A COMPARISON OF WATER BALANCE COMPONENTS IN NATURAL AND PLANTATION FORESTS IN EL SALVADOR, CENTRAL AMERICA[1] /

*NORMAN W PRICE**

Resumen

La precipitación bajo el bosque, el flujo de precipitación por los tallos, la humedad de suelo, la evaporación y la transpiración fueron medidas en cuatro tipos de bosques en el área de Metapán-Montecristo, El Salvador. El tipo de bosque (latifoliadas vs. coníferas) tiene gran importancia sobre el balance hídrico de una región.

*Los cuatro tipos de bosques incluyeron: una plantación de ciprés (*Cupressus lusitanica *Mill.), una plantación de pino (*Pinus pseudostrobus *Lindl.), un bosque mixto de pino-roble (*P. oocarpa *Schiede y* Quercus peduncularis *NEE.), y un bosque de regeneración natural.*

Según un análisis de los cinco factores estudiados, se llegó a la conclusión de que la plantación de ciprés tiene el mayor impacto sobre el balance hídrico del área, seguida en orden por el bosque mixto de pino-roble, la regeneración natural dominada por latifoliadas, y la plantación de pino.

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* Coordinator, Agroforestry Short Course, Dept. of RNR. CATIE.

Introduction

Reforestation with rapid-growth tree species in tropical regions may lead to unwanted changes in local and/or regional water balances. An understanding of the impact of rapid-growth species, particularly the conifers, on the water resources is thus essential for evaluation of land-use and water management priorities.

Differences between the impact of conifers and natural hardwood stands on the water balance have been established for temperate and some tropical regions. Higher percentages of interception of rainfall by conifers have been established by several researchers (1, 9, 23), and Swank, *et al.* (30, 31, 32) showed that lower streamflow result from conversion of natural hardwood stands to pine due to evaporation of the greater amount of intercepted rainfall.

The objective of this research was to compare conifers and natural hardwoods, in relation to their respective impact on the water balance, in a tropical region. The field research was undertaken between July 1976 and March 1977.

Research Area

The field research was carried out in the Metapan-Montecristo region of northeastern El Salvador, an area rough and mountainous, underlain by faulted sedimentary strata and strongly dissected by rivers and ravines. Slopes are variable, but average about 60% and usually exceed 50 m in length. Drainage is typically dendritic.

The four sites used in this investigation were between 1600 and 1800 masl with a mean annual rainfall of 1940 mm and a temperature range of 8°C to 23°C. Thus, they fall within the sub-tropical wet forest zone. The area is covered by a mosaic of conifer plantations of various ages, various stages of succession, mixed stands of oak-pine, and pasture.

Generally, during the study, rainfall was well below the six year average though still within the limits of standard deviation. Air temperatures corresponded to the long-term average with a tendency towards warmer days and cooler nights.

The four sample areas consisted of a nine-year-old plantation of *Pinus pseudostrobus* LINDL. (pinabete), situated at 1800 m, a nine-year-old plantation of *Cupressus lusitanica* MILL. (ciprés) at 1600 m, a natural stand of *Quercus aff. sapotaefolia* LIEBM. (encino), *Q. peduncularis* NEE. (roble) and *P. oocarpa* SCHIEDE (pino ocote) at 1760 m, and a stand of natural regeneration, dominated by *Leucaena* sp. (guaje), *Roupala montana* AUBL. (zorrillo), *Winmeria cyclocarpa* RADLK. (lloroncito), *Cassia* sp (vainillo), and *Sauravia pseudorubriformis* BUSC. (siete pellejos) at 1800 m.

The plantations of pinabete and ciprés were both situated in an area slightly to moderately sloping. Spacing in both was 2.5 by 2.5 m. DBH and heights were 15 cm/7.6 m and 12 cm/10.5 m respectively for the pinabete and ciprés. Undergrowth was dense and controlled by slashing about once a year.

The mixed oak-pine was situated on relatively flat terrain. The dominants averaged 38 cm in DBH with heights ranging from 13-26 m. A moderately dense second storey canopy occurred at 9 m with stems ranging from 4 to 10 cm in diameter. The age of the stand was approximately 60 years.

A site approximately 35 years of age on a bench near a large ravine was the location of the natural regeneration treatment. DBH varied between 10 and 51 cm with an average of 18. Heights were on the average about 8 m.

Further detail with respect to the different forest stands can be found in Price (24), "Highland Deforestation and Approaches to Forest Recovery in the American Tropics: the Metapan-Montecristo example of El Salvador."

Throughfall and Stemflow

Materials and Methods: Rain gauges were constructed from 6.5 cm`diameter plastic funnels attached to 5 litre plastic reservoirs. The capture surface was set 45 cm above the ground since this height had been shown by experience to be the best compromise to avoid additions from splash-back or interference from wind.

Stemflow channels were formed from plasticine. The channel was concave and extended about 2 cm from the trunk. Polyetheline tubing led from the end of the channel to a litre plastic jug which served as the reservoir.

Throughfall and stemflow were measured in the morning before the afternoon rains, though ocassionally two or three days delay occurred.

The gauges were positioned in a regular pattern throughout the site, with one gauge being situated in the most open location and another situated at the most closed; six to eight gauges were used. Stemflow was measured at five locations at each site, based on DBH, with trees representing the average and a range of diameters being selected.

Results: It was assumed that the meteorological station at Los Planes, which is within 300 meters of the Natural Regeneration site, would provide gross precipitation data to represent the above canopy condition. However, variation between sites suggests that this assumption did not hold. The variation mentioned above is evident in the summary of mean throughfall by site as a percentage of gross precipitation (i.e. meteorological station) given in Table 1.

To avoid the assumption of uniform precipitation over the entire area, analysis of throughfall was restricted to the specific site by calculating mean throughfall as a percent of the gauge with the largest consistent catch. The assumption in this case is that rainfall over a particular site on any given occasion

Table 1. Mean throughfall by sites as a percentage of mean rainfall in open*.

	Date	Natural Regneration	Mixed Oak-Pine	Pine	Cypress
	July 27				
	Aug. 13		$\frac{1.60^a}{4.7^b} \div 100 = 34$	30	30
	Aug. 14		42	60	41
	Aug. 15		102	89	129
	Aug. 17	76	60	53	50
	Aug. 24	72	85	99	103
	Aug. 31	105	103	159	163
WET	Sept. 2	4	9	59	126
SEASON	Sept. 3	23	4 543	2 917	4 254
	Sept. 7	76	56	69	66
	Sept. 8	55	75	39	99
	Sept. 21	75	206	250	223
	Sept. 23	78	67	64	62
	Sept. 24	66	83	48	63
	Oct. 5	37	76	76	81
TRAN-	Oct. 29-				
SITION	Nov. 9	33	9	20	19
	Nov. 17	578	55	58	69
	Nov. 18	124	21	114	25
	Nov. 20	75	80	69	57
	Nov. 25	98	0	1	0
DRY	Dec. 1	134	29	93	78
SEASON	Dec. 6	54	0	0	0
	Dec. 7	42	0	0	0
	Dec. 9	82	0	0	0
	MEAN	94.5	286.8	209.8	286.9

* As recorded at the Los Planes de Montecristo Meteorological Station.

a Throughfall as recorded at site.

b Rainfall as recorded by Meteorological Station.

was evenly distributed. Considering the relatively small size of the sites, this is a reasonable assumption. Also assumed is that the gauge with the most consistently high catch gives a good estimate of the gross precipitation. Three means for throughfall were calculated for each site; one for the wet season, one for the dry and the third for the overall record (Table 2). During the rainy season, both the Natural Regeneration site and the Pine site appear to permit the greatest amount of throughfall, with mean throughfall percentages close to 85 percent. Also closely grouped together are the Mixed Oak-Pine and Cypress sites with a lower mean throughfall of 68 percent. This same pattern follows into the early dry season, though a change in the distribution of rainfall, favouring the Natural Regeneration site, is noted. In point of fact, the Mixed Oak-Pine, Pine, and Cypress received no further precipitation after December 6, while the Natural Regeneration site was frequently under low, wind-blown cloud. A change is apparent at the Natural Regeneration site as well. This can largely be explained by much more open site conditions resulting from the combination of dry conditions and strong winds causing a degree of defoliation of the vegetation.

When considered in relation to the area of capture, stemflow does not appear as a significant quantity with means of 0.06 mm/m^2, 0.02 mm/m^2, 0.06 mm/m^2, and 0.04 mm/m^2 respectively, for Natural Regeneration, Mixed Oak-Pine, Pine, and Cypress. However, as a "per stem" measure (Table 3) the contribution of stemflow to the soil is more readily apparent. Stemflow at the Natural Regeneration and Pine sites is the greatest, being 5.1 and 4.4 times greater than the maximum mean gauge catch for their respective sites. The Mixed Oak-Pine and Cypress sites are grouped closely with stemflows of 2.6 and 2.8 times their maximum mean gauge catches.

Discussion: Precipitation variability, in mountainous terrain, is a complex function of large– and small-scale topographic parameters super-imposed upon weather conditions (5). As long as the measurements of rainfall are confined to a given watershed a small density network of gauges is adequate to provide a coefficient of variation of less than 10 percent (21). However, inter-gauge distance and elevational differences are highly correlated with variation in catch (5). This correlation with inter-gauge distance, and possibly elevational differences, is apparent in the mean throughfall data by site as a percentage of gross precipitation (i.e. meteorological station). In fact, even distances as short as 300 meters, such as that between the meteorological station and the Natural Regeneration site, are significant enough to cause extreme variation. The degree of variation between the meteorological station is more surprising than similar differences between this station and the other three sites, all of which are on a different watershed (though at similar elevation and relatively close).

A trend towards a redistribution of rainfall is evident from the rainy season into the dry season. This has not been previously investigated in the area and could be an important consideration in the silvicultural treatment of present and future plantations, which deserves further attention.

The literature indicates differences in the results of researchers interested in forest-type effects on interception and throughfall, particularly in relation to hardwoods versus softwoods. Whereas some authors (9, 10, 29) have pointed to or found significant differences between hardwoods and softwoods, others (16, 25, 26) have not. The results of the present study seem to lie between these two groups. Throughfall, based on a comparison of mean gauge catch with the particular sites' gauge with the maximum mean catch, at the Natural Regeneration

Table 2. Mean throughfall as a percent of the gauge with largest receipt.

	Date	Natural Regeneration	Mixed Oak-Pine	Pine	Cypress
	Aug. 13	–	74	79	33
	Aug. 14	–	87	115	62
	Aug. 15	–	81	62	84
	Aug. 17	288	105	74	80
	Aug. 24	65	88	72	74
WET SEASON	Aug. 31	83	61	79	73
	Sept. 2	75	48	88	86
	Sept. 3	68	77	74	77
	Sept. 7	95	56	71	66
	Sept. 8	106	40	127	51
	Sept. 21	–	63	69	59
	Sept. 23	88	69	77	59
	Sept. 24	79	48	98	56
	Oct. 5	102	66	67	82
TRANSITION	Oct. 29-Nov. 9	30	6	58	–
	Nov. 17	98	59	131	25
	Nov. 18	101	71	–	25
	Nov. 20	98	68	97	52
	Nov. 25	179	0	0	0
DRY SEASON	Dec. 1	101	56	123	30
	Dec. 6	250	0	0	0
	Dec. 7	–	0	0	0
	Dec. 9	128	0	0	0
	Overall Mean	101.89	53.17	70.95	60.59
	Wet Season Mean	84.9	68.79	82.29	67.29
	Dry Season Mean	136.43	33.87	50.14	48.82

Table 3. Summary of mean stemflow by site and 'event'.

Date	Natural Regeneration	Mixed Oak-Pine	Pine	Cypress
Aug 13	–	–	24.24	5.63
Aug 14	–	2.65	229.04	38.80
Aug 15	–	15.70	57.02	38.70
Aug 17	–	166.71	210.31	59.66
Aug 19	–	108.99	252.53	150.81
Aug 24	200.64[a]	65.70	188.25	210.86
Aug 31	0	0	21.41	31.44
Sept 2	0	174.73	196.65	134.06
Sept 3	252.53	191.24	152.53	184.49
Sept 7	46.19	1.15	17.78	5.92
Sept 8	252.53	95.97	237.60	166.93
Sept 21	2.66	188.95	252.53	234.35
Sept 23	56.08	18.68	48.32	18.75
Sept. 24	252.53	252.53	252.53	0.36
Nov 9	3.68	0.32	0.47	0
Nov 17	44.62	0	1.52	5.56
Nov 18	51.59	0	145.71	5.56
Nov 20	233.33	191.57	234.57	0
Nov 25	252.53	0	0.06	0
Dec 1	6.18	0	0.25	0
Dec 6	214.67	no precip.	no precip.	no precip.
Dec 7	26.32	–	–	–
Dec 9	253.53	–	–	–
Dec 15	8.99	–	–	–
Dec 18	54.20	–	–	–
Dec 22	3.54	–	–	–
MEAN	105.6 mm/stem	77.6 mm/stem	131.2 mm/stem	85.4 mm/stem
As a % of Max. Mean Gauge Catch	511	259	437	278

a Each datum represents the average of 5 stemflow gauges.

and Pine sites was found to be the highest, at 85 and 82 percent respectively. In a similar grouping, the Mixed Oak-Pine and Cypress sites had the lowest throughfall (or conversely, the highest rate of interception), at 68 and 67 percent. These percentages apply during the rainy season; similar groupings arise from the overall (i.e. both rainy and dry seasons) means but are distorted as a result of changes in precipitation patterns during the transition and early dry season. The close similarity between the Mixed Oak-Pine and Cypress sites is interesting considering the difference in development of the two stands; the Mixed Oak-Pine being a mature stand, some 60 + years old, whereas, the Cypress plantation is only nine years old. Depending upon silvicultural treatment, the amount of interception can be expected to increase at the Cypress site as the trees continue to grow and expand their leaf surface area.

Extreme variation is the rule rather than the exception in the pattern of interception, and, consequently, for its complement, throughfall (7). Though not discussed in any detail in the literature, differences in the amount of variation between forest types appears to be significant. This is important in determining patterns of soil moisture and is a factor to be considered in inter-forest-type sampling of throughfall, if comparable data are to be produced.

Stemflow is frequently calculated in precipitation studies using the area of capture of the trees to which gauges are attached. Determined in this manner, stemflow is often concluded to be unimportant. Some authors, however, prefer to consider stemflow as a "concentrated application of water to the soil where conditions are ideal for entry" (13). Calculated on a millimeter per square meter basis stemflow, in the present study, was found to be minimal. However, the mean "per stem" quantities for stemflow, as measures of a "concentrated application of water to the soil" are significant. Consequently, the greater amount of stemflow, such as indicated between the Pine plantation and the other three sites, particularly the Mixed Oak-Pine and the Cypress, is certain to favour better soil moisture conditions. This could well be important in an area that has already been shown to receive less rainfall than other areas such as the Natural Regeneration site. Similarly, the lower amount of stemflow at the Cypress site, situated in the same area as the Pine, could in time limit productivity by limiting soil moisture. As to differences between hardwoods and conifers, data reviewed by Geiger (8) indicated that hardwoods tend to have more stemflow than conifers. In the present study, there is a split between the two hardwood stands and the two conifer stands, with the Natural Regeneration stand aligned beside the Pine as the greatest conductors of stemflow and the Mixed Oak-Pine and Cypress closely grouped together with an average stemflow of about two-thirds that of the former two sites.

Soil Moisture

Materials and Methods: Percent Available Soil Moisture, at the different sites, was monitored with a Bouyoucos Moisture Meter (Beckman Instruments, Inc.) and a dozen CEL–WFD Gypsum Moisture blocks. Three gypsum blocks were placed at each site in sequence at 10.2, 30.5 and 61 cm depths. The gypsum blocks were fitted into an undisturbed column of soil as per instructions as supplied by the manufacturer.

Readings were taken from the blocks during the regular routine of visiting the site. Readings were discontinued during the dry season after all sites at all three levels had reached zero percent available soil moisture.

Soil moisture, field capacity and wilting point measurements were carried out as a part of soil sampling done early in the study and again at the end by the laboratories at the Centro Nacional de Tecnologia Agropecuaria (CENTA) and the Dirección-General de Riego y Drenaje (i.e. Drainage and Irrigation). The final sampling consisted of soil moisture samples taken at one-foot (30.5 cm) intervals to a five-foot (152.5 cm) depth.

Results: Differences with respect to field capacity, wilting point, and storage capacity are evident between sites, and within sites, between organic and mineral soil horizons (Table 4). Considering storage capacity as the most relevant comparative measure, since this factor represents the particular soils ability to hold a given quantity of water, the data shows the Mixed Oak-Pine site to have the greatest storage capacity, followed closely (18% difference) by the Pine site. The Cypress and Natural Regeneration have the lowest values.

The month of September is noted as the time of the year, from a meteorological point of view, that the Intertropical Zone of Convergence is the closet to El Salvador. Characteristically, this is a month of high rainfall, much of it resulting from "temporales," interspersed with prolonged periods of low, dark clouds. The record of percent available soil moisture (Figures 1a and b) for the Natural Regeneration site appears to reflect this, with soil moisture at all depths at about 90 percent availability broken by a period of 12 days (i.e. from September 9 to 20) of no rain in which soil moisture availability markedly decreased. Available soil moisture returned to higher levels with the advent of new storms and remained high until into mid-October, after which a continual decline

Table 4. **Summary of field capacity, wilting point and storage capacity for the organic and mineral soils for each site.**

	Natural Regeneration		Mixed Oak-Pine		Pine		Cypress	
	0-16 cm	16 + cm	0-12 cm	12 + cm	0-12 cm	12 + cm	0-7 cm	7 + cm
Field capacity (%) (0.33 atm)	41.25	39.74	47.28	42.90	33.65	49.47	56.96	59.26
Wilting point (%) (15 atm)	31.65	29.29	23.65	20.40	18.22	31.90	44.54	39.06
Storage capacity (mm/cm)	0.93	0.98	2.35	2.33	1.89	1.93	0.88	1.59

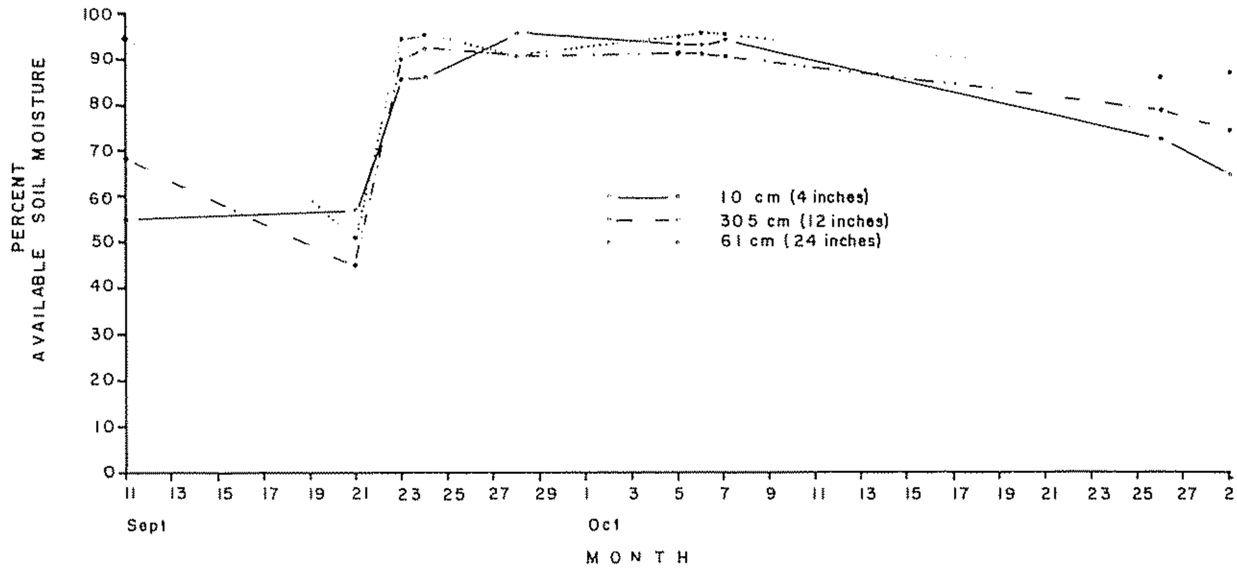

Fig. 1a. Recorded percent available soil moisture between sept. 11 and oct. 20 at natural regeneration site.

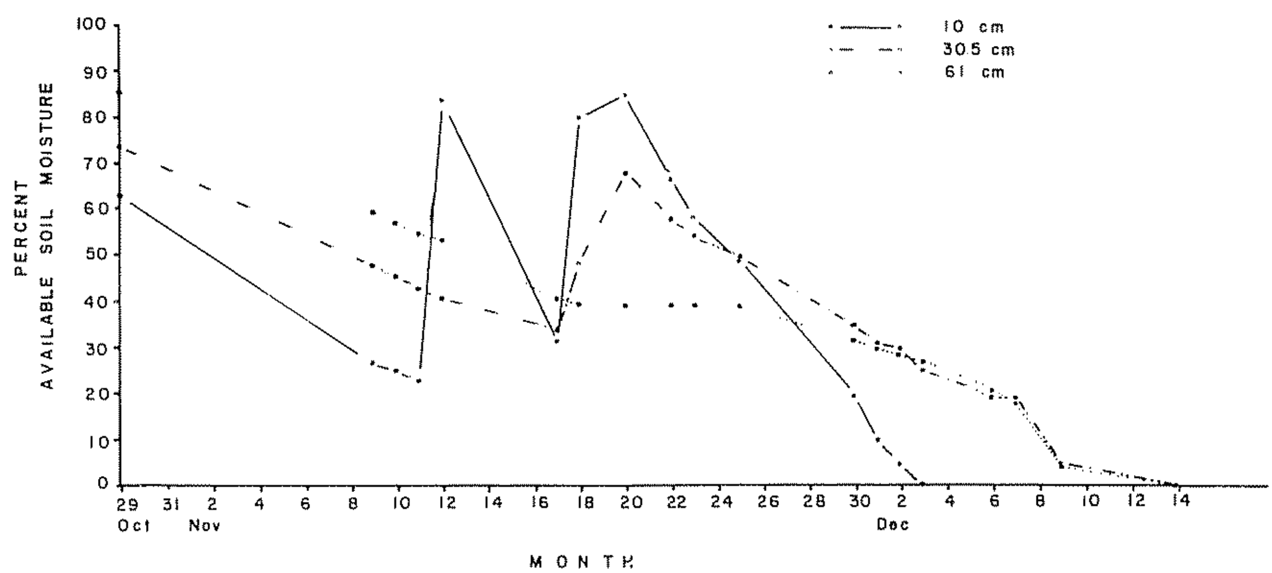

Fig. 1b. Percent available soil moisture between oct. 29 and dec. 14 at natural regeneration site.

began, broken only by a couple of heavy storms in mid-November, with all depths recording zero percent available soil moisture by December 14th.

The curve shows a deficit from mid-December to late-April (transition from dry to wet season) and then fluctuates around 90 percent available soil moisture during the rainy season, except for July. In July there is a retreat of the Intertropical Zone of Convergence and the occurrence of "caniculas," periods of sunny rainless days, resulting in a low rainfall for the month. Consequently, soil moisture depletion would occur at this time (possibly causing a deficit at certain sites). Soil moisture depletion would again occur after late September (i.e. the end of the rainy season) leading to a deficit by mid-December.

Inter-site comparisons (Figures 2, 3 and 4) are limited to the period between November 9 and December 15, when data for all four forest-types is available. The dominant characteristics of the soil moisture curves are as follows. The trend is towards depletion with the Cypress site having the most rapid rate at all three levels sampled. At the 10 cm level, Cypress is closely mimicked, with the exception of the early part of the curve, by the Natural Regeneration site. The Natural Regeneration and Mixed Oak-Pine sites have very similar curves at both the 30.5 and 61 cm levels. Except for the 10 cm level the curves for the Mixed Oak-Pine site are consistently, at all levels, those with the lowest rates of moisture depletion.

Discussion: Field capacity, wilting point and storage capacity is determined for the most part by the nature of the soil (2). In the particular situations investigated in this study the data obtained reflects the historical development of each site, including the evolution of the present forest types now present. Though it is accepted that individual species do affect the physical and chemical properties of the soil (6), the available data in this instance are not adequate to definitely indicate possilbe contributions by the forest species found at the different sites towards the variation in these three factors, between sites. Nonetheless, certain inferences seem reasonable, although they are made guardedly. For instance, Hoover (13) has indicated that forest soils under old-growth tend to have an almost unlimited infiltration capacity; undoubtedly as well, these same soils also have high storage capacities. The high storage capacity at the Mixed Oak-Pine site does appear to suggest this. The lowest storage capacities at the Pine and Cypress sites, consequently, may reflect their youth and, as well, their recent disturbance (i.e. 9 years past) during planting. The slower rates of decomposition of conifer leaves (8) may also be a factor too, with attendant retardation in organic soil buildup. In the case of the Natural Regeneration site, with its very low storage capacity, greater age does not seem to have resulted in greater storage capacity.

Some of the differences seen between the sites at the 10 and 30.5 cm depths are explainable on the basis of previously presented data for throughfall. A radical variation in soil moisture at the Natural Regeneration site, relative to the other sites, is apparent between November 11 and 12. At this time, while

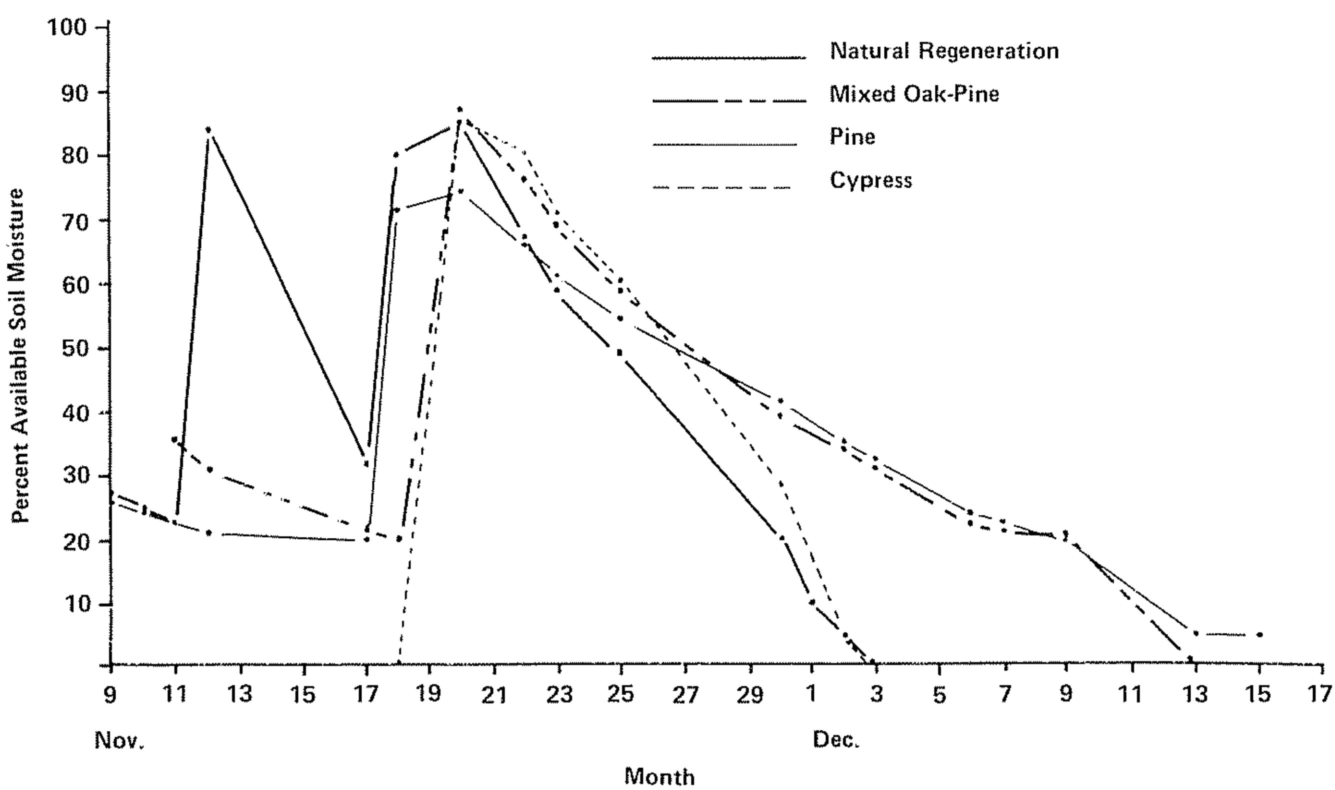

Fig. 2. Soil moisture trends by site at the 10 cm depth.

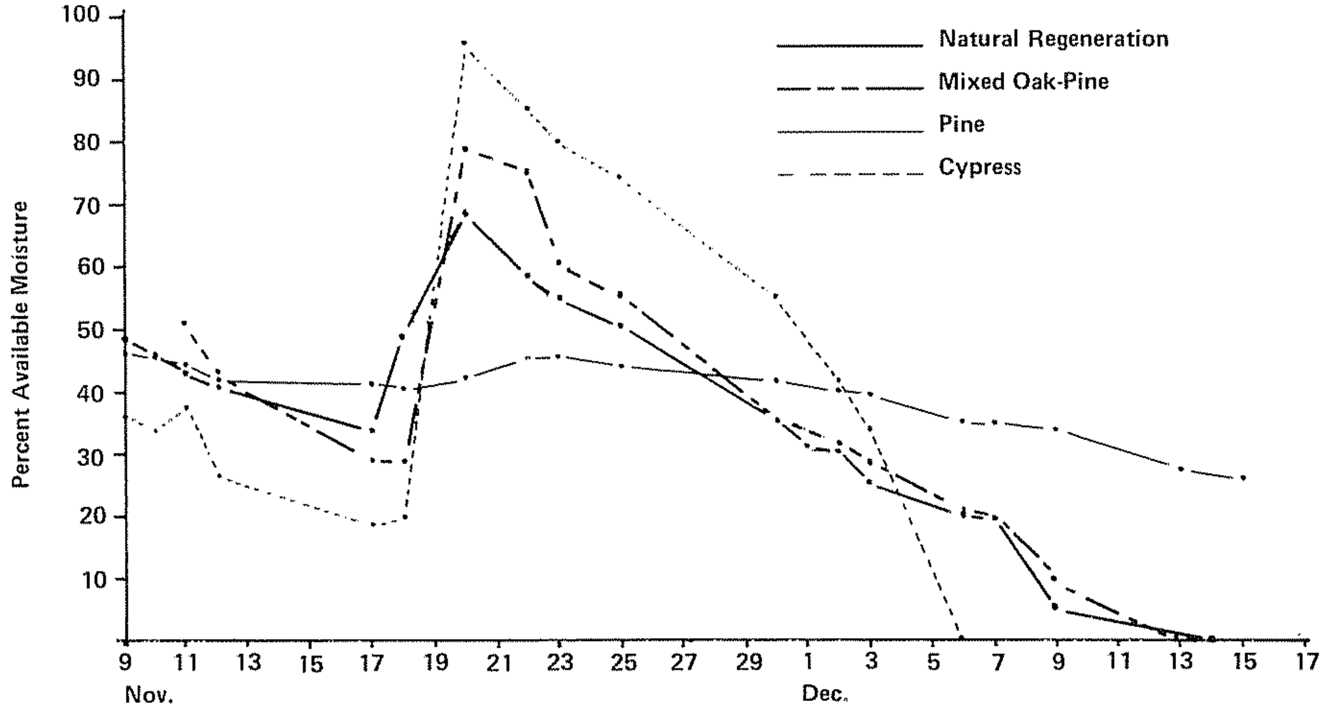

Fig. 3. Soil moisture by site at 30.5 cm depth.

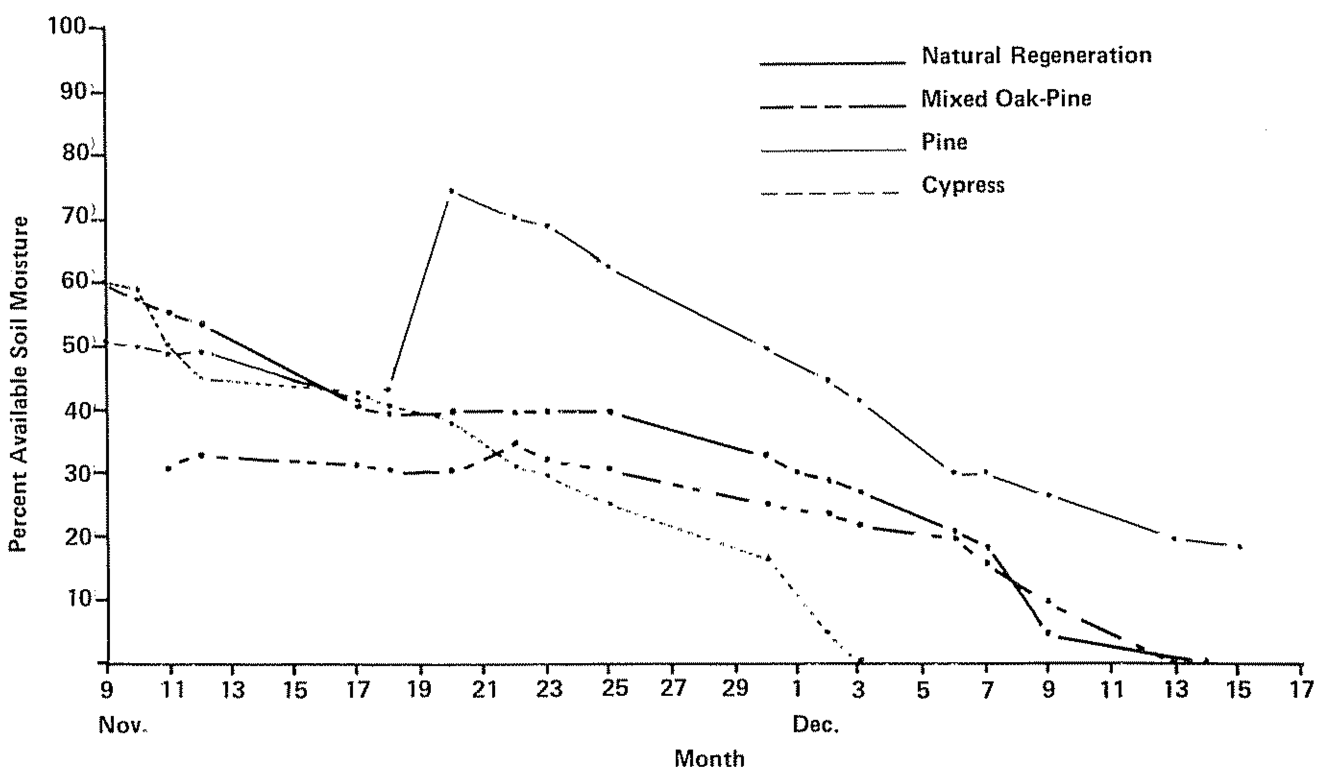

Fig. 4. Soil moisture trends by site at 61 cm depth.

other sites experienced a decline in soil moisture, the Natural Regeneration jumps from 26 percent available soil moisture to 84 percent. Though no field data is available on throughfall at the sites, 8.8 mm of precipitation was recorded at the meteorological station at Los Planes. Throughfall was checked on the 17th at which time it was noted that the Natural Regeneration site had received some six times as much rain as the other sites. Consequently, this departure from the dominant trend appears to reflect a situation of unequal distribution of precipitation over the area.

Evaporation

Materials and Methods: The objective of the evaporation measurements was to obtain a comparative measure of "evaporation potential" or "evaporativity" near the ground in the different forest types. This was carried out using Livingston Spherical Atmometers (white) as part of an evaporimeter. Construction and operation of the evaporimeters were adapted from Livingston (17) and Read (25, 26).

The atmometer bulbs were pre-calibrated at the factory before shipping and each carried a correction coefficient which standardized readings for all the atmometers. Directions for maintenance, as given in Livingston (17) were followed as closely as possible. Atmometers were allowed to operate for three months before being replaced with new unused atmometer bulbs.

Readings consisted of recording the amount of distilled water needed to bring the reservoir back to a mark. The date and hour were also recorded for later use in calculating the rate of evaporation. There were three evaporimeters placed at each site, except for Natural Regeneration, the third instrument from which was placed at the meteorological station at Los Planes. Readings were taken every day or every other day, though longer periods between readings occasionally occurred.

One evaporimeter was suspended in the canopy at each site in order to observe the difference in evaporativity with height. These evaporimeters were suspended on the same platforms used for transpiration trials.

Results: A comparison of the mean values (Table 5) for evaporativity for the sites indicate a close similarity between the Mixed Oak-Pine, Natural Regeneration and Pine. The Cypress site, with a mean of 0.79, has an evaporativity 1.58 times that of the Pine whose mean of 0.50 is the greatest of the three remaining sites.

One-way analysis of variance (Table 6) for the combined data for evaporativity, including data from the meteorological station at Los Planes, indicates the presence of highly significant variation at the 0.001 level of probability.

The intersite comparison showed no significant difference among the Mixed Oak-Pine, Natural Regeneration and Pine, as would be expected from the previous comparison of the means. All sites, except the Cypress, had highly significant differences when compared to the Meteorological Station; the Cypress had a significant difference with the Meteorological Station at the 0.05 level of probability. Differences between the Cypress and the other three sites were all highly significant.

Differences between the Cypress and Pine sites could be expected to approach each other more closely as the Pine site was possibly affected by a line of giant cypress which formed a windbreak up-wind of the site.

Three things are indicated by Figures 5 and 6; these are intersite variation, the fluctuating nature of evaporation and the marked difference in evaporativity between the Rainy/Transition Season and the Dry Season. The difference between the Cypress site and the other three sites is highlighted, particularly during the period of measurement in the Dry Season

Table 5. Summary statistics of evaporativity (ml/hr) by site.

	Number of Cases	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation (%)
Mixed Oak-Pine	51	0.47	0.22	0.06	1.16	47.0
Natural Regeneration	49	0.43	0.23	0.05	0.91	53.0
Pine	51	0.50	0.23	0.06	0.94	45.3
Cypress	54	0.79	0.30	0.14	1.50	38.4

Table 6. Summary of intersite T-test results.

	Meteorological Station	Mixed Oak-Pine	Natural Regeneration	Pine	Cypress
Meteorological Station		8.28[a]***[b] 10.4[c]	8.68*** 102	7.81*** 104	3.35*
Mixed Oak-Pine			0.90 98	– 0.67 100	– 6.16*** 103
Natural Regeneration				– 1.54 98	– 6.77*** 101
Pine					– 5.55 103

(a) = T-value; (b) = Significance; (c) = Degrees of Freedom.
* = Probably Significant at 0.05; ** = Significant at 0.01; *** = Highly Significant at 0.001.

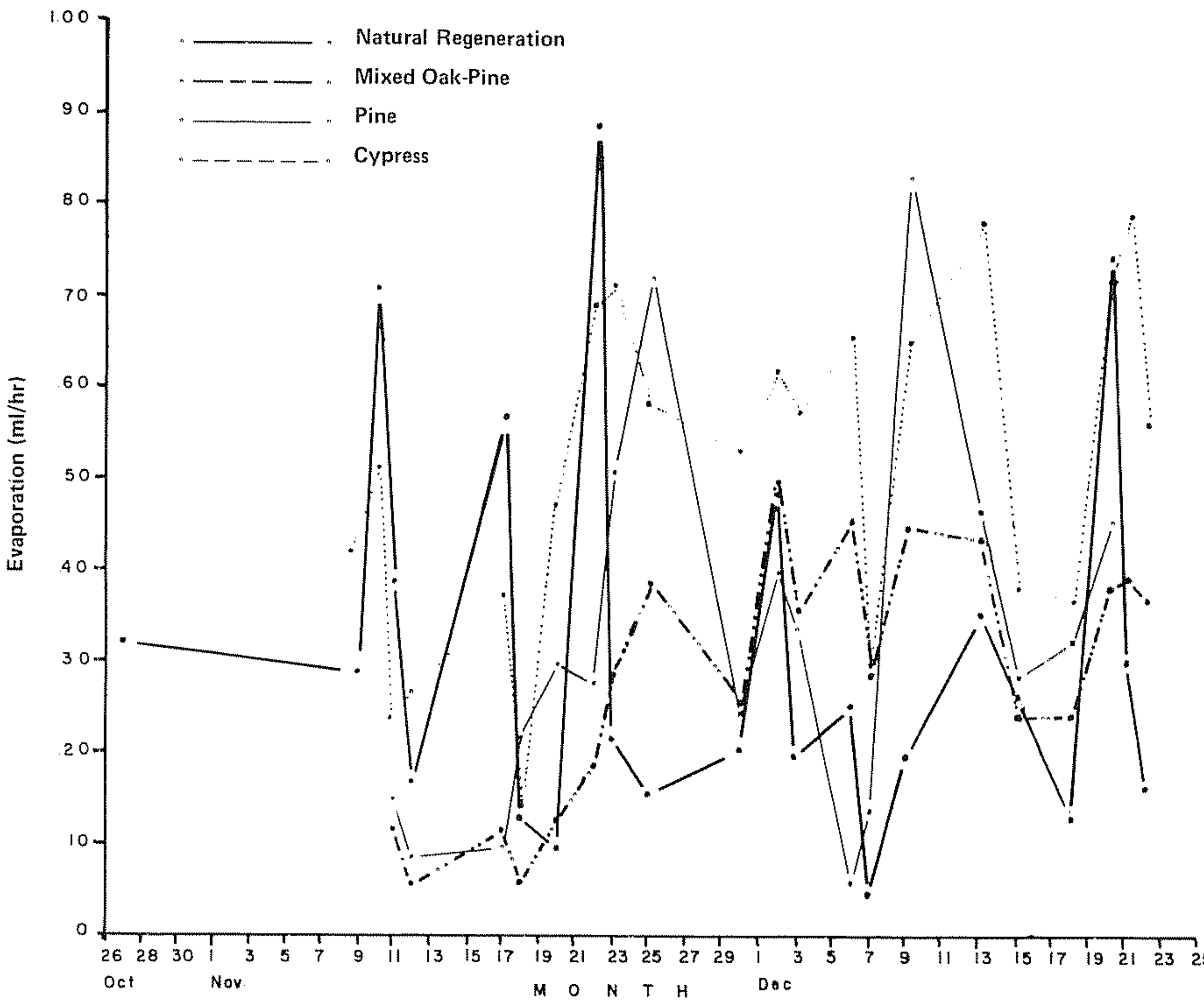

Fig. 5. Summary of evaporativity data for the four forest-types.

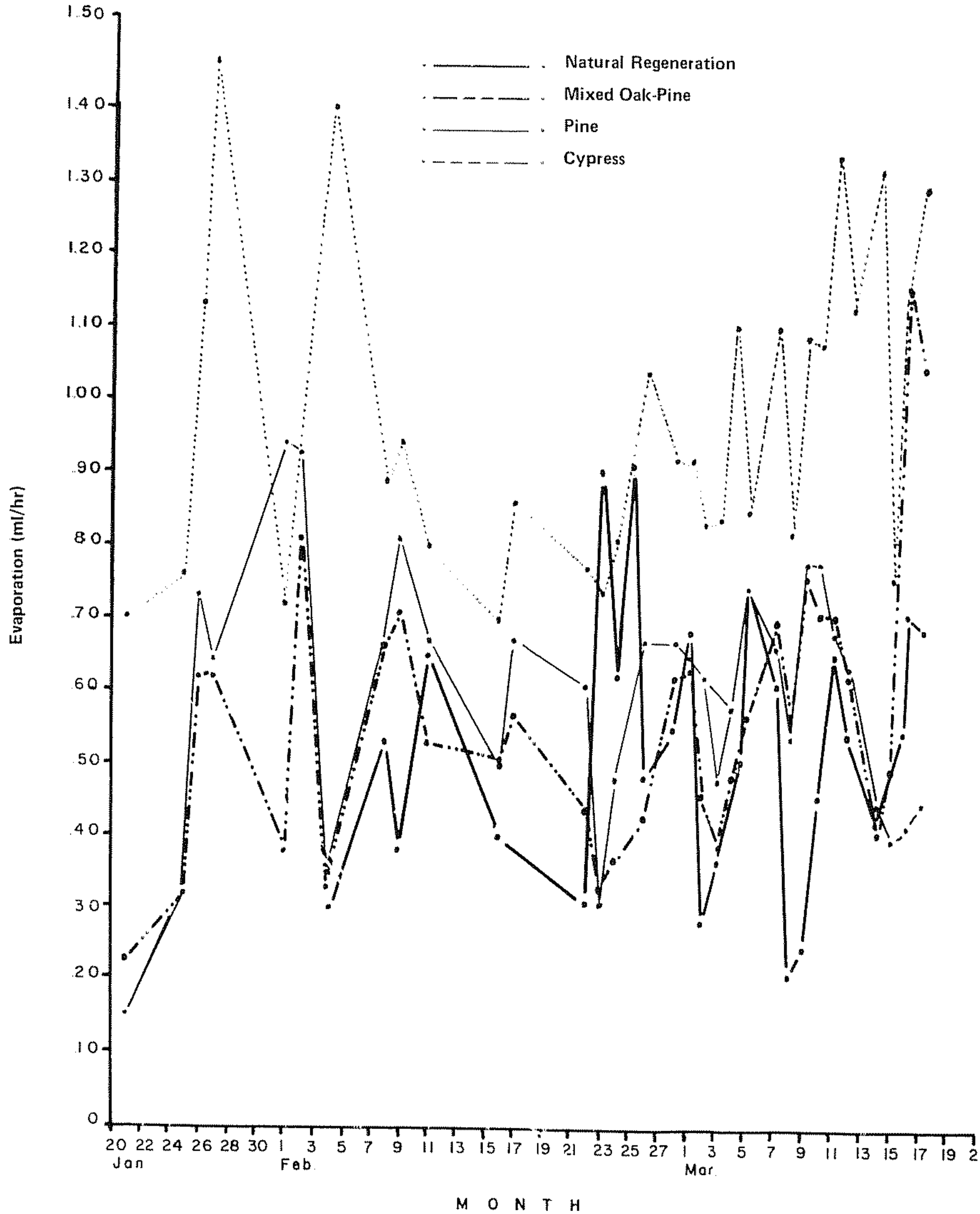

Fig 6 Summary of evaporativity data for the four forest-types

(i.e. Jan. 25 – Mar. 17). Variation between the sites is mainly reflected in different rates of evaporation; however, though all the sites tend to follow the same trend in fluctuations, there occurred a number of occasions when a particular site was not consistent with the others in relation to this trend. Differences in trend are probably a reflection of a particular topographic location. This explanation would account for the greater number of occasions on which the Natural Regeneration site was not consistent with the others, situated as it was the head of a small valley down or up which were channeled the prevailing winds, in contrast to more dispersed movements over the other three sites. The contrast between mean evaporativity for the Late Rainy/Transition Season and the Dry Season (Table 7) is marked by rates of evaporation during the Dry Season of approximately twice those during the former season. These higher rates are a result of the generally dryer conditions and the influence of the cool, dry northerly winds which prevail during this period. The Average Percent Relative Humidity during January, February and March (March value for 1976) was 72, 75 and 70% compared to values of 85, 83 and 80% for the months of October, November and December. Average wind speeds were about 19 km/hr, with maximums in the 80's or near 80's. Mean Montly Maximum and Minimum temperatures showed a trend towards increasing through August to March, particularly during March and the preceding month of February. The monthly means presented in Table 8 are more indicative than absolute, based as they are on an incomplete monthly record; however, the trend towards increasing temperatures and the differences between sites are clear and consistent. A comparison of the mean rates of evaporation at the sites during the Rainy/Transition Season and Dry Season, as indicated in Table 7 correspond well with the mean maximum temperatures for the corresponding periods, with the exception of the Mixed Oak-Pine site during the wet period. The Mixed Oak-Pine site, though experiencing

Table 7. Comparison of mean near-ground evaporativity (ml/hr) for Late Rainy Season/Transition and Dry Season.

	Oct. 26 – Jan. 21	Jan. 25 – Mar. 17	Ratio
Mixed Oak-Pine	0.286	0.580	0.286/0.580 = 0.49
Natural Regeneration	0.320	0.526	0.320/0.526 = 0.61
Pine	0.332	0.606	0.332/0.606 = 0.55
Cypress	0.530	0.983	0.530/0.983 = 0.54

Table 8. Mean maximum and minimum temperatures for August through March at sites.[a] (°C).

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Mixed	21[b]	20	23.3	22.2	21	22.2	25.5	26.6
Oak-Pine	12.2[c]	13.3	12.7	13.3	13.3	8.8	12.7	12.7
Natural	18.8	18.3	18.8	17.7	17.7	19.4	21	21.6
Regeneration	12.2	12.2	12.2	11.6	11.6	7.7	10.5	11.6
Pine	18.8	18.8	21	20.5	21	21.6	23.8	26.1
	11.6	11.6	12.2	13.3	12.7	8.8	12.2	12.2
Cypress	21.6	21.6	22.2	22.7	23.8	21.6	25	26.1
	12.7	12.7	12.7	12.7	12.7	8.8	11.6	12.7

a = Average number of records equals 8
b = Maximum
c = Minimum

temperatures similar to the Cypress site, nonetheless, had the lowest mean evaporation rate for this latter period. This may reflect local site conditions such as higher relative humidities and less sub-canopy turbulence which would tend to suppress vapour pressure deficits and in turn evaporativity.

Evaporativity at mid-canopy was one third greater than the corresponding level near the ground (Table 9), with the exception of the Cypress site. Excessive shading may be the cause of differences found between the Cypress canopy evaporimeter results and the other sites.

Discussion: The higher evaporativities at the Pine and Cypress sites agree with the results of Swank *et al.* (30, 31, 32) which indicated that coniferous stands lose more water to evaporation than similar deciduous stands. In part this is due to the large leaf area of conifers (average of 59.5 m^2 and 65.9 m^2 respectively, for *P. pseudostrobus* and *C. lussitanica* found in plantations studied) which provides a large interceptive, and consequently evaporative, surface. The open and uniform nature of plantations permits the development of organized mass air flows which also favors greater loss of moisture to evaporation both from the soil and the vegetation.

The evaporativity at canopy level and at the Meteorological Station was much higher than the near-ground forest evaporativity as was expected from previous studies (26, 33).

Transpiration

Materials and Methods: The objective behind the measurement of transpiration was to obtain a comparative measure of transpirational water loss for the different forest types. The "cut-stem potometer" technique used for measuring transpiration in this study was adapted from Weaver *et al.* (34).

In choosing stems, attention was paid to maintaining consistency within and between trials with respect to size, position in canopy (e.g. all stems were taken from mid-canopy), and exposure in order to reduce variation within species.

Stems were cut using garden shears attached to a long pole and were placed into water contained in a 250 ml graduated cylinder within seconds of being cut. A one-holed cork stopper held the stem in place and partially sealed the cylinder. The cylinders were further sealed using plasticine around the rim and around the stem and opening of the stopper. Additional sealing was accomplished using a fast drying cement (Seal-All, Allen, Stevenson Products).

At each of the plantation sites, four replicates were prepared during each trial, since only one species was involved. For the natural regeneration site, five different species were tested and during a given trial, four species with two replicates each were involved. Three species were tested at the Mixed Oak-Pine site, one Pine (Pino ocote), one Oak (Encino) and one sub-canopy species (Trompillon).

Once the potometers for a particular site were all prepared, they were then all raised into mid-canopy on a small platform where they were left for a period of 48 hours. Measurement involved determining water loss from the graduated cylinder and leaf area of sample.

Though the method does not give quantitatively reliable data in an absolute sense, it has been shown to be an economical and relatively simple method to obtain data sufficient to establish transpirational differences among forest types and species (15, 34).

Results: A comparison of the mean transpiration rates (Table 10) for the different sites indicates that the Pine Plantation with a mean of 2.37 the lowest rates. The Mixed Oak-Pine, with a mean of 3.98 is

Table 9. Summary of canopy evaporativity (ml/hr).

	Mixed Oak-Pine	Natural Regeneration	Cypress	Pine
Number of Readings	9*	22	9*	23
Mean	0.89	0.86	1.00	0.95
Standard Deviation	0.35	0.31	0.28	0.25
Ratio of Near Ground** to Canopy Evaporativity	0.64	0.64	0.98	0.65

* Instruments were damaged during high winds, which prevented further measurements.

** Readings for Near Ground Evaporativity were recorded together with those for the Canopy at the same time

Table 10. Summary statistics of transpiration data ml/m²/hr by species and site.

Species / Sites	Mixed Oak-Pine	Natural Regeneration	Cypress	Pine
	Quercus aff. *Sapotaefolia* Liebm.	*Leucaena* sp.	*Cupressus lusitanica*	*Pinus pseudostrobus*
Mean	3.35	2.89	4.03	2.27
S.D.[1]	2.19	2.34	1.25	1.09
	Cleyeratheaeoides (sw) Choicy	*Roupala montana* Audi		
Mean	5.48	6.26		
S.D.	1.53	1.86		
	Pinus oocarpa Schiede	*Sauravia pseudo-rubriformis* Busc		
Mean	3.11	6.75		
S.D.	0.77	3.64		
		Cassia sp.		
Mean		8.78		
S.D.		1.43		
		Winmeria cyclocarpa Radlk		
Mean		9.12		
S.D.		5.34		

1 Standard Deviation.

1.76 times greater than the Pine and is followed closely by the Cypress Plantation at 4.03 (i.e. 1.77 times Pine). The Natural Regeneration site, with a mean of 6.76 experiences transpiration rates some 2.98 times greater than that of the Pine Plantation.

Statistical variation among the cross-species comparisons ranged from not significant to highly significant. Differences in mean transpiration rate between Pinabete and Ciprés, four of the Natural Regeneration species (the exception being Guaje), and Trompillon from the Mixed Oak-Pine site were highly significant. A significant difference was also found between Pinabete and Ocote pine. Besides the highly significant difference found with Pinabete, Ciprés also showed highly significant differences with all species from the Natural Regeneration site except Guaje. No significant differences were uncovered between Encino and Trompillon or Ocote pine of the Mixed Oak-Pine though a possible significant difference was indicated between Trompillon and Ocote pine. None of the three species from the Mixed Oak-Pine site has a statistically important variation when compared with Guaje of Natural Regeneration site. However, both Encino and Ocote pine had highly significant differences with Zorrillo, Vainillo and Lloroncito of the Natural Regeneration species and a significant difference with Siete Pellejos. Amongst the Natural Regeneration species, a highly significant difference was found between Guaje and Zorrillo, Vainillo and Lloroncito. Significant differences were found between Guaje and Siete Pellejos, and Zorrillo and Vainillo.

The results of the one-way ANOVA (Table 11) comparing the grouped data for the broad-leaved species to the grouped data for the conifers indicated a highly significant difference between the two groups. The mean transpiration rates for the broad-leaved and coniferous groups were, respectively, 6.62 and 3.08. The broadleaved group has, overall, a mean transpiration rate some 2.14 times greater than that of the conifers.

Discussion: Published transpiration rates obtained by Weaver *et al.* (34), using similar techniques to those used in the present study are comparable in range to that found in the broadleaves species. Data from McLean (18) is similar in its lower range as is data from Odum *et al.* (22). In cross-species comparisons, data from Henrici (11) indicates lower transpiration rates for both Cypress (*C. lusitanica*) and Pine (*P. radiata*) when compared with *Acacia* and *Eucalyptus*. This relationship held true for five of the

Table 11. Analysis of variance (grouped broadleaved versus grouped conifers).

Source	D.F.	Sum of Squares	Mean Squares	F. Ratio	F. Prob.
Between Groups	9	349.2043	38.8005	4.149	0.000
Within Groups	102	953.9250	9.3522		
Total	111	1 303.1294			

seven broadleaved species in the present study. However, no significant difference was found between any of the conifers in the study and Encino. Oaks are the principal dominants in mature natural stands in the study area. Transpiration rates for Cypress and *Pinus radiata* were almost the same in Henrici's study, while in the present report Cypress has a rate of 1.30 times greater than *P. oocarpa* and 1.78 times greater than *P. pseudostrobus*. Kittredge (14) found average daily transpiration for pines greater than various species of Oaks, whereas, in this case no significant statistical difference was found between Encino and either pine. Transpiration rates for pines in the present study are also comparable to those found by Minkler (19).

Consideration of the exact meaning of transpiration rates, in terms of water loss, must include comparative measure of the leaf surface area of the species involved. The two plantation species, *Pinus pseudostrobus* and *Cupressus lusitanica,* had mean leaf surface areas of 59.5 m^2 and 65.9 m^2, respectively. Data for broadleaf species was not obtained nor found in the literature, but are likely to be less based on subjective impressions from field observations. Some of the broadleaved species, notably *Leucaena* sp. and *Cassia* sp., experience partial defoliation during the dry season, which would lessen their impact on available soil moisture.

Conclusions

It is clear that the Cypress site is the driest of the four sites. Low throughfall, high evaporation and moderately high transpiration (together with a large leaf surface area) combined to give the most rapid rate of soil moisture depletion and produce very dry site conditions. Following in order of dryness were the Natural Regeneration and Mixed Oak-Pine sites, both of which had similar site conditions when all factors were considered. The Pine site, with greater throughfall, moderate evaporation rates and low transpiration rates, was the least dry of the four sites.

These conclusions have important implications for the area. In terms of the water balance the implications are: 1) run-off, and, consequently, streamflow, is reduced under plantations of conifers, particularly cypress and 2) higher evapotranspirational losses will lead to increased rate of regression of streamflow as present plantations mature and new ones are plantes.

The principal management implications are: 1) reduced streamflow will reduce the danger of flooding during the rainy season of the San Jose River; 2) vegetative cover, in the form of a canopy and litter, as provided by the conifer plantations, provide protection for the soil and reduce the potential for soil erosion; 3) rapid rates of soil moisture depletion, as found under cypress, along with a deep layer of litter and abundant brush lead to dry conditions which increases fire hazard, and 4) reduced streamflow, arising from greater evapo-transpiration by the forest, leads to reduced availability of irrigation water and thus will prolong the effective drought season.

These implications apply to the immediate are in which the study was undertaken and may extend to other areas in El Salvador where reforestation is occurring as well.

Management priorities will determine the importance of reduced streamflow from the area. A number of factors argue strongly for placing the management for water yield as the first priority. The most compelling being that El Salvador, as Moore (20) has stressed, is first and foremost an agricultural country dependent upon export for foreign exchange earnings. Moreover, the country experiences an annual drought period of approximately five months and, consequently, is a country where water is an extremely valuable resource sufficiently scarce already that rationing occurs throughout a portion of the year in many parts of the country.

Reforestation is an urgent necessity in order to preserve soil resources and, as well, to provide jobs and revenues in many areas of the world. Undoubtly, various species of conifers such as *Pinus* sp. and *Cupressus* spo., have an important role to play; it is not the intent of this research to discredit their utility. However, the choice of reforesting with one species versus another can have important implications, as this study indicates. Yet, huge gaps in our present knowledge concerning the characteristics of forest species in relation to factors such as evapotranspiration exists, which prevent proper evaluations of such choices and their long-term significance. It is towards the objective of reducing this gap that this research has been directed and the discussion of the advantages and disadvantages of conifers versus natural broadleaved species addressed.

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