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Productivity and Water Stress in Cacti Progress Report

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PROGRESS REPORTS ON PROCESS STUDIES (2.3)

Productivity and Water Stress in Cacti (2.3.1)

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Abstract

The objectives of this study are to determine the biomass contribution of cacti to the Sonoran Desert ecosystem and the productivity rates and water flux that influence this biomass. Harvesting and sampling of cacti and other perennials have shown the significant contribution of cacti to the ecosystem. Growth rates are shown to respond to rainfall and temperature regimes. Cacti are shown to be major recyclers of nutrients. Carbon dioxide exchange measurements of cacti are being used to pinpoint the environmental conditions and times of best growth.

Objectives

The basic objectives of this study were to determine the productivity of cacti (especially a prickly pear and cholla species) under different environmental conditions including variable moisture stress conditions. In order to achieve these objectives, secondary objectives were established during 1970. These included determination of (1) the relative importance of cacti in a typical Sonoran Desert community, (2) actual environmental conditions that influence cacti productivity and moisture stress, (3) total biomass of selected species of cacti in a limited study area as well as dry weight ratios between plant parts for future estimation of biomass, (4) growth rates of plants, especially stem parts in cacti, in relation to time and environmental factors, and (5) differential CO_2 exchange through time as a measurement of short term productivity rates. It was not intended when establishing these secondary objectives that results would be obtained during 1970 to completely satisfy all the primary objectives.

Methods

A few cactus plants have been studied in South Mountain Park south of Phoenix, Arizona; however, most work has been carried out at a study site in Usery Mountain Regional Park northeast of Mesa, Arizona at 2,200 ft. elevation. An 100 x 100 m plot has been set aside for permanent study while actual harvesting of plants has been done outside of the plot.

Vegetation Analysis

In order to determine the contribution of cacti to the vegetation of the study area, fifty 5 x 5 meter quadrats within the 100 x 100 m plot were sampled for total perennial vegetation. Density, frequency, and aerial cover were determined for each species. These were converted to relative figures and summed to give an importance value for each species in the stand.

Environmental Conditions

Soil moisture and air and soil temperature are being measured at the Usery study site. Soil moisture is being measured both gravimetrically and by Colman blocks at 10 cm and 30 cm depths at four locations. Both air and soil temperatures are being measured with Sixes type maximum-minimum thermometers. Two thermometers on stands measure air temperatures 30 cm above the soil surface and four thermometers in metal containers measure soil temperatures 10 cm in the soil. These are read periodically and only the maximum and minimum temperatures are recorded. Precipitation data used is an average of data from three U. S. Weather Bureau Stations located within a ten mile radius of the study site.

Biomass Determinations

One hundred prickly pear cactus (Opuntia engelmannii) pads were harvested to determine the relationship between pad dimensions and dry weight. Length times width of each pad is best for estimating pad dry weight. One hundred prickly pear fruits were harvested to obtain an average dry weight per fruit. Eight total prickly pear plants were harvested to determine dry weight relationships between pads (photosynthetic stems), stems (with corky tissue), fruits, and roots. These plants ranged in size from 20 pads per plant to 110 pads per plant. All of these data have been used in estimating the total biomass for prickly pear cacti within the study area. Similar data are being collected for staghorn cholla (Opuntia acanthocarpa).

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Growth Rates

Selected pads from prickly pear plants have been measured periodically as to length, width and thickness. These data can be used to determine the gradual increase and fluctuations in biomass relative to time and environment.

Carbon dioxide exchange and water loss. Carbon dioxide exchange patterns of prickly pear cactus are being meausred with a Beckman 215R infrared gas analyzer. Laboratory studies are under controlled light and temperature regimes whereas field studies are under conditions as similar as possible to the existing environmental situation. Whole plants are used when they are small but excised parts of larger plants, shown to vary little from intact plants (Patten and Dinger, 1969), are used for most experiments. Water loss by the plants is being measured by differential psychrometry between inflow and outflow air streams from the plant chamber.

Findings

Vegetational Composition

Bur sage (Franseria deltoidea) is the dominant species in the study area (Table 1). The cholla cacti (Opuntia acanthocarpa, O. leptocaulis, and O. fulgida) are the dominant cacti while prickly pear (O. engelmannii) appears to contribute little to the community as expressed by Importance Value (Table 1). Palo Verde (Cercidium spp.) and ironwood (Olneya tesota) were not sampled because no wash intersected the sampled area; however, they were present in the desert area surrounding the study site.

Table 1. Importance Values (I. V.) of the perennial species sampled at the Usery Mountain study site.

Species	I. V.
Franseria deltoidea	145.1
Larrea divaricata	37.3
Opuntia acanthocarpa	30.9
O. leptocaulis	20.0
O. fulgida	16.0
Mammillaria microcarpa	12.9
Simmondsia chinensis	11.2
Echinocereus engelmannii	8.0
Ferocactus acanthoides	5.6
Brickellia coulteri	4.1
Cereus giganteus	4.1
Opuntia engelmannii	2.6
Lycium sp.	2.2

Environment

Temperatures, soil moisture, and precipitation from June into November 1970 are presented in Figure 1. Soil moisture responds directly to precipitation with shallower soil wetting up faster and to a greater extent than the deeper soils. Although most of the soil moisture measurements were taken shortly after a rain (24 hours), the maximum water content measured was six percent. Air and soil temperatures show fluctuations through the summer and then a gradual drop toward winter. Although data from December 1970 are not in Figure 1, minimum air temperatures during December have dropped below freezing.

Biomass Measurements

Using dry weight measurements of totally harvested prickly pear plants and calculated estimates from other plants it was possible to develop a biomass ratio between pad dry weight and stem dry weight (Fig. 2). The curve established by these ratios can be used for estimating total dry weight of a plant when knowing only the number of pads on the plant and relative dimensions of representative pads.

Total biomass of the prickly pear cactus plants and of the various plant parts is presented in Table 2. These data are based on estimates of (1) dry weight of the pads determined on a curve relating pad dry weight to length times width calculations similar to the relationship shown in the mid-year report for pad dry weight compared to length x width x thickness; (2) ratios of pad dry weights to stem dry weights (Fig. 2); and (3) average fruit dry weight. As one might expect, the pads make up more than half of the total dry weight of the plants but, unexpectedly, the fruit, which are shed each year, make up more than ten percent of the total dry weight. The estimate for total dry weight of prickly pear cactus at the study site of 83 kg/ha is much more accurate than the 75 kg/ha reported at mid-year (1970). Similar data are not complete for the cholla cactus being studied.

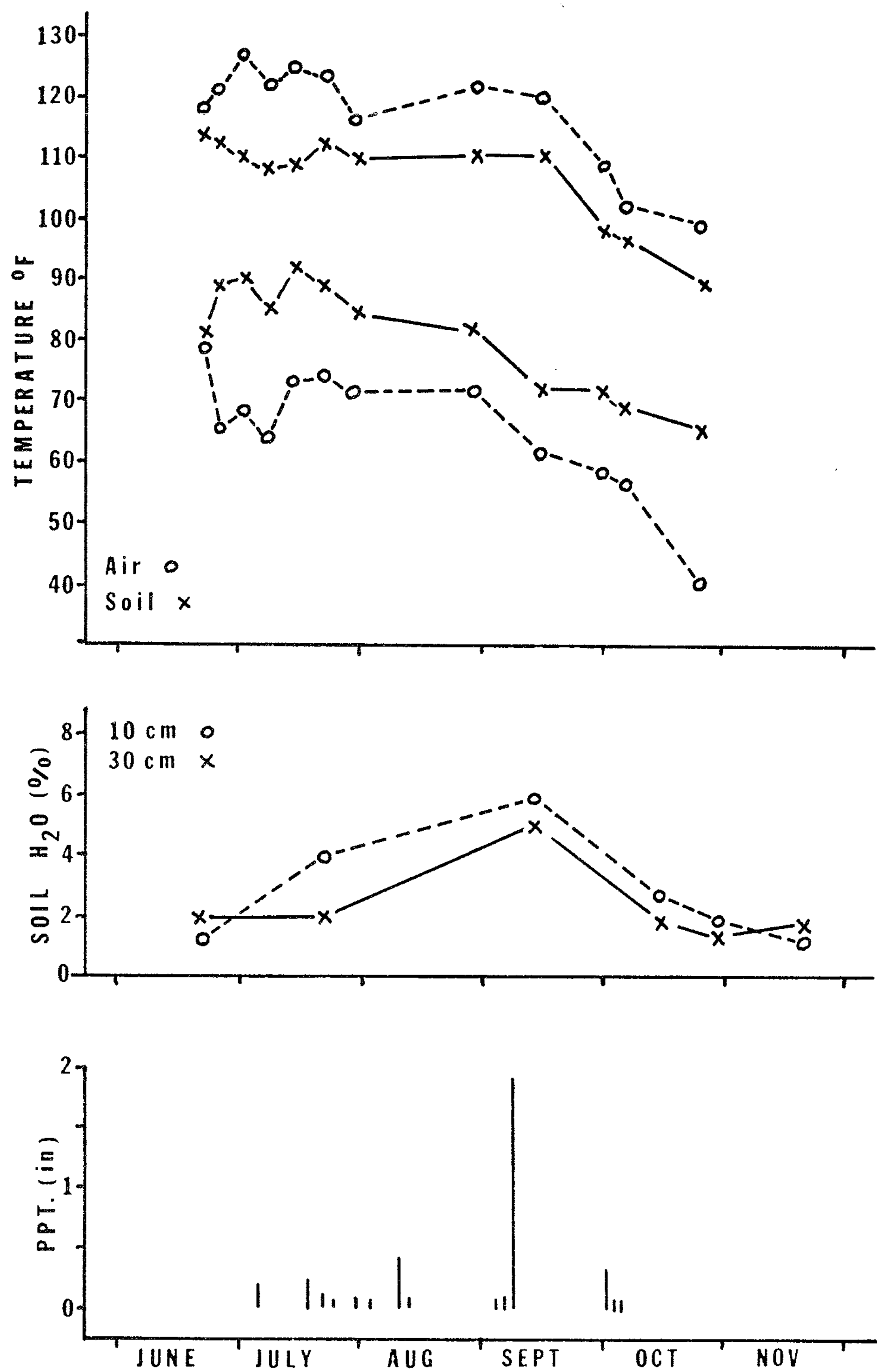

Fig. 1. Average air and soil temperatures (max. and min.), soil moisture, and precipitation data from the Usery Mtn. Park site.

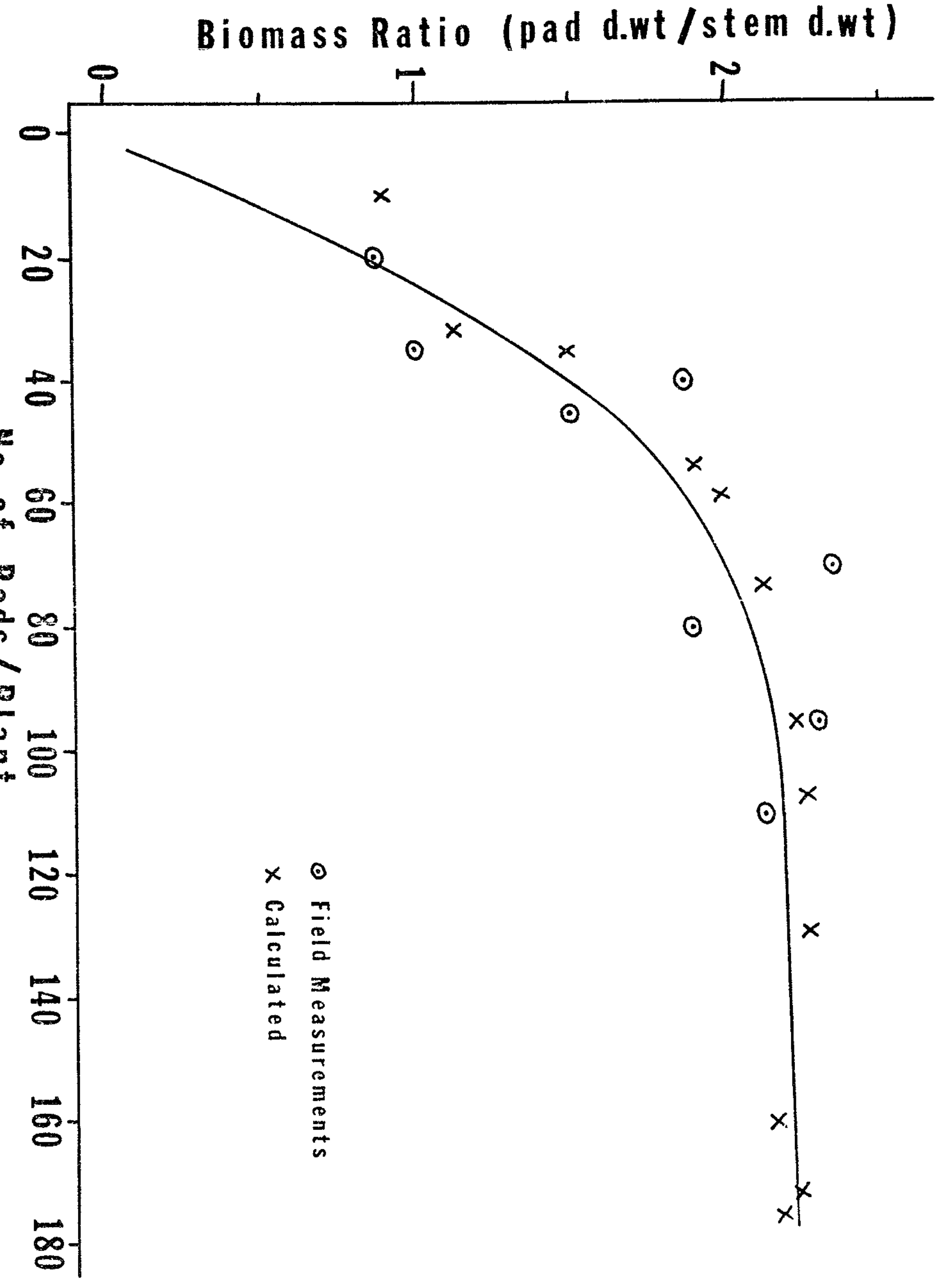

Fig. 2. Relationship between pads per plant and the dry weight ratio between pads and stems of prickly pear cactus.

Table 2. Biomass relationships of prickly pear cactus in a 100 x 100 m study plot in the Usery Mountains, Arizona

Plant No.	Number of pads	Number of fruits	Biomass (gm) pads	stem	roots	fruits	Total
1	161	320	5320	2450	400	2330	10,482
2	175	103	2312	1050	140	725	4,227
3	35	9	1171	780	100	63	2,114
4	107	215	3886	1710	220	1500	7,316
5	129	180	5101	2230	319	1260	8,910
6	106	30	4201	1861	238	210	6,510
7	58	2	1840	920	115	14	2,889
8	40	12	1367	910	100	84	2,461
9	31	39	1007	890	81	273	2,251
10	28	2	609	550	45	14	1,218
11	177	150	7505	3350	400	1050	12,305
12	54	19	1365	720	85	143	2,313
13	36	7	1407	755	112	49	2,323
14	10	2	280	310	35	14	639
15	78	46	2095	980	125	322	3,522
16	95	57	4576	2050	284	400	7,310
17	9	2	288	330	27	14	659
18	73	29	3755	1770	245	203	5,973
Totals	1402	1224	48,067	23,616	3,071	8,668	83,422

Pads = 57.6% of total biomass

Stem = 28.3% of total biomass

Roots = 3.7% of total biomass

Fruits = 10.4% of total biomass

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Growth Rates

Periodic measurements of dimensions of selected prickly pear pads show the growth to be a series of surges rather than a single development of new pads in the spring (Fig. 3). Some of the growth follows rainy periods but other surges appear to occur during periods of some available moisture and optimum temperatures. The dimensional increases of length times width are maintained following a growth surge, whereas, thickness measurements fluctuate in relation to available moisture following rain storms. The growth surges shown in Figure 3 were measured after the initial rapid development of the new pad. The beginning part of the curves is probably the end of the development stage.

Carbon Dioxide Exchange and Water Loss

Early measurements of prickly pear cactus CO_2 exchange were inaccurate due to problems with the plant chamber. Field measurements made in December show little or no CO_2 exchange from the plants during the day at air temperatures of 57°F (14°C). Laboratory studies are beginning to show CO_2 exchange patterns similar to those we have previously measured in other cacti under controlled conditions. Not enough data have been accumulated yet to yield any significant results comparable to the biomass measurements.

Discussion

The cacti make up a significant part of the Sonoran Desert vegetation at 2,200 ft elevation. The biomass of the cacti probably contributes more to the total biomass of area than do the biomass of shrubs or annual plants. Prickly pear cactus with a low I.V. of 2.6 still contributed 83 kg/ha in biomass. The cholla undoubtedly will contribute more. A comparison of biomass of cacti compared to that of the woody shrubs should be made.

Shrubs have always been considered important in terms of nutrient recycling due to leaf and twig fall, whereas the cacti have been considered as biomass that is tied up and not recycled except when the plant dies. To the contrary, ten percent of the biomass of prickly pear cactus is recycled annually in the form of fruits that are either eaten by rodents and other animals or disintegrate after falling. This percentage of recycling is probably considerably more than that from leaf and litter fall of woody plants.

Growth of the prickly pear cactus comes in surges. The greatest surge occurs in spring when new pads and fruits are formed. This new growth is greater than ten percent of the total dry weight of the plant because this amount is contributed just by the new fruits and not the new pads. Periodically during the summer, especially following rains, and again in the fall there are smaller surges of growth in the pads. Pad thickness fluctuates widely during this time but since the fluctuation is due in part to water uptake it might be disregarded. However, increased water content is concomitant with an increase in polysaccharides thus the fluctuation in thickness is also a growth response. As the pad thickens the increase in soluble carbohydrates accumulates in the pad and, as the pad becomes thinner the carbohydrates are probably translocated to another location. We should continue to consider all dimensions as significant in terms of growth patterns.

Carbon dioxide and water flux measurements will help to more accurately determine the periods of growth surges. These measurements will also tell what environmental regimes are best suited for growth and which tend to put the cactus in a semidormant state. The ultimate of tying together environment, growth, and water relations of the cacti can only come after a few years of gathering data through fluctuating environmental conditions.

Literature Cited

Patten, D. T. and B. E. Dinger, 1969. CO_2 exchange patterns of cacti from different environments. Ecology 50:686-688.

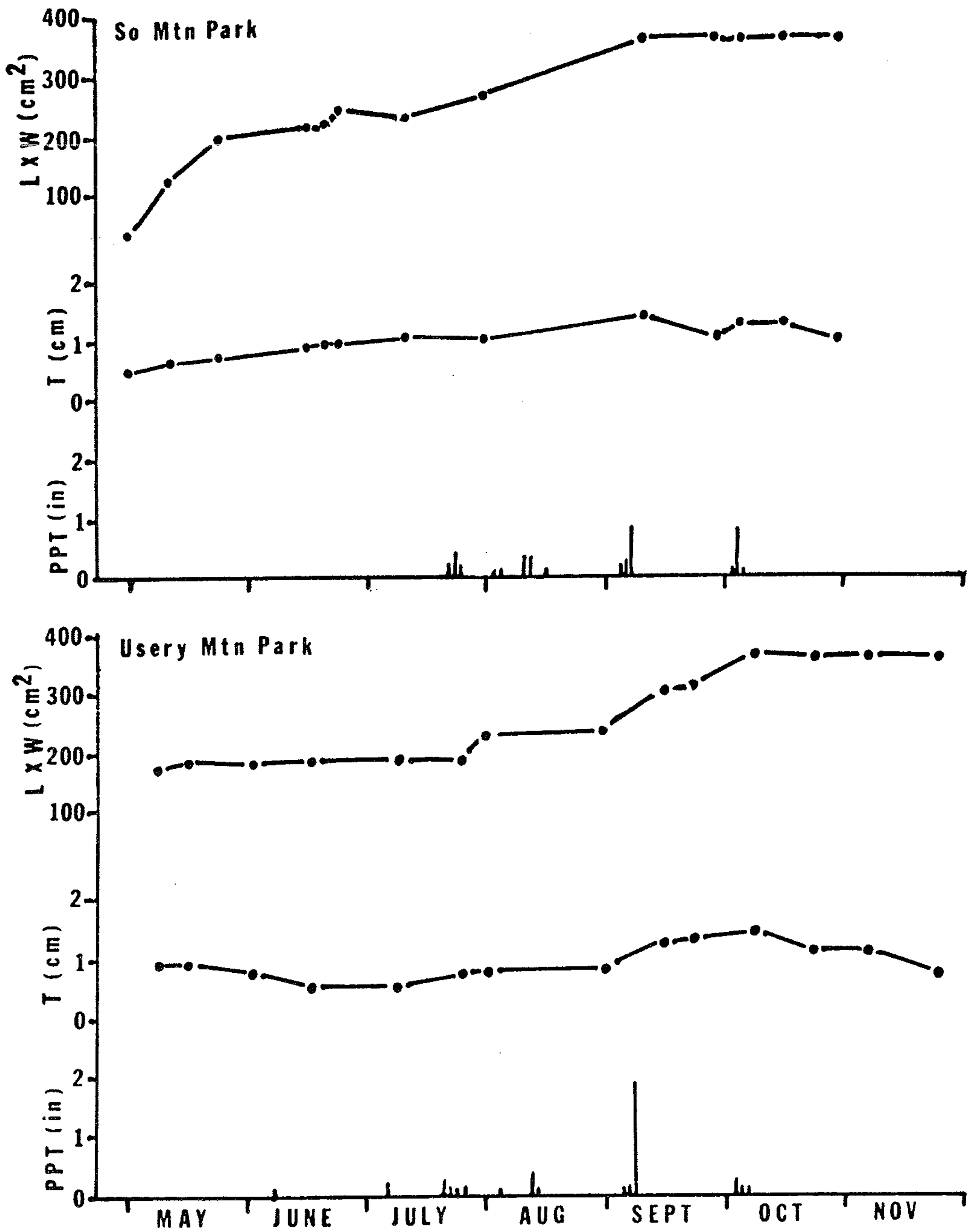

Fig. 3. Growth rates of prickly pear cactus expressed as an average of length times width (L x W) and thickness (T) measurements of pads from cacti at South Mtn. Park and Usery Mtn. Park compared to precipitation (Ppt.)