Research Report

Fog Precipitation in the Cloud Forests of Eastern Mexico

INTRODUCTION

The Sierra Madre Oriental of eastern Mexico extend in a chain from northern Mexico to the State of Oaxaca in the south. East of the mountains lies the dry coastal plain of the Gulf of Mexico, while to the west a high dry plateau forms the interior of Mexico. The prevailing northeasterly winds gather moisture as they sweep over the Gulf of Mexico. After passing over the arid coastal plain the moisture-laden air flows up the eastern slopes of the mountains bringing heavy rains and frequent fogs to the upper elevations. Beyond the mountains toward the interior plateau, the climate rapidly becomes dryer and the vegetation changes to that of a semidesert, characterized by scattered pines, *Agave* and *Yucca*.

Dense, luxuriant cloud forests dominated by oaks and other tree species are found on the higher slopes above 1000 meters. A rich herbaceous flora, often accompanied by huge tree ferns, forms the understory (Gomez-Pompa 1966). Many species such as *Liquidambar, Nyssa, Carpinus* and *Ostrya* are also found in the deciduous forests of Eastern United States (Miranda and Sharp 1950). Good examples of the cloud forest are found in the Sierra de Chiconquiaco of western Veracruz and east of Teziutlán, near the border of Veracruz and Puebla. At one time these forests were more extensive, but they have become fragmented as a result of post-Pleistocene climatic changes and also by the clearing of land for agriculture. Now even the best stands are quite disturbed by grazing and cutting. It is evident that this unusual vegetation is fast disappearing.

Moderate temperatures and high moisture content in the atmosphere of the higher mountains provide the climatic conditions necessary for the formation of the cloud forests. Drizzles and dense fogs are frequent throughout the year. Often the fog is blown inland beyond the cloud forests into areas where rainfall has diminished and semi-desert type vegetation prevails.

Fog precipitation from maritime warm air masses in subtropical zones can be sizeable. There is a broad range of droplet sizes in these fogs and, frequently, droplet diameters of 8-14 μ are formed which are of ideal size for producing fog precipitation (Grunow 1960). The present investigation was designed to measure fog precipitation on the dry coastal areas of central Mexico, across the zone of the cloud forests in the mountains, and onto the dry plateau lands above. The study is aimed at showing the significance of fog precipitation as a factor controlling the limits of the cloud forests, as well as demonstrating that fog can provide an important source of water in the regions where fogs are of frequent occurrence.

METHODS

Simple, fog-measuring gauges were made from one liter oil-cans. One end of the can was removed and the inside and outside sprayed with white enamel. The inside of the can was marked off into 50 ml divisions numbered from 1 at the bottom; the can then contained 1100 ml at the rim. Some gauges were fitted with a cylinder of aluminum window screen, (288 mesh per square inch), which protruded 17 cm above the rim. The screen intercepts tiny fog droplets as the wind moves them through the mesh. The droplets collect on the screen and trickle to the bottom of the gauge. Rain gauges and rain gauges with screens were paired at each station where measurements were taken. The rain gauge without a screen collects only rainfall, while the gauge with a screen collects both rainfall and fog moisture. Volume differences in contained water between the paired gauges give a measure of the relative amount of fog precipitation at different locations. Each 100 ml water collected is equivalent to 16.66 mm rainfall.

Twelve stations were selected to monitor the relative effects of fog precipitation (Fig. 1). Three were located on the dry coastal plain in the State of Veracruz, at Veracruz, at Rinconada, and at Soledad de Doblado. Seven

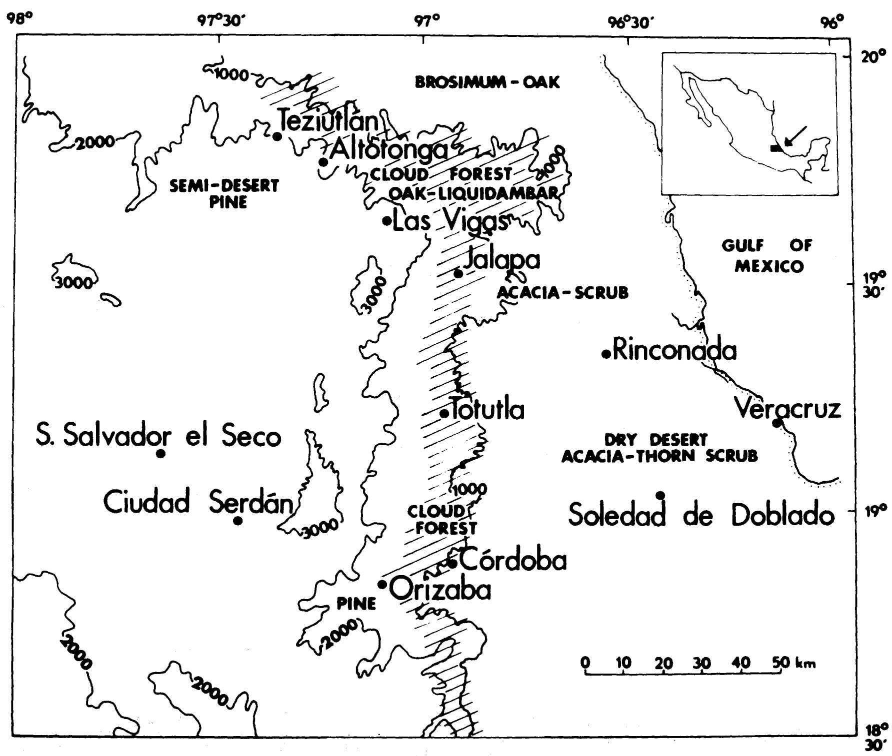

Fig. 1. Location of Mexican stations used to measure fog precipitation. Shaded area is approximate extent of cloud forest.

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stations were established within or near the cloud forest zone at Teziutlán, Totutla, Córdoba and Orizaba, all of which are in Veracruz. Two stations were set up on the dry plateau above the cloud forests in the State of Puebla at San Salvador el Seco and Ciudad Serdán. The data collection at these stations was done by regular weather observers who were more or less familiar with the gathering and recording of scientific data. Because of questionable or incomplete results it was necessary to eliminate the data from Ciudad Serdán, Orizaba and Córdoba.

The gauges were read at weekly intervals every Sunday morning. Water levels were read to the nearest 50 ml division. If the water level was exactly between divisions, it was recorded as such. Three or four drops of light machine oil, to serve as a retarding film, were added to each gauge weekly to reduce evaporation. The experiment was in progress for 55 weeks beginning 6 January 1969 and ending 25 January 1970. The data for Veracruz cover only 37 weeks. For several weeks during the rainy season, heavy downpours caused some gauges to overflow before they were read. However, data for most of the year give a good index of the relative amounts of fog precipitation over the region studied.

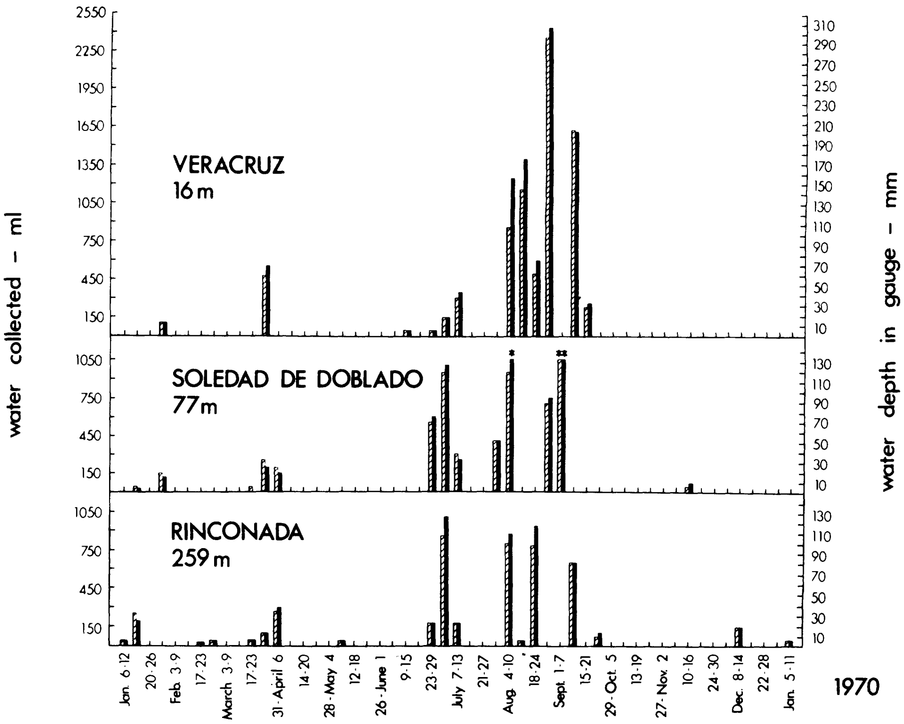

Fig. 2. Weekly fog interception from 3 stations on the dry coastal plain. Cross hatched bars show rainfall measurements while solid bars include rainfall plus fog precipitation. The asterisk * above a bar indicates that water collecting gauges were full and therefore may have overflowed.

RESULTS

Annual Fog Precipitation

Weekly data for one complete year, beginning 6 January 1969 and ending 11 January 1970, are given in Figs. 2-4. The difference in the volume of water collected by the rain gauge with a screen over the plain rain gauge was determined and recorded as percent gain or loss. The station at Rinconada, on the dry, thorn-scrub coastal plain, gave an 8.1 percent increase of the gauge with a screen over the rain gauge while at Soledad de Doblado the increase was 0.4 percent. Data for 37 weeks at Veracruz showed an increase of 12.1 percent in the gauge with a screen over the rain gauge. Almost all of the increase was recorded during the rainy period from 4 August to 21 September.

The stations within or at the fringe of the cloud forest zone showed high, fog precipitation yields ranging from 16.9 percent at Teziutlán to 31.3 percent at Totutla. However, weekly collections made during the rainy period at Teziutlán are incomplete because gauges overflowed for several of the weekly periods.

The gauges at San Salvador el Seco located on the high, dry plateau above

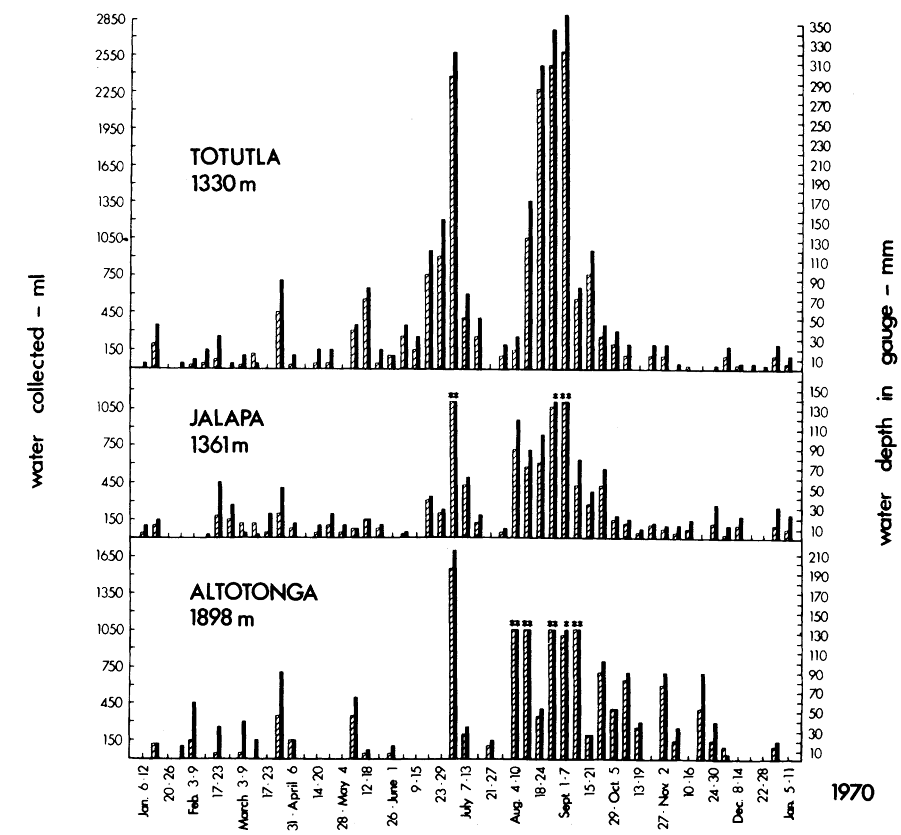

Fig. 3. Weekly fog interception from 3 stations within the cloud forest zone.

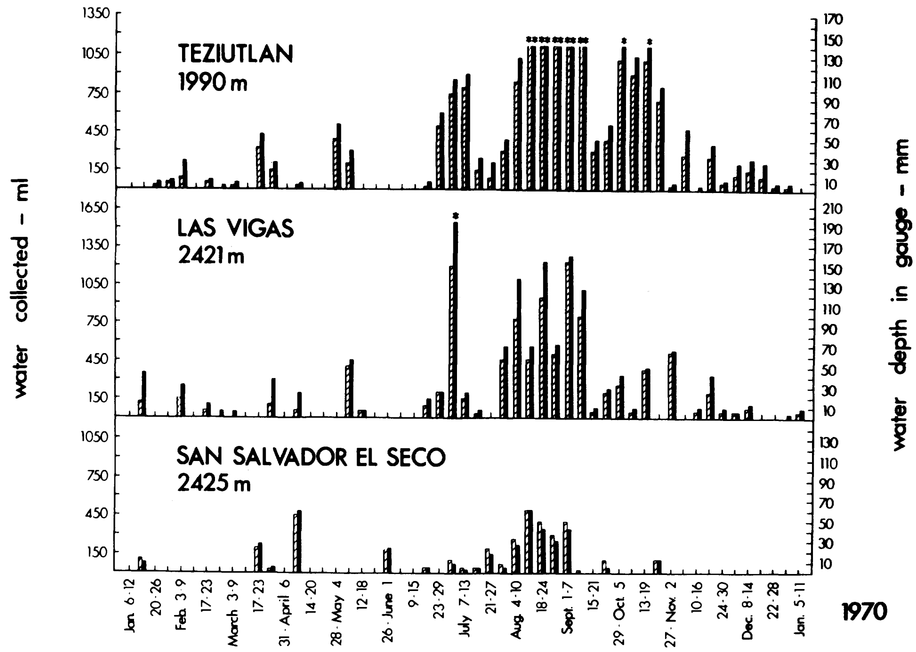

Fig. 4. Fog precipitation from 3 stations at the upper limits or outside the cloud forest zone. Teziutlán is barely within the zone while Las Vigas is above the cloud forest. San Salvador el Seco is well beyond the fog belt and lies in the semidesert plateau.

the cloud forest showed a loss of 9.1 percent of the gauge with a screen over the rain gauge.

Fog Precipitation During the Dry Season

Since the rainfall differences between the rainy and dry periods are pronounced, the data are grouped according to the rainy and dry seasons for each station (Table 1). Although the onset of the rainy season is fairly abrupt, the end of the rainy period sometimes tapers off and is less well defined (i.e., Altotonga, Teziutlán, Las Vigas). The duration of the rainy season was considered to be the period during which the heaviest and most frequent rains occurred. At most stations the rainy season lasted for about 11 weeks, but at a few stations it extended for as long as 18 to 21 weeks.

Stations within or near the cloud forest show pronounced percentage increases in fog interception during the dry season as compared to the rainy season. Altotonga recorded a 102.9 percent increase in water collected by the gauge with a screen during the dry season compared to only a 14.0 percent increase during the rainy period. All but one station on the dry coastal plain and on the dry interior showed either no difference or less water collected by the gauge with a screen during the dry period. The station at Soledad de Doblado showed a decrease of 23.3 percent during the dry season as compared to a 4.1 percent gain during the rainy period. The only exception was at Veracruz, where an 11.1 percent increase in water collected from coastal fog was obtained during the dry period. Percentages of fog moisture collections for the dry season are shown in relation to elevation in Fig. 5.

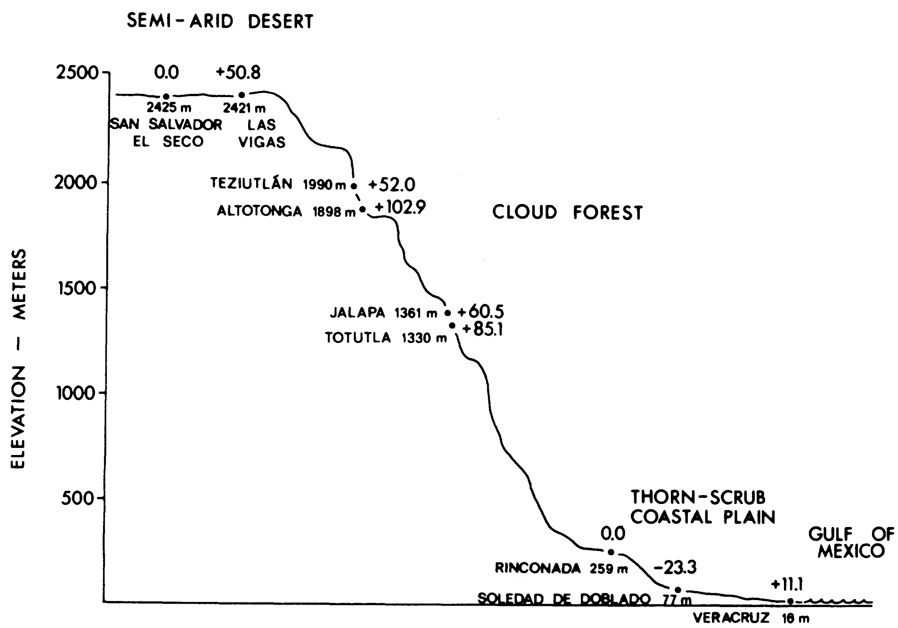

Fig. 5. Schematic diagram showing relationship of elevation to percentages of water collected by rain gauges with screens over plain rain gauges during the dry season.

DISCUSSION

The data clearly show that fog interception is a significant ecological factor on the upper windward slopes of the Sierra Madre Oriental, especially between elevations of 1300 and 2400 meters, the approximate zone of the cloud forest. Little or no fog interception occurs on the dry coastal plain where fogs are absent, except occasionally along the very edges of the coast. The high and semiarid plateau above the cloud forest showed little or no appreciable collections of fog moisture.

When rainfall occurs without fog the gauges with screens collect less water than the rain gauge. This indicates that the screen interferes with the normal collection of rainfall. The explanation for this is that since the droplets often fall at an angle, the screen tends to scatter them. Such decreases were also noted in fog precipitation studies made in the Green Mountains of Vermont (Vogelmann et al. 1968).

The most significant aspect in the analysis of data is the incidence of high fog interception recorded during the dry months at Altotonga and Las Vigas. During the period from 6 January to 29 June, the gauge with a screen at Altotonga recorded an increase of 118.8 percent over the rain gauge while at Las Vigas the increase was 79.1 percent. The increase at Altotonga gives a value of 262 mm of precipitation as opposed to a normal rainfall of 221 mm, while at Las Vigas the increase is 158 mm as compared to 200 mm of rain for the same period. Altotonga is barely within

Table 1. Collections of water (ml)[1] from rain gauges and gauges with screens during wet and dry seasons – 6 January 1969 – 11 January 1970.

Station and elevation	Season	Rain gauge	Gauge with screen	Gain or loss	Percentage gain or loss
Veracruz[2]	Rainy (6 wks)	6700	7525	+825	+12.3
(16 m)	Dry (31 wks)	1125	1250	+125	+11.1
	Total	7825	8775	+950	+12.1
Soledad	Rainy (11 wks)[3]	4900	5100	+200	+ 4.1
de Doblado	Dry (42 wks)	750	575	-175	- 23.3
(77 m)	Total	5650	5675	+ 25	+ 0.4
Rinconada	Rainy (11 wks)	3300	3675	+375	+11.4
(259 m)	Dry (42 wks)	1300	1300	0	0.0
	Total	4600	4975	+375	+ 8.1
Totutla	Rainy (14 wks)	14500	17150	+2650	+18.0
(1330 m)	Dry (39 wks)	3525	6525	+3000	+85.1
	Total	18025	23675	+5650	+31.3
Jalapa	Rainy (13 wks)[3]	6850	8050	+1200	+17.5
(1361 m)	Dry (40 wks)	3100	3100	+1875	+60.5
	Total	9950	9950	+3075	+30.9
Altotonga	Rainy (21 wks)[4]	10750	11800	+1450	+14.0
(1898 m)	Dry (32 wks)[5]	1675	3400	+1725	+102.9
	Total	12425	15200	+2775	+22.3
Teziutlán	Rainy (18 wks)[3]	13250	14625	+1375	+10.4
(1990 m)	Dry (35 wks)	2450	3725	+1275	+52.0
	Total	15700	18350	+2650	+16.9
Las Vigas	Rainy (18 wks)[6]	6625	7900	+1275	+19.2
(2421 m)	Dry (35 wks)	3100	4675	+1575	+50.8
	Total	9725	12575	+2850	+29.3
San Salvador	Rainy (10 wks)	2350	2025	- 325	- 13.8
el Seco	Dry (43 wks)	1225	1225	0	0.0
(2425 m)	Total	3575	3250	- 325	- 9.1

[1]Each 100 ml water collected is equivalent to 16.66 mm precipitation.

[2]Data missing after 21 September.

[3]Gauges overflowed in some weeks during rainy period.

[4]Gauges probably overflowed some weeks during rainy period, although not recorded by observer.

[5]Data lost for one week when high winds blew gauges away.

[6]Gauge with screen overflowed one week during rainy period.

the upper limits of the cloud forest while Las Vigas is just beyond in a semiarid zone where vegetation is sparse and characterized by scattered pines, oaks, and *Yucca*.

It is known that fog droplets are intercepted by the leaves and branches of trees and by other vegetation (Kittredge 1948, Ooura 1953). Tiny fog droplets collect on these structures, eventually coalescing into larger drops which then fall to the ground. Soil moisture is thus increased and, conceivably, so will be the ground water content. When trees are removed, the soil is deprived of this source of water.

The effect of fog interception is dramatically shown in Fig. 6, by an isolated group of pines, in a dry area near Las Vigas. As the fog moves across the dry plateau, it is intercepted by the tree crowns and droplets were observed steadily falling from the needles and branches. The soil under the canopy was saturated to a depth of 8 to 10 centimeters. Beyond this canopy the soil is powder dry.

Forests which once grew on the lands adjacent to the upper limits of the cloud forest have long since been cleared for cultivation. Clearing may have occurred hundreds, or even thousands of years ago, as early farmers sought out new lands for agriculture. Removal of the original forest, which probably was comprised largely of pine, may have contributed to the semiarid conditions which prevail today. The elimination of fog-intercepting trees could result in depriving the region of a sizeable amount of water which is swept inland as fog. It is especially significant that appreciable amounts of fog water are lost during the dry season when the presence of even small amounts of moisture are important.

The arid region over which fog interception could play a significant ecological role is probably extensive. The fog zone may penetrate as much as 20 kilometers or more into the dry plateau, judging from the extent of fog observed during the course of the investigation. If one assumes the zone of fog influence extends southward from Huauchinango, Puebla, to Orizaba, Veracruz, a distance of 200 kilometers, approximately 4,000 square kilometers (2,400 square miles) could be affected. This is probably a conservative estimate, since a map of annual rainfall distribution (Garcia 1965) shows mountainous areas with precipitation in excess of 1,500 mm, extending in an arc from about 23° N. lat. to about 17° N. lat., at the base of the Yucatan Peninsula – a distance of 1,000 kilometers. High rainfalls in these mountains are likely to be accompanied by fog. Heavy and frequent fogs within such an extensive range would not be continuous, but it is to be expected that the effects of fog locally have considerable influence on the water budget.

Fig. 6. Fog moisture collects under pines near Las Vigas, Veracruz, Mexico. The dark shadow below the trees is from soil being wetted by droplets falling from the pine needles. Soil was saturated to a depth of 8 to 10 cm. Elsewhere, the ground was powder dry.

Fog precipitation has long been known to be a significant source of water, especially in mountainous and coastal areas (Loewe 1960). However, little published information is available on the extraction of water from fog in arid regions. Water collections from fog can be expected whenever there is a combination of frequent fog, suitable droplet size, and wind movement. Some parts of California, Central America, the Coast of Chile, and the Azores are but a few examples where the conditions are suitable for collecting fog moisture. Conceivably the reforestation of some areas, or the use of artificial water trapping devices such as screens, could produce enough water to greatly enhance the productivity of the land.

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