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Further Observations on the Water Relations of *Prosopis tamarugo* of the Northern Atacama Desert

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Summary. *Prosopis tamarugo,* a tree native to the Atacama desert of Chile apparently has unique water relations. It is proposed that in its native habitat, where there is essentially no precipitation, establishment occurs during the rare flooding periods, with water coming as runoff from the Andes. These plants subsequently exist as phreatophytes tapping the relatively shallow ground water. Although phreatophytic, the plants appear to come under increasing drought stress as the growing season progresses. Because of the very low water potentials of the salty surface soils, water evidently moves from the plant into the soil under certain conditions. This water may be reabsorbed subsequently and used by the plant as the water table capillary fringe is depleted toward the end of the leafy period.

Introduction

There has been considerable interest in the reports of the capacity of leaves of the tree, *Prosopis tamarugo,* a plant native to a virtually rainless desert, to take up atmospheric moisture (Sudzuki et al., 1973; Went, 1975).

Here we review the data available on the water relations of this species, as well as providing some new information in order to evaluate the pathway of water between this plant and its environment.

Background

Prosopis tamarugo Phil. (tamarugo) is a mesquite tree native to the Pampa del Tamarugal region of the Atacama Desert in northern Chile. The northern parts of the Atacama Desert are for the most part totally barren. The tamarugo occurs in rather limited, apparently specialized localities, and reaches its greatest abundance in the Salar de Pintados, southeast of Iquique (Fig. 1). This ancient lake bed is highly saline and for the most part is covered with a thick crust of sodium salts. In the past these salts have been mined for nitrates.

The tamarugo is very abundant in parts of the basin, occurring mostly as plantation trees. The old tamarugo plantations were established by removing the salt crust and stacking it in rows, forming small basins several meters across between the rows. Seedlings were then planted on the south – or cool-facing – base of the rows. Now holes are dug directly through the 40 cm or so crust, and seedlings are planted at the base of the holes and watered for an initial period of several months.

The tamarugo produces a protein-rich fruit, which can be used for forage by goats, and there are a number of villages in the basin that are supported primarily by goat farming. The water to maintain these villages comes from wells.

The entire plain is underlain by an underground water basin, the depth of which is quite variable (Fig. 1). The hydrology of this area has been described in considerable detail (Castillo Urrutia, 1960; Tricart, 1960). These authors indicate that tamarugo exists as a phreatophyte with ground water at 5 to 12 m depth. Apparently the depth to the water table has been decreasing in recent years, likely due to the increased planting of tamarugo.

Rainfall is essentially nonexistent in the Salar de Pintados region. The mean annual precipitation reported for Canchones is 0.7 mm (7 yr record) and for Pintados 0.3 mm (12 yr record), totally insufficient to support tree growth. Although there is little rain, there are on rather infrequent occasions floods in the basin. These arise from runoff from the Andes to the east. Since there are no drainage channels within the basin, the water flows unrestricted over the basin floor. Such a flood occurred at the beginning of 1977.

The climate of the region is not only dry but is quite hot. The mean daily temperature at Canchones for the hottest month of the year is 32.2° C (February), and for the coldest 28.3° (June). The coastal mountains block the inward movement of marine air on a daily basis, but marine air does penetrate the basin on occasion.

In summary, the habitat of tamarugo is hot and dry. There is essentially no input of moisture to the soil from the atmosphere, but there is abundant ground water at depths of 5 or more meters. Surface ground water comes as infrequent floods.

Past Research

Sudzuki first worked on the water relations of tamarugo in 1969. She conducted detailed experiments that indicated that this plant could transport tritiated water form a *saturated* atmosphere surrounding its leaves to the soil surrounding its roots. Further, she described the unique rooting behavior of the plant. At a depth starting at less than a meter there is a dense rooting mat, which extends downward for a half meter or so. Tap roots extend below this rooting mat. The remarkable observation was made that,

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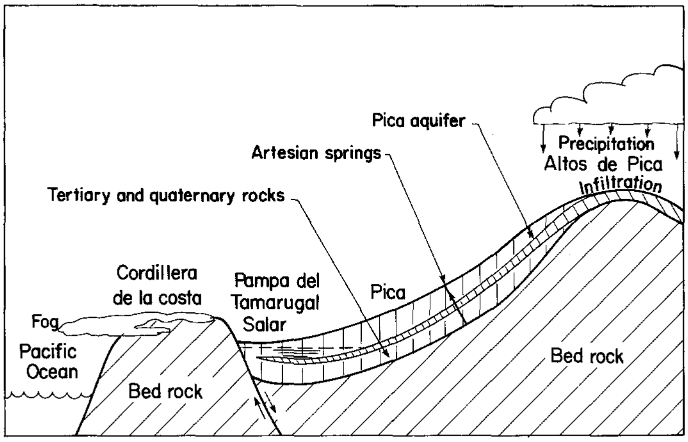

Fig. 1. Profile through the Pampa del Tamarugal region (modified from Klohn, 1972)

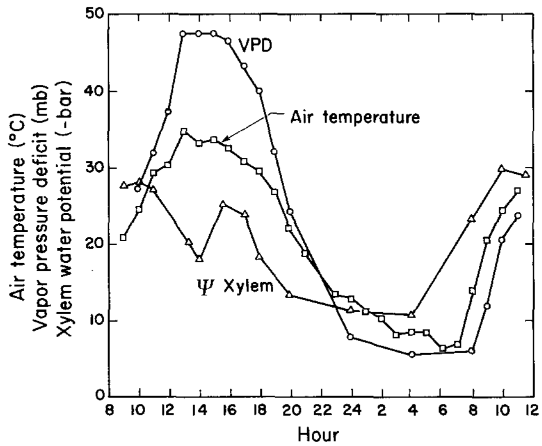

Fig. 2. Hourly course of air temperature, vapor pressure deficit and xylem water potential of tamarugo near Canchones on October 5–6, 1978

although both immediately above and below the rooting mat the soil was quite dry, the soil within the rooting mat had a considerable amount of moisture – in fact, exceeding field capacity for that soil. Went (1975) also made excavations and noted that the soils were moist in the rooting mat.

Sudzuki and others made further observations on the water relations of tamarugo in 1973. In this latter study they measured xylem water potentials, which ranged from an average of −13 bar at 0.400 to −28 bar at noon in summer (February). In winter (August), which must have been near the end of the leaf period, the average 04.00 xylem water potential was −27 bar, and at noon −28 bar. The lowest water potential measured was about −33 bar.

Sap velocity during the course of the day was also measured during both summer and winter. In summer, in the early morning hours, flow from the leaves to the roots was noted, whereas in winter no such reverse flow was noted.

Sudzuki et al. (1973) measured air relative humidity for a series of days for different seasons, noting that, although rare in this arid region, the relative humidity does reach 100% on occasional nights during each of the summer months. Daytime relative humidities less than 10% are not uncommon. Went (1975) further notes that dew has not been noted on the leaves of tamarugo.

Went in his 1975 study analyzes the climate of the tamarugo region and notes that there is sufficient moisture in the air column above the tamarugo to support its transpiration water loss, if the water were condensed in dew formation.

Current Study

During a visit to the Salar de Pintados tamarugo area in the spring (October) of 1978 we were able to make some additional measurements on the water relations of the tamarugo. We worked in an old plantation very close to the site used by Sudzuki.

Temperatures and vapor pressures measured during a 24-h period (Fig. 2) are indicative of the aridity of this region. Daytime temperatures reached a high of 37° C. At this time the vapor pressure deficit was nearly 48 mb (the relative humidity was 7%). At night the temperature dropped to 6° C, giving a day-night differential of over 30° C. The lowest vapor pressure deficit measured at 04.00 h, was 4.5 mb.

During the first daylight period the vapor pressure of the air averaged 4.5 mb. Starting at midnight the vapor pressure rose to 8 mb (dew point of 4° C), indicating the mixing of some marine air.

Xylem water potentials were measured with a Scholander pressure chamber, conductances with a Lambda diffusion porometer and xylem water movement using the heat pulse technique (Swanson, 1962). At 04.00 h an average xylem water potential value of −10.8 bar was measured, the highest for the day. The lowest average midday value was nearly −30 bar.

Measurement of sap velocity during this same period indicated flow only in the direction from the roots to the leaves.

There were indications of active stomatal control of the water balance of tamarugo. During the beginning of the period of highest vapor pressure deficit the stomata closed, and the water potential subsequently rose (Fig. 2). Midday stomatal closure in response to a high VPD has been noted for a number of other species of *Prosopis* (Mooney et al., 1977).

The osmotic potentials of leaves and soils were measured with thermocouple psychrometers kept at a constant temperature. The leaves were macerated and the soils brought to field capacity for these measurements. Duplicate soil samples were taken from above, within and just below the root mat. The soil osmotic values were, respectively, < −70, −15, and −57 bar. The leaf tissue had an average osmotic potenial of −21.3 bar (hardly a halophyte).

Discussion

We propose here that *Prosopis tamarugo* is using ground water for its growth rather than atmospheric water. This proposal does not contradict any of the measurements that have been reported for this species.

We offer no direct evidence that *P. tamarugo* is tapping the water table, but there are numerous indications that it is indeed doing so. Members of the genus are notable phreatophytes. The deepest root ever recorded was that of a mesquite, over 50 m (Phillips, 1963). The tree we observed had roots 3.5 cm in diameter penetrating straight down at a depth of over $3^1/_2$ m, which was as deep as we could reach in the excavation available. We were informed that the depth of the water table has increased in recent

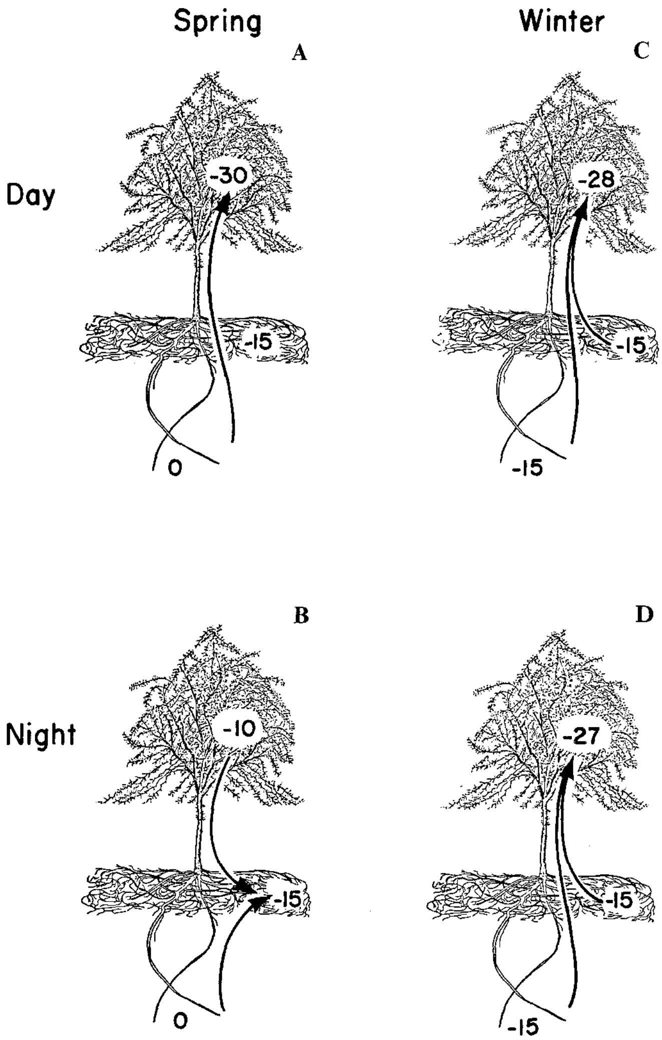

Fig. 3. Proposed pathways of water movement between soil and tamarugo during different times of the day and seasons spring indicates beginning of leat period and winter toward the end-see text. (tree figure modified from Sudzuki, 1969)

times, possibly because increased culture of tamarugo is lowering the water table.

The tamarugo trees are centered at the lowest points in the basin. Both to the east and to the west, the higher parts of the basin, trees are not successful.

It appears that tamarugo comes under increasing water stress as its growth season progresses. As with other mesquite species, tamarugo leafs out in the spring. Our measurements in October were on plants that had just leafed out. At this time the dawn water potential was about -10 bar. According to Sudzuki et al. (1973), by summer the dawn value for xylem water potenial was -13 bar, and apparently by the end of the leaf period in August the dawn value had dropped to -27 bar. A comparable drop in water potential through the season has been noted for the phreatophytic *Prosopis glandulosa* growing in Death Valley, California (Mooney et al., 1975).

Thus, even though a plant may be tapping the water table, apparently sufficient water is utilized from the capillary fringe to exceed the replacement rate, and the plants come under increasing stress. Further, it was noted in the plantation region that extra dense stands were doing poorly, implying competition for ground water rather than for atmospheric water.

Given that there is essentially no input of water into the soil as rainfall, the anomalous root mat at a depth of about one meter remains to be explained. This mat has been confirmed by all observers. Sudzuki (1969) gives soil moisture measurements indicating that this mat region is quite moist and considerably moister than soil above and below it.

It is axiomatic that roots grow only where there is water. Water is evidently present in the mat root zone. Where does it come from? Sudzuki et al. and Went proposed that it came from atmospheric water. Since conditions are such that saturating humidities or dew are rather rare events in this region, it would seem unlikely that such a pathway could support the growth of this tree. We offer an alternative explanation. As proposed earlier, the plants are tapping ground water. However, as the season progresses, this water becomes less available. The soils of the upper root zone have a low osmotic potential, with the root mat zone having the highest value at about -15 bar. During a spring or summer day water would pass from the capillary fringe above the water table through the roots to the leaves and into the atmosphere, as indicated in Fig. 3a. At night, as the atmospheric evaporative demand decreases, the water potential of the plant rises so that the lowest water potential is now in the root mat zone. Water thus moves both from the capillary fringe to this zone and from the crown downward to this zone (Fig. 3b). The characteristically steep drop in the VPD in the afternoon would permit the establishment of the reverse gradient between the shoot and the root zone. Such a water movement pattern would explain the observations of a reverse stem sap flow, as noted by Sudzuki et al. (1973), as well as how the root mat becomes wet without the input of precipitation.

The question thus becomes "why does the plant develop a root mat at all if this would result in a net loss of water?". We propose that the root mat serves a water storage region. As the capillary fringe becomes depleted, water moves not only from the fringe zone to the canopy but also from the mat zone to the canopy, thus potentially extending the productive period of the plant (Fig. 3c and d).

This model is, of course, highly speculative, but it fits all the observations made thus far. One may ask why such a system has not been described elsewhere. It is probably true that the soil and environmental conditions prevailing at the Pampa del Tamarugal, which are necessary for such a system to operate, are unique in the world.

How does the tamarugo ever become established in the first place under natural conditions? Although precipitation is lacking, at infrequent intervals there are flood waters originating as runoff from the Andes (Natives said it had been 70 years since there had been a flood equalling that of 1977). We noted numerous seedlings in small flood basins that lacked the thick salt crust characteristic of the region. The trees are long-lived enough to maintain populations between these flood events. Establishment of plantations today and in the recent past has required the removal of the salt crust. It is thus very likely that the current density of tamarugo far exceeds that in prehistoric times, and this may well be the cause of the current lowering of the water table.

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