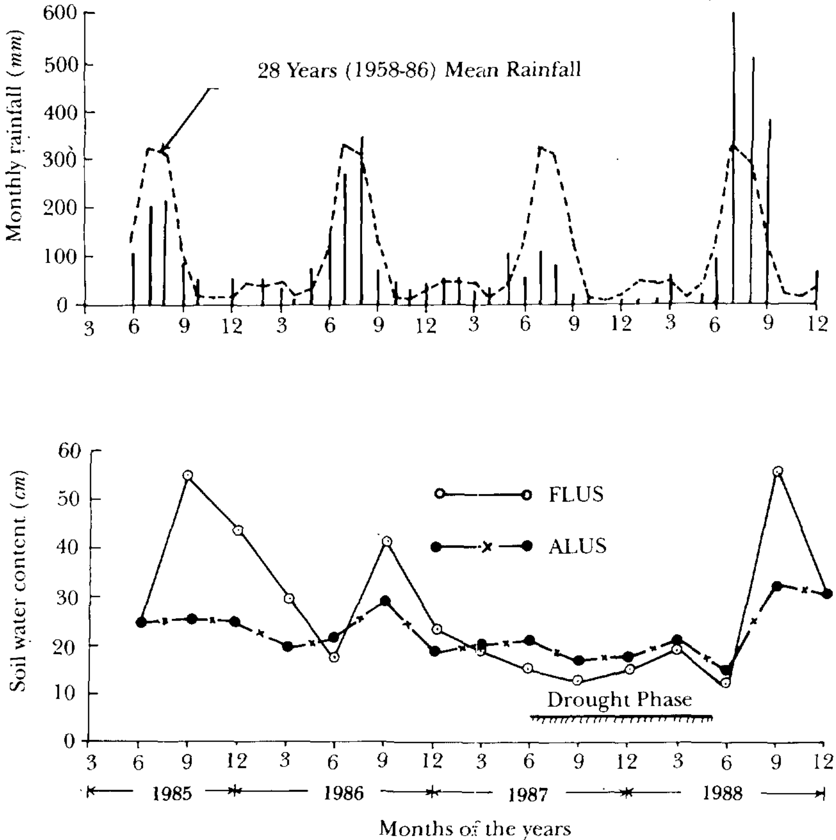


**Figure 3.** Periodic soil water content of 0-300 *cm* deep soil profile under FLUS and ALUS between June 1985 and December 1988 including mean and monthly rainfall distribution

Due to the seasonal nature of the field crops, efficient use of profile stored soil water was low. Either there was no crop or crop stands were not fully developed to exploit soil water at some points of time. For example, between 10.10.1988 and 19.12.1988, there was no rain for 70 days but sufficient water was available in the 0-120 *cm* soil profile of the field crop. In the first 35 days, there was no crop and in the remaining 35 days, the crop stand was not fully developed to tap this water and hence only 26 *mm* of water could be used from the profile. On the other hand, in the case of *Eucalyptus*, 264 *mm* of water was used in the same period. Similarly, between 12.9.1986 and 22.12.1986, the profile water use was 195 *mm* in the FLUS and only 98 *mm* in the ALUS. Gupta *et al.* (1975) also reported higher soil moisture recharge in a *Eucalyptus* plantation as compared to fallow land, grass land and *Acacia* forest in an arid zone of India.

## *Water use*

The study started with almost the same amount of initial soil water content beneath both the systems (Table 3). Interestingly, at the end of the study in December 1988, the residual soil water left in the profile was again almost equal.

The annual water use (ET) values for 1985-86, 86-87, 87-88 and six months of 1988-89 were 976, 1062, 435 and 1141 *mm* respectively in the FLUS and 774, 806, 417 and 816 *mm* respectively in the ALUS. The corresponding mean monthly water use values were 86 and 67 *mm* and annual use values were 1033 and 801 *mm*.

The mean annual water balance components show (Figure 4) that the FLUS used about 29% more water than the ALUS. The extra water use was permitted by the greater water recharge beneath the forest crop whereas beneath the agricultural crop runoff was much greater. Considering the drought year of 1987-88 as an exception, the annual water use progressively increased in the FLUS as the plantation grew. Water use was nearly uniform in the case of the ALUS. The seasonal water use of both the systems, however, varied according to moisture availability index given by the ratio of seasonal rainfall (RF) and standard pan evaporation (PET). Water use was maximum during the rainy season and lowest during the winter season (Figure 5). Monthly ET was highly correlated with seasonal RF/PET ratio (Figure 6), for both the land use systems indicating higher use of water as and when it was available.The ET/PET ratio was highest during the rainy season in both the land uses but lowest in the summer for the FLUS and in the winter for the ALUS (Table 4). This obviously means that the soil moisture supply is more critical for *Eucalyptus* in summer (April-June) and for field crops in winter (January to March). The overall annual ET/PET ratios were 0.53 and 0.36 in the FLUS and the ALUS. The ALUS appears to have permitted more loss of water through soil evaporation particularly during periods when there was no or inadequate plant cover. For example, most of the ET of October to December and March to June periods was evaporation and much less transpiration. In the case of the perennial stand of *Eucalyptus*, evaporation of water from the soil may be low because of shade and leaf litter cover, and transpiration may be relatively more than soil evaporation.

In the comprehensive review of ecological effects of *Eucalyptus* (FAO 1985), it has been reported that interception of *Eucalyptus tereticornis* may vary between 11 and 20% of precipitation (for mature stands), it may create soil water deficit of 250 *mm* per year in deeper soils, its ET may vary between 1.5 *mm* per day in winter and 6.0 *mm* per day in summer and its average water use in well stocked plantation may be around 1000 $mm\ y^{-1}$ for rainfall regime of 1200 $mm\ y^{-1}$. In our study conducted on a deep alluvial soil with four years mean annual rainfall of 1045 *mm*, the yearly soil water deficit was 189 *mm*, the mean annual, monthly and daily ET were 1033 *mm*, 86 *mm* and 2.9 *mm*. These values appear in agreement with the data reported earlier. The study conducted by Banerjee (1972) also provided almost similar results. Dabral and Raturi (1985) found average annual ET of 1630 *mm* for a 3-y-old *Eucalyptus tereticornis* plantation with a mean annual rainfall of 2042 *mm*. The use of 29% more water by *Eucalyptus tereticornis* as compared to the field crops by conserving runoff water seems to be in agreement with the observation on runoff reduction from watersheds planted with *Eucalyptus*. Such a reduction in runoff was reported as 16% by Samraj *et al.* (1977) in the Nilgiri hills of South India, 28% by Mathur *et al.* (1976) in the Doon valley of north India and 30% by Van Lill *et al.* (1980) in South Africa.

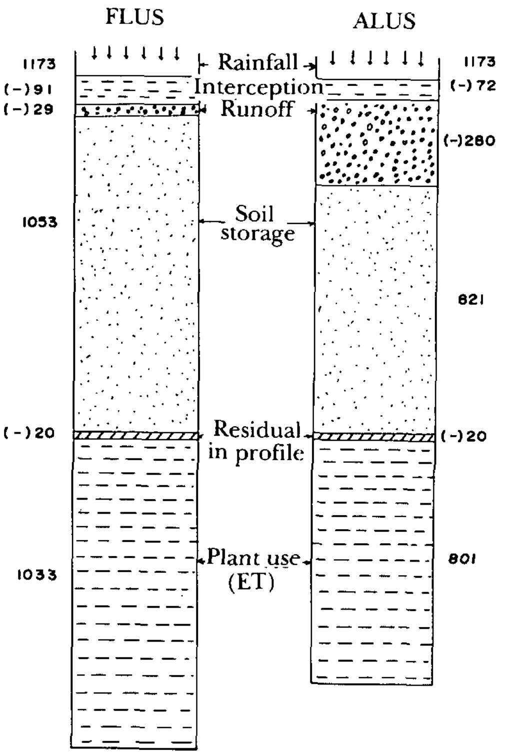


**Figure 4.** Annual water balance components computed for two land use systems (*mm*)

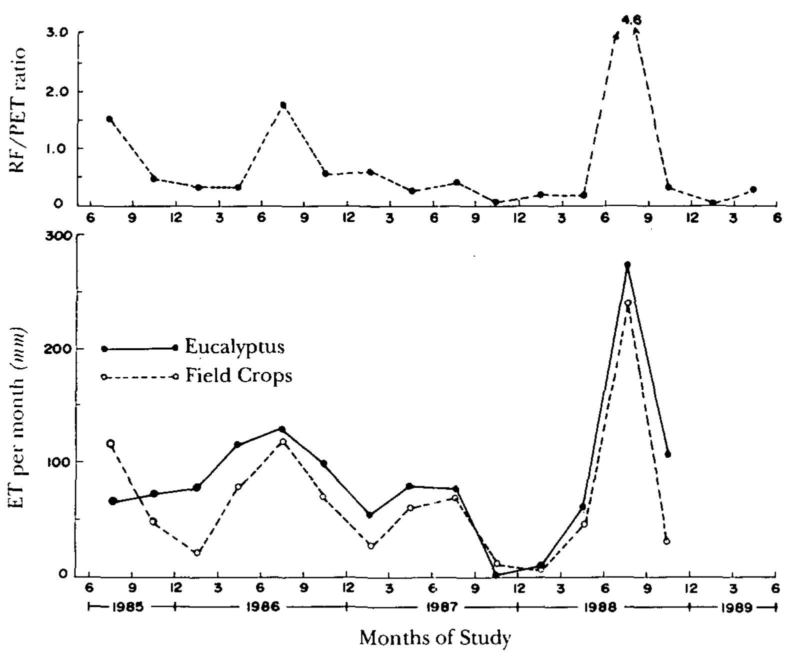


**Figure 5.** Evapotranspiration(ET) and ratio between rainfall (RF) and potential evapotranspiration (PET) for various seasons during 1985-1989

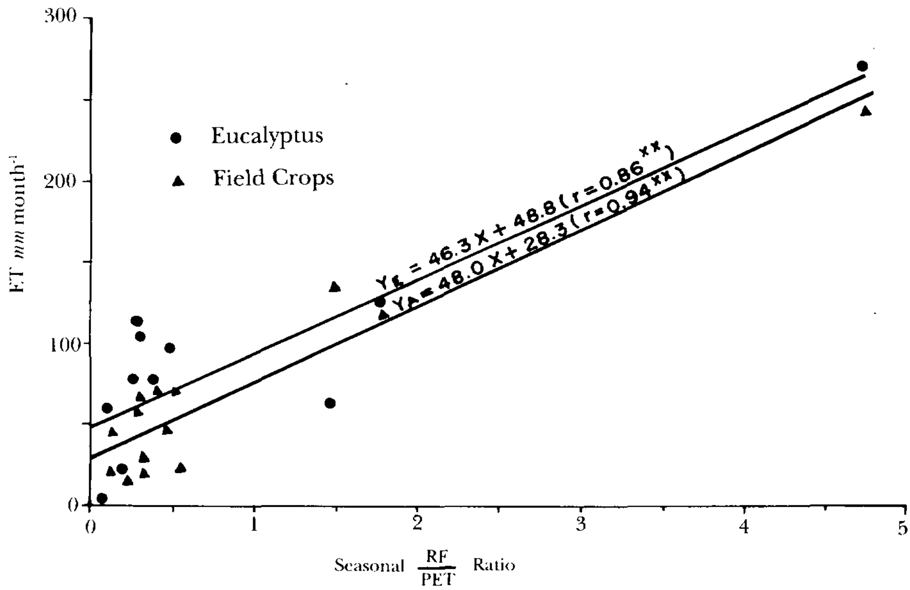


**Figure 6.** Correlation between RF/PET and ET of the two land use systems

**Table 4.** Relationship between PET and ET of the two land use systems during different seasons of the year

| Season/months | Mean monthly values (*mm*) | | | | |
|---|---|---|---|---|---|
| | PET | ET | | ET/PET | |
| | | FLUS | ALUS | FLUS | ALUS |
| Monsoon season (7,8,9) | 153 | 167 | 136 | 1.09 | 0.89 |
| Post monsoon (10,11,12) | 114 | 69 | 39 | 0.61 | 0.34 |
| Winter season (1,2,3) | 111 | 45 | 16 | 0.41 | 0.14 |
| Summer season (4,5,6) | 313 | 84 | 62 | 0.27 | 0.20 |
| Mean | 173 | 91 | 63 | 0.53 | 0.36 |

The study started with a 25% below normal rainfall year and ended with a 55% above normal rainfall year with four years overall mean almost equal to the 35 years average rainfall. Heavy rainfall was received in the last year of the study and as a result most of the soil water deficit of the FLUS was recouped. But nevertheless, it was preceded by an exceptional drought year during which exceedingly high water depletion was observed. Such rainfall variations are common in the region and have truly been represented in this study. Higher amount of monsoon season rainwater storage (244 *mm*) in the FLUS than the ALUS (68 *mm*) was attributed to higher soil water deficit created before the monsoon rainfall and as well as between rainfall events and as a consequence maintenance of high rate of infiltration. At the end of the study, the Ist, 2nd and 3rd hourly rates of infiltration were 3.2, 1.4 and 1.2 *cm* respectively in the ALUS and 47, 3.5 and 3.3 *cm* respectively in the FLUS against 3.3, 1.5 and 1.3 *cm* respectively at the start of the study in both the systems. Moreover, 10,000 augerholes (6 *cm* width and 120 *cm* depth) made for 1×1 *m* planting of seedlings may have acted as preferential channels for rapid entry of rainwater to lower profile layers. The total amount of runoff in the study period was 831 *mm* from the ALUS but only 104 *mm* from the FLUS. The FLUS thus saved 727 *mm* (831-104) of water by reducing runoff. It used 811 *mm* (3614-2803) of more water than the ALUS and this was mainly the runoff water otherwise going waste. *Eucalyptus tereticornis* was therefore a more efficient user of rainwater resource than field crops. It appeared that the deep rooted trees could efficiently use soil water but relatively shallow rooted field crops could not efficiently use the profile stored soil water. The ground water table being at 50 *m* of depth, lowering of water table by exploiting water from the water table by the FLUS appeared improbable. The results of this study may be more valid for plantations raised in field size plots and may have to be suitably modified for large size plantations.

## Conclusions

Against the mean soil water storage of 244 *mm* from the monsoon rainfall by the FLUS, the ALUS stored only 68 *mm*. The mean annual, monthly and daily ET were 1033, 86 and 2.9 *mm* respectively in the FLUS and 801, 67 and 2.2 *mm* respectively in the ALUS. *Eucalyptus* used about 29% more water than the field crops but this extra use was made by conserving more of the rainwater going to waste as runoff from alluvial land. It may not seriously deplete the soil of its water reserve when grown with 1000-1200 *mm* of annual rainfall for one short rotation by conserving rainwater through the construction of interplot earthen embankments. The deep rooted perennial stand of *Eucalyptus*, but not the relatively shallow rooted seasonal crops, could efficiently use the profile stored soil water. The maintenance of relatively higher rate of infiltration by *Eucalyptus* plantation facilitated the storage of rainwater resource in the soil reservoir for subsequent use.

## References

AGNIHOTRI, Y., BANSAL, R. C., SINGH, PRAHALD & MITTAI, S.P. 1989. Climatological features of Chandigarh. *Bulletin No.T-20/C-1 of the Central Soil and Water Conservation Research and Training Institute, Research Centre, Chandigarh India* : 3.

BANERGEE,A.K.1972. Evapo-transpiration from a young *Eucalyptus* hybrid plantation of West Bengal. Pp. 17-23 in *Proceedings of Symposium on Man-made Forests in India.* June 8 -10, 1972. Dehra Dun, India.

BHATIA,C.L. 1984. *Eucalyptus* in India - its status and research needs. *Indian Forester* 110(2): 91-96.

CHOPRA, S.L. & KANWAR, J. S. 1976. *Analytical Agricultural Chemistry.* Kalyani Publishers, New Delhi.

DABRAL, B.G. & RATURI, A.S. 1985. Water consumption by *Eucalyptus* hybrid. *Indian Forester* 111(12): 1053 -1069.

ELRICK, E.E. 1968. The microhydrological characterisation of soils. *IA HS-AISH* Pub. 83 : 311-317.

FAO, 1985. *Ecological Efforts of Eucalyptus Cultivation.* FAO Forestry Paper No 59. FAO Rome.

FOLEY, G & BERNARD, G. 1984. *Farm and Community Forestry.* International Institute for Environment and Development Forestry. Technical Report No 3. Earth-Scan Energy Information Programme.

GEORGE, M. 1978. Interception, stem flow and throughfall in *Eucalyptus* hybrid plantation. *Indian Forester* 104(11): 719 - 726.

GOSH, R. C., AGRAWALA, N.K. & SHARMA, K.K. 1979. *Eucalyptus* for planting. Country Report 1977, Forest Research Institute and Colleges, Dehradun, UP, India.

GREWAI, S.S. 1988a. Effect of limited profile modification on biomass production of trees and grass grown together on light textured sandy soil. *Annual Report, Central Soil Water Conservation Research and Training Institute, Dehradun, India* : 96 - 99.

GREWAL, S.S. 1988b. Evaluation of fuel cum fodder plantation of *Leucaena leucocephala* in terms of soil and water loss and biomass production. *Annual Report, Central Soil and Water Conservation Research and Training Institute, Dehradun India* : 104 - 105.

GREWAL, S.S., SINGH, KEHAR & JUNEJA, M.L. 1993. Response of high density energy plantation of *Eucalyptus tereticornis* to basal nitrogen source, dose and phosphorus application on an alluvial soil. *Journal of Tropical Forest Science* 5(3): 387 - 402.

GUPTA, J.P. ULLAH,VASI & ISSAC, V.C. 1975. Note on some moisture changes under permanent vegetation covers. *Indian Forester* 101: 523 - 526.

HILLEL, D. 1971. *Soil and Water: Physical Principles and Processes.* Academic Press, New York : 226 - 230.

KAUL, R.N. & MANN, H.S. 1977. Tree planting and energy crisis: firewood. *Indian Farming* 26(2): 79 - 81.

KONDAS, S. 1985. Social forestry in India. *Indian Forester* 111(11): 887 - 896.

MATHUR, H.N., BABU, R., JOSHIE, P. & SINGH, B. 1976. Effect of clearfelling and reforestation on runoff and peak rates in small watersheds. *Indian Forester* 102(4): 219 - 226.

MATHUR, R.S., KIMOTHI, M.M. & GURUMURTI, K. 1984. Quest for improving the productivity and availability of forest biomass - a review. *Indian Forester* 110(8): 695 - 725.

MITTAL, S.P., BANSAL, R.C., SUD, A.D. & DYAL, S.K.N. 1988. Hydrological behaviour of agricultural watershed. *Annual Report, Central Soil and Water Conservation Research and Training Institute, Dehradun, India :* 91 - 93.

PEARCE, M.L. 1983. Coppiced trees as energy crops. Pp. 137-139 in *Energy from Biomass.* Applied Science Publishers, London.

PIPER, C.S.1950. *Soil and Plant Analysis.* University of Adelaide, Australia.

RICHARDS, L.A. (Ed.). 1954. *Diagnosis and Improvement of Saline and Alkali Soil.* USDA Hand book 60. United States Salinity Laboratory, Reverside, California.

RIEDL, 0. & ZACHAR, D. 1984. *Forest Amelioration: Developments in Agricultural and Managed Forest Ecology.* Elsevier Science Publishers, Amsterdam, The Netherlands : 46 - 47.

SAMRAJ, P., CHINNAMANI, S. & HALDORAI, B. 1977. Natural versus man-made forest in Nilgris with special reference to runoff loss and productivity. *Indian Forester* 103: 460 - 465.

SRIVASTAVA, B.P. 1981. High density short rotation forestry for mitigating the energy crisis in India. *Indian Forester* 107: 767 - 776.

VAN LILL, W.S., KRUGER, F.J. & VANWYK, D.B. 1980. The effect of afforestation with *Eucalyptus grandis* Hill ex Maiden and *Pinus patula* Schlecht. ex Cham. on stream flow from experimental catchments of Mokobulaan, Transvaal. *Journal of Hydrology* 48 : 107 - 118.