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Phenology and Function of Sonoran Desert Annuals in Relation to Environmental Changes

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PHENOLOGY AND FUNCTION OF SONORAN DESERT ANNUALS IN RELATION TO ENVIRONMENTAL CHANGES

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ABSTRACT

Annual plants can produce a significant part of the net primary production in the Sonoran Desert. The objectives of this study were to determine productivity rates, total net production and energy conversion efficiency of the desert annuals in relation to different environments of different microhabitats as well as for a total desert community. A site near Cave Creek, Arizona, representative of the upper Sonoran Desert, was selected for this study. Comparisons of two years of data show the significance of rainfall, soil temperatures and the time of growing season initiation on total net primary production. Spatial distribution of shrubs and trees as well as the microenvironments they create also control total community net primary production of annuals. Net production is related to different microhabitats and, using these data and community structure, the net primary production of annuals for the total community is calculated. Great differences in production are shown between the 1972-73 and 1973-74 growing seasons.

INTRODUCTION

Sonoran Desert annual plants are productive only during seasons when temperature, precipitation and other environmental factors are optimal or near optimal for germination and growth. The vagaries of the rainfall and wide fluctuations in temperature create an environment that can be harsh or moderate from season to season or from year to year. The desert annuals can thus become a major source of primary production one year and of little or no consequence to desert productivity another. For this reason, if no other, the productivity of these plants is interesting to study.

Patten and Smith (1973, 1974) and Halvorson and Patten (1975) have shown that the productivity of Sonoran Desert annuals is spatially variable. Differences in microenvironments from interspaces to small shrubs or trees as well as drainage and aspect, all play a role in influencing productivity rates and total biomass accumulation.

Biomass accumulation or net productivity is probably best measured through harvesting techniques, although CO_2 exchange measurements can give an indication of carbon accumulation rates. The correlation between these two methods has not been accurately determined and could lead to a better understanding of primary productivity.

This study of annuals in the Sonoran Desert can be correlated with Desert Biome studies of annuals by Paul Whitson in the Chihuahuan Desert and Lionel Klikoff in the Great Basin Desert, as well as with desert annual studies at the US/IBP Deserb Biome validation sites. These comparisons should show variations in mesic plant productivity (i.e., the desert annuals) between the main deserts of North America.

OBJECTIVES

The main objective of this study is to determine the productivity rates of desert annual plants in the Sonoran Desert in relation to the changing environments of the desert. The secondary objectives that permit a better understanding of primary production of the annuals are 1) measurement of phenological stages of the annual plant species in relation to environmental conditions and biomass accumulation with time, 2) determination of energy efficiency of the annuals in different microenvironments and 3) calculation of total net primary production of Sonoran Desert annuals in relation to other deserts.

METHODS

Field data were collected at the study site near Cave Creek, Arizona, on the abiotic microenvironmental conditions of the habitats where the desert annual plants may or may not occur, and on the development and growth of individual plant species.

Microenvironmental data were measured both in the interspaces (away from trees and shrubs) and in areas influenced by the canopies of trees and shrubs (primarily *Cercidium microphyllum*). The trees and shrubs that were selected for abiotic measurements were not influenced by the shade of other perennials.

The abiotic parameters that have been measured and which are continuing to be measured include: a) solar radiation, in interspaces and under the various shrub and tree species, measured with a Belfort pyrheliometer (DSCODE A3UPB05); b) amount and duration of precipitation measured in the open with a recording raingauge (A3UPB06); c) air temperature (weekly max., min. and mean) at 15 cm under shrubs and 15 cm and 120 cm in the interspaces, measured with hygrothermographs and then calculated from six daily temperatures and relative humidities (A3UPB07); d) air temperature (weekly max., min. and mean) at 1.5 cm in the interspaces and under shrubs measured with Moeller distance recording thermographs and calculated from six daily temperatures (A3UPB08); e) soil temperatures (weekly max., min. and mean) at 1.5- and 7.5-cm depths in the interspaces and under shrubs with Moeller distance thermographs (A3UPB10); and f) soil moisture measured two ways in the interspaces and under shrubs, gravimetrically at 0-3 cm and 6-9 cm (A3UPB11) and with Colman resistance blocks at 1.5, 7.5, 15 and 30 cm (A3UPB12). All of these data are not presented in the results of this report.

Sampling of annuals was also related to shrub canopy and open conditions. Square plots, 2 x 2 dm, were sampled for annual plants in random locations in the open and at specific locations under the shrubs. Depending on the size of the canopy shrub, samples of annuals were taken under as much of the canopy as possible for small shrubs and near the base and just inside the canopy edge for large shrubs such as *Cercidium*. The samples from under the shrub canopies were taken at the north-south aspects for small shrubs and north-south-east-west aspects for *Cercidium*. The plants were separated into species, counted and dried to determine dry weight biomass. The data were grouped as total primary productivity in the open and under shrubs (A3UPB13). Productivity rates were also determined on a seasonal basis.

Calculations were also made of total seasonal primary production of annuals on an area basis through measurement of interspaces and shrub cover and the associated annual plant productivity.

Energy conversion efficiency of different annual plants was calculated through comparison of total cumulated solar energy entering a specific microhabitat and the caloric content of the annual plant community of that microhabitat determined through microbomb calorimetric measurements of representative annual plants.

RESULTS

For purposes of continuity between the 1973 study (Patten and Smith 1974) and this study, comparisons of abiotic and productivity data will be made. Because the primary growing season of the study site is in the winter (October or November through March or April), data comparisons are made for this period and not on a calendar year basis.

Abiotic Environment

Solar Radiation

Figure 1 shows a comparison between cumulative solar radiation for the 1972-73 and 1973-74 growing seasons. The measurements start at different points because the growing seasons were triggered at different times by seasonal rains. Except for the differences in starting points, the curves for solar radiation measurements in the open and under *Cercidium* are basically the same. These data will be used to determine photosynthetic (energy conversion) efficiency of annuals in the two microhabitats; therefore it should be noted that the total cumulative solar radiation was much lower in 1973-74 than in 1972-73 for the "growing season."

Air Temperatures

Air temperatures during the 1972-73 and 1973-74 growing seasons were basically the same for the two habitats presented (Fig. 2). For example, maximum temperatures in March were around 20 C for both years while minimum temperatures in December and January were below 10 C. It must be remembered that the growing season started in October in 1972-73 when maximum temperatures were above 30 C whereas in 1973-74 the growing season started in late November when maximum temperatures were around 20 C. The moderating effect of the tree canopy also shows up consistently between the two seasons, the maximum-minimum ranges being about 5 to 10 C less under the trees than in the open.

Soil Temperatures

Figure 3 represents soil temperatures in the interspaces and under *Cercidium*. Although the graphs for 1972-73 and 1973-74 seem quite similar, 1972-73 shows a generally

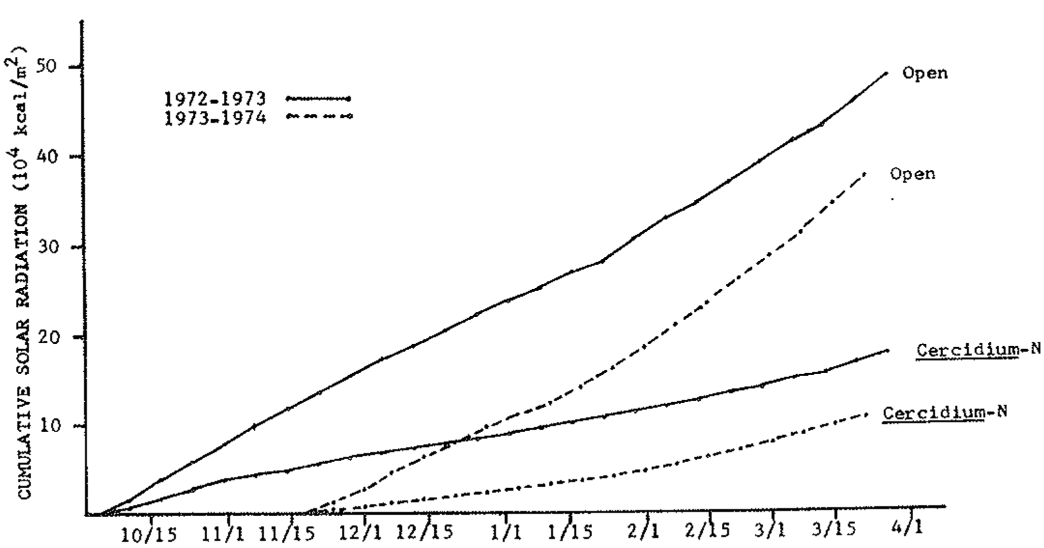


Figure 1. A comparison of cumulative solar radiation in the interspaces and under *Cercidium* for the 1972-73 and 1973-74 growing seasons (A3UPB05).

cooler trend of about 5 to 10 C throughout the growing season. This may be due, in part, to the fact that 1972-73 was a much wetter year and the soil moisture content was also greater for that season.

Precipitation and Soil Moisture

As previously mentioned, 1972-73 was a much wetter growing season than 1973-74 due to the fact that rainfall started earlier, early October as compared to mid-November in 1973-74, and occurred more often in 1972-73 (Fig. 4). As a result, soil moisture remained high or, at least, available during the whole growing season of 1972-73, which was not the case in 1973-74. In either year, soil moisture content reacted dramatically to rainfall and the following drying periods.

Annual Plant Productivity

Related to Microhabitat

The primary production of annual plants, over time, in relation to microhabitats is presented in Figures 5a and b. In addition, these figures indicate the seasonal and maximal productivity "rate" (slope) for the 1972-73 and 1973-74 growing seasons. In all cases 1972-73 was a much more productive year for annuals than was 1973-74. In general, when the microhabitat was more exposed, such as in the open or on the south edge of a *Cercidium* tree, the differences between the two years were not too great; whereas, productivity near the base of the shrubs or trees was much greater throughout the whole growing season in 1972-73 than in 1973-74. Similarities in primary production of annuals can also be noted between the south base of *Cercidium* and either location under *Ambrosia* and the north edge of *Cercidium* and in interspaces.

On a Hectare Basis

All of the annual plant harvesting was done under *Cercidium*, *Ambrosia* and *Larrea*, the three dominant species of the study site as shown in Patten and Smith (1973). The nonduplicated cover for a 1.5-ha study plot of these species, other perennials and interspaces is shown in Table 1.

Based on the actual cover of the shrubs, trees and interspaces (Table 1) and on calculated seasonal productivity of annuals in the various microhabitats, it is possible to determine the productivity of annuals on a time and seasonal basis for an area of desert (Fig. 6). As a result of these determinations the primary production of annuals during 1972-73 is shown to be nearly 10 times that of 1973-74 while the productivity rate on a per-day basis is nearly eight times greater.

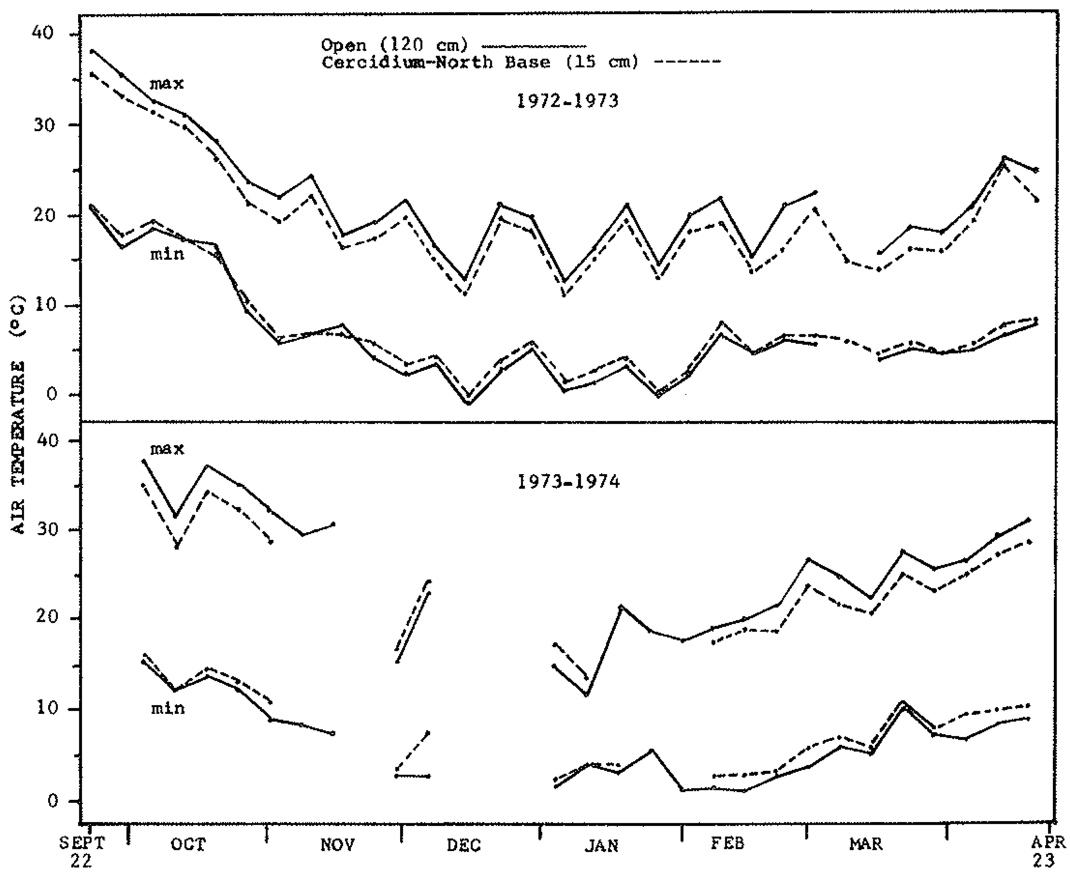


Figure 2. A comparison of mean weekly maximum and minimum air temperatures in the interspaces (120 cm) and under *Cercidium* (15 cm) for the 1972-73 and 1973-74 growing seasons (A3UPB10).

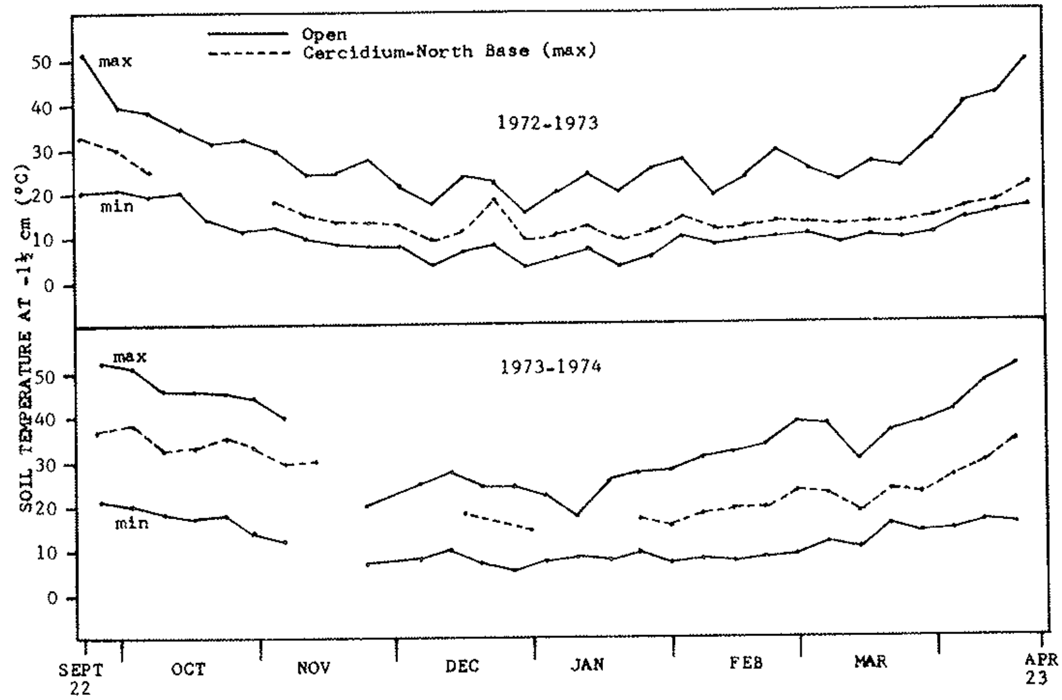


Figure 3. A comparison of mean weekly soil temperatures (1.5 cm) in the interspaces (maximum and minimum) and under *Cercidium* (maximum only) for the 1972-73 and 1973-74 growing seasons (A3UPB10).

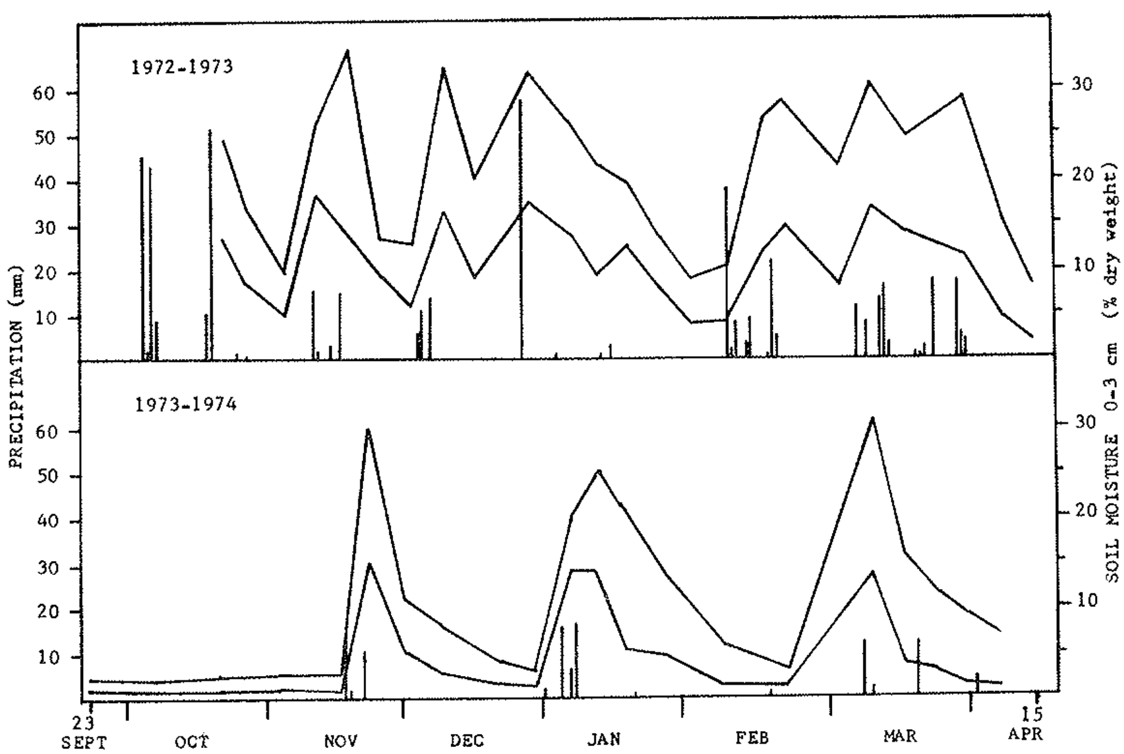
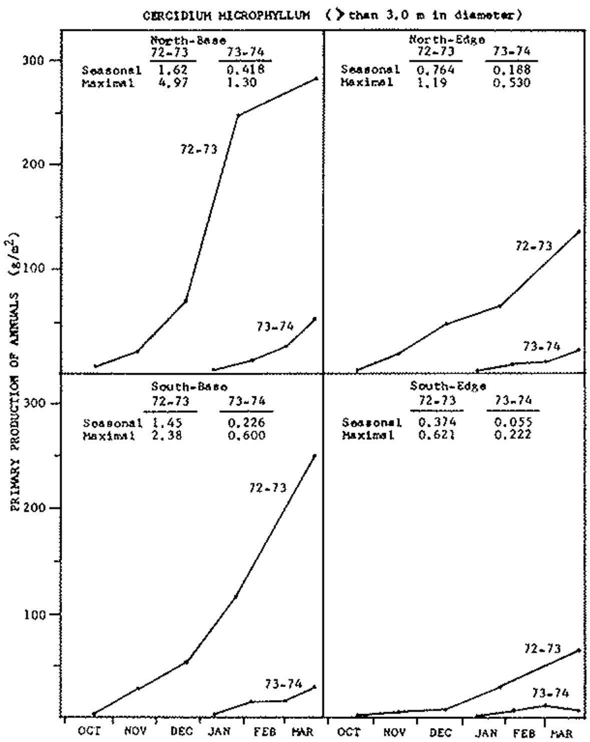


Figure 4. A comparison of precipitation (A3UPB06) and soil moisture (0-3 cm) (A3UPB11) in the interspaces for the 1972-73 and 1973-74 growing seasons.

5a



5b

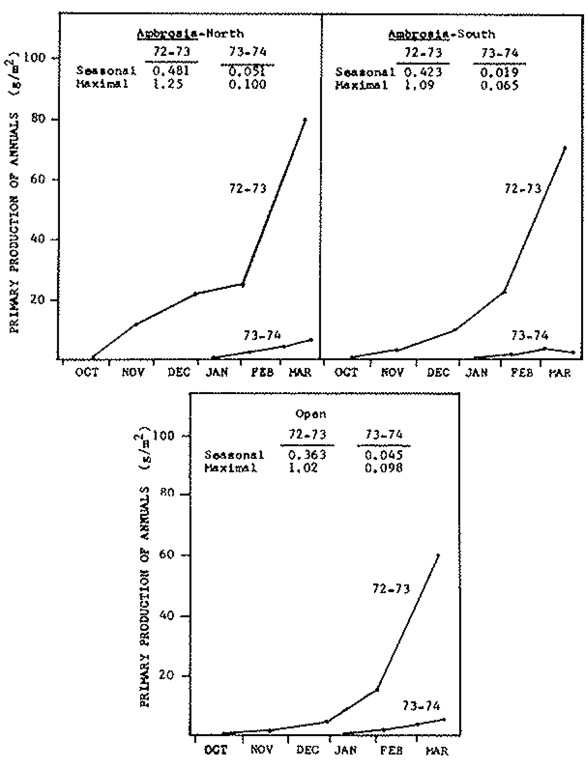


Figure 5. A comparison of primary production of annuals and seasonal and maximal "rates" of productivity at (a) various aspects under the canopy of *Cercidium* and (b) aspects under the canopy of *Ambrosia* and in the interspaces for the 1972-73 and 1973-74 growing seasons (A3UPB13).

Table 1. Nonduplicated cover for 1.5-ha study area

Species	Cover (m^2)	Percent of area
Cercidium microphyllum (< 3 m diam)	2,384	15.9
Cercidium microphyllum (> 3 m diam)	640	4.3
Larrea tridentata	2,060	13.7
Ambrosia deltoidea	1,950	13.0
Other perennials	733	4.9
Interspace	7,233	48.2
Total	15,000	100.0

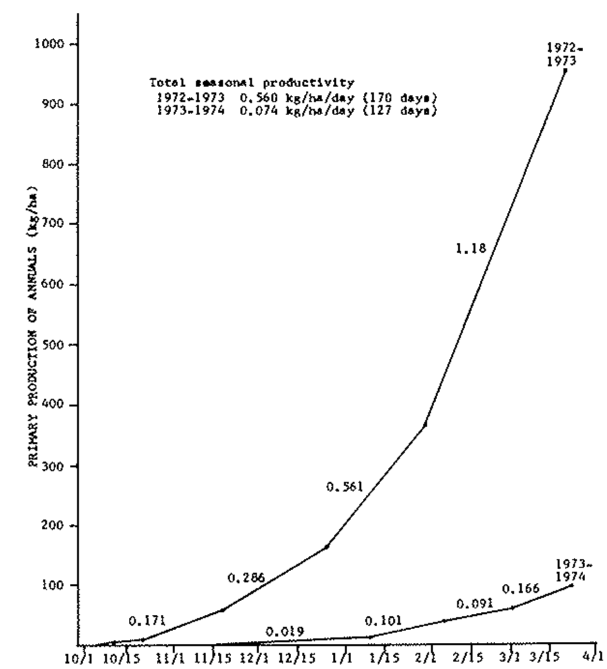


Figure 6. A comparison of primary production of annuals over time and total seasonal production showing productivity "rates" between each sampling date for the total study site community for the 1972-73 and 1973-74 growing seasons.

Comparison of Net Primary Production Between Deserts

Using Figure 1 from Norton (1974) as a pattern, a comparison of net primary production of annuals on a kg/ha basis can be made among the three major deserts of North America (Fig. 7). The data for the Sonoran Desert are based on this study. In all cases, differences in primary production are closely correlated with precipitation during the growing season; however, in the Great Basin Desert (cool desert), there is more net primary production of annuals in relation to amounts of rainfall than in the hot deserts (Mohave, Sonoran).

In the Sonoran Desert, the small amount of rainfall in 1972 (actually 1971-72) was not enough for any annual plant growth while a small increase in rainfall in 1974 (1973-74) stimulated some annual plant production. A similar relationship can be seen in the Mohave Desert but, although the amounts of rainfall are equivalent between Mohave-1972 and Sonoran-1974, the annual plant production in the Sonoran Desert is greater.

Photosynthetic Efficiency (Solar Energy Conversion) of Annuals

As shown in Figure 1, the amount of solar radiation available to plants under *Cercidium* is much less than in the open. However, comparison of net primary production shows the microhabitat under the trees to be more productive. The caloric content of the annual plant stands under the trees and in the interspaces, when compared with the total available solar energy, determines the efficiency of the plant community to convert solar radiation. Because of less primary production and higher solar energy input the open habitat is much lower in efficiency than the microhabitats under the trees (Table 2). During periods of rapid growth during a good growing season, efficiency under the trees is as high as 5%, while efficiency remains well below 1% in the interspaces.

DISCUSSION

A comparison of two or three years of microenvironmental data and net primary production of Sonoran Desert annuals shows the critical nature by which the variabilities of the environment drastically influence the availability of plant food sources for the consumers in the desert. Although precipitation can be singled out as probably the most important factor, temperature plays a more important role in total production of annuals during one growing season than imagined.

The 1972-73 growing season was the most productive of the three seasons studied. A comparison of the precipitation data would immediately cause one to say that the early October rains and continual seasonal rains were the reason; however, following the October rains the soil temperatures dropped, reducing evaporation and water loss. The cooler soil temperatures also probably reduced the heat load on the young annual plants.

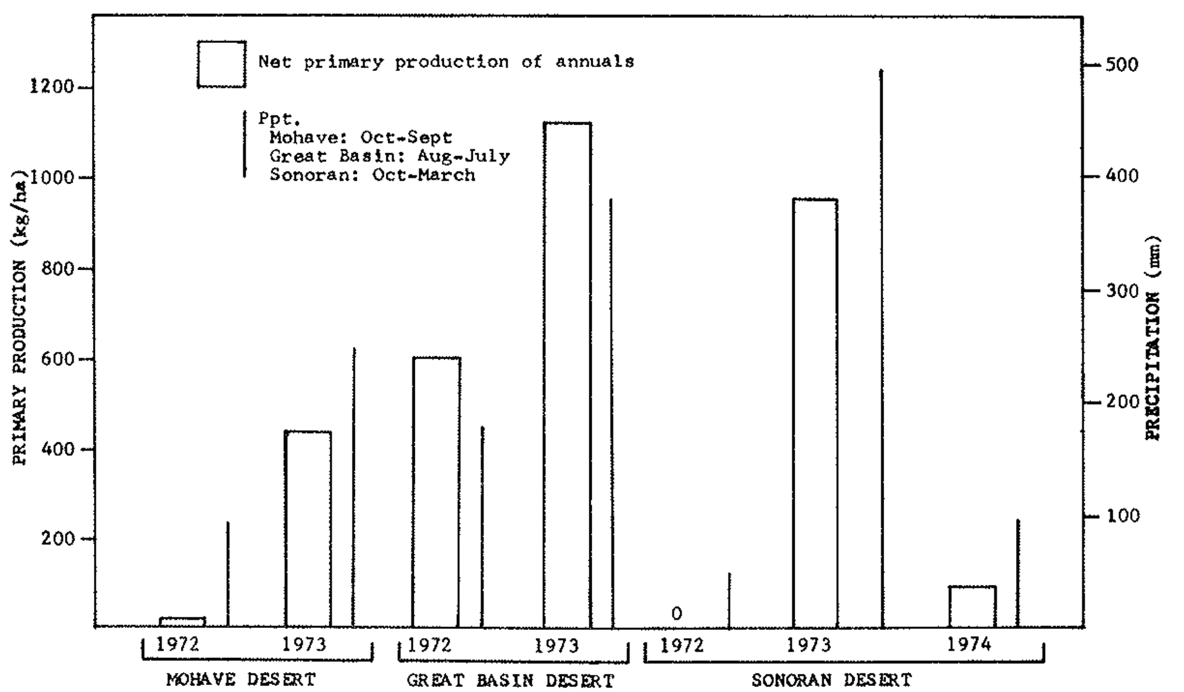


Figure 7. A comparison of primary production of annuals for different growing seasons for three desert sites in relation to precipitation. Data for the Mohave and Great Basin Deserts are from Norton (1974) and for the Sonoran Desert from this study.

Table 2. Efficiency of above-ground net primary production of a Sonoran Desert annual plant community

Time period	% Efficiency		
	Entire study area	Open	*Cercidium*-N-Base
1972-1973			
Nov. 4 - Dec. 22	0.062	0.019	0.68
Dec. 23 - Jan. 27	0.19	0.11	5.03
Jan. 28 - Mar. 25	0.32	0.30	0.34
Entire growing season	0.17	0.12	1.28
1973-1974			
Nov. 17 - Jan. 10	0.0070	0.0052	0.072
Jan. 11 - Feb. 6	0.030	0.013	0.385
Feb. 7 - Mar. 2	0.022	0.016	0.389
Mar. 3 - Mar 23	0.031	0.020	0.80
Entire growing season	0.021	0.013	0.39

The 1974 report (Patten and Smith 1974) showed how certain species responded to different microenvironments in terms of net primary production. This report explains this differential, in part, through a comparison of the energy conversion efficiency of the annual plant communities in the different environments, the shaded environment having the most efficient conversion rates. There is no question that the energy conversion efficiency, solar energy to stored plant energy, is greatly influenced by the microenvironmental controls as much as by the physiological makeup of the annual plant species.

Differences in community net primary production of desert annuals are probably a result of a few major factors. These include precipitation and the resultant available moisture, temperature variations in the air, but probably more importantly in the soil, and the density and spatial distribution of shrubs and trees which create favorable microenvironments for annual plant growth.

EXPECTATIONS

Desert annual plants have been shown to be excellent subjects to determine the effects of desert microenvironmental extremes on the growth and functioning of a desert organism. The plants are short lived and respond relatively quickly to environmental changes. In order to understand these changes and to relate the net primary production of the annuals, as measured in the field, to their physiological responses to environment, this project changed course in the latter part of 1974 and will continue on this path in 1975.

Carbon dioxide exchange rates have been measured extensively on some of the desert plants and reported in various process studies in the Desert Biome. This study has also had a limited amount of gas exchange measurements included in it. It is difficult, however, to relate the gas exchange measurements to the net primary production measured in the field. Thus, this study will try to closely correlate, under controlled laboratory conditions, the gas exchange rates of annual plants to net primary production. This expected correlation should allow a more thorough understanding of the variations in physiological responses of the annuals to the different environments that produce the measurable standing crop (net primary production) in the field. This correlation should also be applicable to other studies of herbaceous and possibly shrubby plants where gas exchange is the prime measurement and net primary production is an unknown but desired quantity.

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