

DESERT PLANTS AS A SOURCE OF DRINKING WATER.*

By FREDERICK V. COVILLE.

A STRANGER left alone in a desert would die of thirst, and yet there is water in all deserts, and both the native animals and the native races know how to find it. This water is gathered and stored by plants, which have built and filled their reservoirs for their own purposes, but which yield it up, when required, for the use of the animal world.

The extent of the root system in desert plants, by means of which they absorb their water from the soil, is often astonishingly great. In the Mohave Desert of California a branching cactus (*Opuntia echinocarpa*) 48 centimeters (19 inches) in height was found to have a network of roots extending over an area of ground about 5.5 meters (18 feet) in diameter.† The roots lay near the surface, at a depth of 5 to 10 centimeters (2 to 4 inches), a situation which enabled them to take advantage of a single substantial downpour and, before the precipitation had been again absorbed into the parched air, to suck up a supply of water sufficient, if need be, for a whole year's use. Other desert plants send their roots deep into the ground for water, and a certain shrubby species of acacia found about Tucson, Arizona, possesses, according to Prof. R. H. Forbes, a double-root system, in which one series of roots spreads out horizontally, close beneath the surface, and a second series, sharply defined, goes directly downward into the soil. Such an arrangement enables the plant to

tion pore in a plant of humid habitat is shown in Fig. 2. Through the courtesy of Dr. R. E. B. McKenney the structure of a pore of *Echinocactus emoryi* is presented for comparison (Fig. 3). It is to be noted that the cuticle of the latter is excessively thickened. Beneath the epidermis is a deep layer of hypodermis with very thick walled cells and small cell cavities. It can scarcely be doubted that, except at the pores, the epidermal structure is impervious to moisture even under the extreme desiccating conditions of the desert. Beneath the minute opening of the pore is an air chamber, the lower contracted end of which is made up of the walls of the green, moist interior cells of the plant. The portion of the walls of this chamber which lie within the hypodermis, Dr. McKenney has discovered, are cutinized, so as to be impervious to moisture. The cushion of air in the chamber is therefore slowly receiving moisture at its lower end from the interior water supply of the plant and slowly giving it off into the outer air whenever the two guard cells open the narrow slit between them. The whole structure is evidently well adapted to the maintenance of a transpiration current at an exceedingly attenuated rate adapted to the plant's limited supply of moisture.

The interior of the plant consists chiefly of water-storage cells (Fig. 4). These are globular in form, devoid of green coloring matter, and with walls somewhat thickened but possessing thinner sieve-plate areas which permit the ready transfer of water from one cell to another throughout the interior. Dr. McKenney has made a determination of the water in a sample of

in the ground like the domestic hog, that they derive some of their requisite moisture from the underground portions of plants, while another source of moisture is the fruit of opuntia and other cactuses.

Mr. T. S. Van Dyke, in an article on the mule deer,* says:

"When on this food [cactus] deer not only can go without water, but often go without it when it is perfectly convenient. On the great Mexican desert known as the Bolson de Mapimi, I hunted for several weeks in 1884, stopping at a railroad station 25 miles from anywhere, and known to be 25 miles from any other water. Several hundred feet from the station the leakage from the water cars of the railroad made a shallow pond some 50 feet long and a dozen wide. To the leeward of this fresh tracks of deer could be found almost any morning, all near enough to smell the water, but not one of them going to it. I had plenty of other most positive proof that the deer there, as well as the antelope, did not go to water, though the days were hot enough to make a man want water as much as in mid-summer. For many a league there was no green feed except some of the varieties of cactus, and every deer and antelope that I opened in this vicinity was filled with it. The same is true in parts of Sonora and in much of Lower California."

This statement is confirmed by Mr. E. W. Nelson, the American naturalist most widely experienced in Mexican travel and observation, to whom similar instances are well known.

Various authentic records exist regarding the al-



PAPAGO INDIAN DRINKING FROM A BISNAGA (ECHINOCACTUS EMORYI).

seize upon water either from light precipitation or when deeply percolating under dry stream beds.

While the devices for absorption in desert plants are unusual, the mechanical contrivances by means of which these plants are enabled to retain the moisture they have absorbed are still more remarkable. Other factors being equal, the amount of water transpired, or evaporated, from a plant is proportional to the area of its green surface, which, in ordinary plants, is a foliage surface. A specimen of coffee plant (*Coffea arabica*) weighing 20.5 grammes is found to have a leaf surface computed at 164,476 square millimeters, which gives a ratio of 1 to 8,023. A specimen of bisnaga or barrel cactus (*Echinocactus emoryi*), in the conservatories of the Department of Agriculture at Washington, weighing 77,000 grammes (170 pounds) and without leaves, has a green stem surface of 1,032,320 square millimeters, with a ratio of 1 to 13.4 (Fig. 1). Thus for each gramme of tissue a coffee plant, representing the ordinary vegetation of a humid climate, has a green surface 599 times greater than that representing a gramme of tissue in cactus; or in physiological terms, the coffee plant, other factors being equal, is provided with means for the transpiration of 600 times as much water as the cactus.

Not only is the green surface of desert plants very much restricted in extent, but it has such a structure as greatly to reduce the amount of moisture transpired through it. The structure of an ordinary transpira-

this storage tissue and finds the astonishing amount, by weight, of 96.3 per cent. The plant when filled to its capacity is almost a tank of water.

That animals which live in a desert would have difficulty in securing a regular supply of water is evident. But it is a matter of fact that many of these animals go without water for months at a time, deriving all their moisture from the watery tissues of plants; and there is conclusive evidence that some animals never drink water, apparently not knowing what water is, and never eat even ordinary herbage, but subsist on dry seeds alone. D. W. Carnegie records the statement* that while traveling across the desert of southwestern Australia, his band of nine camels went without water from July 29 to August 10, 1896, a period of 12 days, on the latter date taking a full drink averaging 17 gallons each; while two of his camels performed a still more wonderful feat of abstinence in traveling for a period of thirty-seven days, from August 22 to September 28, 1896, on only 13 gallons of water each, which they drank as follows: August 29, after seven days, 2 gallons; September 8, after ten days more, 8 gallons; September 18, after an additional ten days, 3 gallons. Bands of Merino sheep grazing on the tender annual vegetation that springs up on the desert near Phoenix, Arizona, after the winter rains, sometimes drink no water for a period of forty to sixty days. In the desert plain of Sonora, Mexico, west of the railroad station of Torres, are isolated rocky hills in which peccaries live for months at a time without possible access to natural water. It is evident from their habit of rooting



PAPAGO INDIAN PREPARING A BISNAGA (ECHINOCACTUS EMORYI).

most incredible abstinence of some of the small desert rodents of the southwestern United States. Mr. Vernon Bailey, of the United States Biological Survey, informs me that he kept a desert jumping mouse (*Microdipodops megacephalus*) for more than a month, during which period it ate only dry seeds and grain. After it had become very tame he placed water before it, but it would not drink. When the dish was elevated until the water touched the end of its nose, the animal showed every sign of ignorance of the liquid and even repugnance to it. Mr. F. Stephens, of Santa Ysabel, California, has recorded the statement† that he had a pet of the gray pocket mouse (*Perognathus fallax*) which drank no water in the six months during which it had been in his possession; that it would not touch water, and did not seem to know what water was, and that it would not eat green food. He states also that Mr. W. G. Wright, of San Bernardino, California, had a captive specimen of the tuft-tailed pocket mouse (*Perognathus penicillatus*) which had no drink and no food save dry grain for more than two years. Dr. J. A. Allen, of the American Museum of Natural History, states‡ that a pocket mouse from western Texas (*Perognathus merriami*) had been kept for nearly three years without water, his food during that period consisting exclusively of dry mixed birdseed. The domicile of the animal was a tin box 10 by 20 by 14 inches,

* In "The Deer Family," by Theodore Roosevelt and others, pp. 193-194, 1902.

† West American Scientist, vol. vii., p. 38, 1890.

‡ Bulletin of the American Museum of Natural History, vol. viii., p. 58, 1896; American Naturalist, vol. xxxii., pp. 583-584, 1898.

* Reprinted from Smithsonian Institution Report.

† Coville. Contributions from the United States National Herbarium Vol. iv. (Botany of the Death Valley Expedition), pp. 46-7, 1893.

* D. W. Carnegie, Spinifex and Sand, pp. 194, 261. 1898.

open at the top, but with a thick layer of earth at the bottom. Dr. Allen summarized his experience with the animal in the statement, "As no water and no fresh vegetation have been given him for nearly three years, it is evident that the only moisture required for his sustenance is derived wholly from dry birdseed." A water content determination of dry mixed birdseed, made in Washington, December 31, 1903, shows 11.75 per cent of moisture. Freshly matured wheat grains in the climate of the arid portions of California have a water content of only 6 to 8 per cent of their weight. It is impossible that these rodents, performing their functions of respiration, digestion, and secretion, can subsist on this amount of moisture. The subject is one that deserves precise quantitative measurement as well as anatomical investigation. Is it possible that



FIG. 1.—BISNAGA OR BARREL CACTUS (ECHINOCACTUS EMORYI.)
One-ninth natural size.

these animals possess some apparatus by means of which they can abstract moisture from the air hygroscopically and condense it for their own use? Or do they manufacture the water they require by the chemical dissolution of starch?

However this may be, it is clear from some of the cases cited that the water supply of many desert animals, either for long periods or during their whole lives, comes not from natural water, but from that stored in the tissues of plants. It is an old established fact that animals do not possess the power to manufacture their food out of the raw mineral constituents of the soil, but that these constituents must first be elaborated into starch or other food products by plants. To this fundamental dependence of animal upon vegetable life may be added, in the case of many desert animals, their further complete dependence on plants for their supply of water.

Under certain conditions this dependence of desert animals upon plants for their water is extended even to the human race. The rainfall of the desert of Sonora is so small and so irregularly timed that periods of prolonged drought occur, during which many of the customary sources of water supply, always few and far between, fail utterly. To two of the native tribes, the Seris and Papagos, such a condition is not necessarily serious, for they betake themselves to the water stored in cactuses.

Some of the largest cactuses, such as the saguaro, or giant cactus (*Cereus giganteus*), the pitahaya (*Cereus thurber*), and the sina (*Pilocereus schottii*), are not available as a source of drinking water, for their juice is bitter and nauseating. But the juice of certain species of the genus *Echinocactus*, notably *E. emoryi* and *E. wislizeni*, is sweet and palatable. These cactuses, the Mexican name of which is bisnaga, are known by all natives of the desert region as a potential source of drinking water. In February, 1903, the writer, in company with Dr. D. T. MacDougal, while seeking a location for a desert botanical laboratory for the Carnegie Institution, found an opportunity to observe the extraction of water from a bisnaga according to the primitive process and by one of the aborigines themselves.

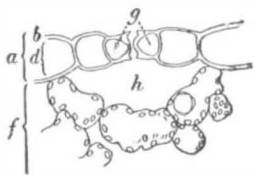


FIG. 2.—TRANSPIRATION PORE OF TRADESCANTIA VIRGINICA.

a, Epidermis; b, outer wall of epidermal cell; c, cavity of epidermic cell; f, green interior tissue; g, guard cells of the transpiration pore; h, transpiration chamber. Much enlarged. After Strasburger.

The locality was in the State of Sonora, Mexico, at a point about 12 kilometers (8 miles) west of the railroad station of Torres. Upon request a Papago Indian, the guide of the party, exhibited the operation. The cactus used was a specimen of bisnaga (*Echinocactus emoryi*) with which the region abounds.

The plant selected was about 1 meter (31-3 feet) high and 0.5 meter (20 inches) in diameter. Its top was first sliced off, exposing the white interior. It was evident that this was saturated with water, but the structure of the tissue was such that the water did not exude of its own accord. The Indian cut a stake of palo verde (*Parkinsonia microphylla*) about 7.5 centimeters (3 inches) in diameter at the larger and blunt end, and with this proceeded to mash the white flesh of the cactus into a pulp. As the churning progressed a bowl was formed in the top of the cactus, and when a suitable quantity of pulp had accumulated in it the Indian, taking this up handful by handful, squeezed out

the water into the bowl, throwing the rejected pulp upon the ground.

From the upper 20 centimeters (about 8 inches) of the cactus about 3 liters (3 quarts) of water was obtained. Its flavor may be described as very slightly salty and somewhat herbaceous. Any really thirsty traveler would have drunk it without hesitation, and our Papago, although he had had plenty of water from

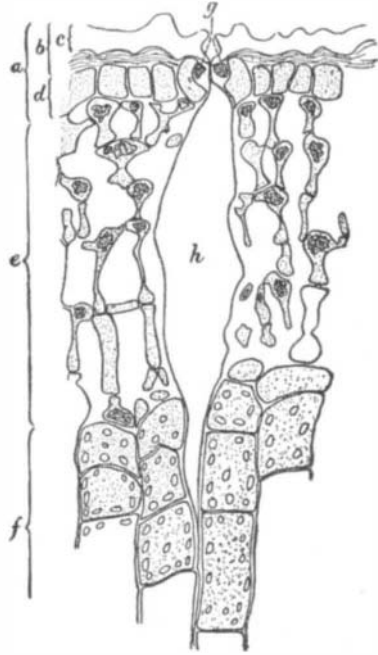


FIG. 3.—TRANSPIRATION PORE OF ECHINOCACTUS EMORYI.

a, Epidermis; b, outer wall of epidermal cell; c, cuticle; d, cavity of epidermal cell; e, hypodermis; f, green interior tissue; g, guard cells of the transpiration pore; h, transpiration chamber. Much enlarged. After McKenney.

the supply we carried, drank the cactus juice with evident pleasure.

A bisnaga of approximately spherical form furnishes a more palatable water than the cylindrical specimens many years older, and care is taken to use for a masher a wood which has no bitter, resinous, or poisonous qualities. No deleterious effect is caused, our Indian stated, through drinking a quantity of the water, unless one subjects himself immediately afterward to violent physical exercise. The natives use the cactus water, if need be, for mixing bread, and evidently it could be devoted to any camp use.

An interesting correlation is to be noted between the palatable flesh of the bisnagas and their effective protection against grazing animals through their impenetrable armor of hooked and rigid spines. Without such protection the bisnaga would be doomed to early extinction by such animals as required a continual supply of moist, herbaceous food. Other cactuses, on the contrary, which have a bitter and nauseating juice, often have only a very imperfect protection by spines, as the giant cactus (*Cereus giganteus*) and the sina (*Pilocereus schottii*). One cactus, the peyote (*Lophophora williamsii*), has no spines whatever at maturity. In appearance it is as plump and juicy as an apple; yet, as is demonstrated by its abundance in certain localities, it is amply protected against the depredations of animals by its bitter and poisonous juice.

Another notable feature in the mechanical construction of the bisnaga is the fluted character of its surface. Between the times when its body is fully distended with water from the absorption following a heavy rain and other times when its interior tissues are

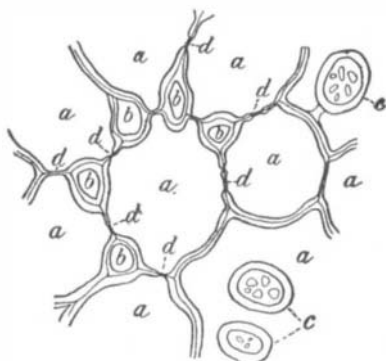


FIG. 4.—WATER STORAGE TISSUE OF ECHINOCACTUS EMORYI.

a, Water storage cells; b, intercellular spaces; c, sieve plates, face view; d, sieve plates, in cross section. After McKenney.

far shrunken after a prolonged drought, the plant, if ordinarily constructed, would be very liable, from the repeated wrinkling and stretching of its hard skin, to injury by cracking. What form could be more admirably suited to accommodate the bisnaga to this feature of its existence than the fluting of its surface, each fluting or rib becoming thick by the absorption of water and thin by its loss?

Strenuous are the conditions to which the plants of the desert are doomed; many and remarkable are the devices with which these conditions are met, and rich are the opportunities for research where such phenomena exist. It is a matter for congratulation that to the United States belongs the credit of first establishing a botanical laboratory in the midst of the desert. Such a laboratory has been founded near Tucson,

Arizona, by the Carnegie Institution of Washington, and we may confidently expect to learn from time to time of results which shall excite our wonder and which shall constitute new contributions to the sum of human knowledge.

ROTARY ENGINES.

THERE are certain problems in mechanical engineering which appear to be always on the point of being solved, and always evading solution. Frequently they offer to the inventor a selection of many methods, and they are invariably of obvious desirability. Moreover, they have the fascinating characteristic that success always seems just within reach. One of these problems is the rotary engine. We hesitate to say what a huge number of inventions of engines of this description have been protected since patent laws began. It certainly runs into three figures, and our own patent office alone, we are confident from a rapid review of the lists of specifications for a few weeks here and there during recent years, must receive at least fifty applications, and probably many more, every twelve months. One very remarkable fact about the invention of the rotary engine is that it never ceases, and that the inventor of to-day never profits by the lessons of his predecessors. Reuleaux, in his classical work—he himself, by the way, if we remember rightly, believed the problem to be solvable—has arranged all types of rotary engines in a number of classes, and has given diagrammatic sketches of representatives of each type. We believe that, although his book is many years old, not a single new type could now be added to Reuleaux's list. Invention keeps going over and over the same old ground, sometimes without any attempt to meet the real difficulties of the problem, and sometimes with full recognition of the obstacles to success and praiseworthy efforts to overcome them. Yet the result is always the same. For a time a rotary engine, here and there, designed better than others, has a short life; but they all, without exception, have hitherto disappeared after a few years into the limbo of history or into an intermediate condition of insignificance.

Years ago, before it was found that reciprocating engines could be run at very high speeds with success and efficiency, the rotary engine received more scientific attention than it does to-day; but since the stream of inventions runs as full as ever, it may be that some of our younger engineers have forgotten the few elementary facts that stand in the way of success. They are true of by far the greater number of designs. The first is the line contact, the second excessive clearance, the third friction produced by unbalanced steam pressure, or centrifugal force, on moving parts. If anyone will look at a number of diagrams of rotary engines he will see that a favorite design is the "crescent chamber type." In this engine one cylinder is placed eccentrically inside another, and is provided with radial abutments of some form or another. In some cases the inner cylinder makes one of the abutments by bearing against the walls of the containing cylinder. The contact between two curved surfaces of different radii is a line contact, and steam-tightness is impossible. That is an elementary fact which is daily forgotten. In some designs the abutments spring from the center of the inner cylinder: hence they are only radial to the outer cylinder in two positions, and, if their extremities are curved to fit the outer walls in these positions they will fit nowhere else; hence, if line contact is to be avoided, a flexible joint of some kind, with consequent leakage and complication, must be employed. If in an endeavor to avoid the first difficulty the inner cylinder is removed some distance from the outer casing, and the changes in the contents between two radial abutments looked to for the propelling power, the clearance at once becomes formidable. The designer therefore finds himself in a quandary. In the one case he loses steam by leakage, in the other by excessive clearance. In another common type of engine abutments are hinged either on the rotating members or on the fixed cylinder; if the former, they are driven out with considerable centrifugal force, if the latter, they are pressed in by the steam, frictional loss increasing in either case to an enormous extent unless provision, again with necessary complications, for removing these objections is introduced. Again, there is the common type in which the revolving portion is cam-shaped, and an abutment either presses on it radially or obliquely. In either case one of two, or both, of the following difficulties have to be met—either the back of the projection is nearly radial, in which case, however quickly the abutment may fall, it cannot prevent clearance being excessive, or the projection may be curved and closely followed by the abutment remaining always in touch with it, when, again, it is difficult in practice, owing to the curvature of the abutment, to avoid line contact, as a few moments' consideration will show.

All older engineers who have studied the question at all are aware of these difficulties, and have long since given up the pursuit; but younger men, even among engineers, still spend their guineas year after year in the vain quest, and it is to them that these few remarks on one or two out of the many difficulties that beset the rotary engine are addressed. We have touched only two or three types, but we invite our inventors to study Reuleaux's pages, and to apply his lucid critical observations to their devices before they take out patents. One very important thing they must note, and that is that many rotary engines are reciprocating engines in disguise, having masses with alternating motions just as ordinary engines have, and