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The Distribution of ORCUTTIA CALIFORNICA (Poaceae) in the Vernal Pools of the Santa Rosa Plateau, Riverside County, California

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Abstract

THE DISTRIBUTION OF *ORCUTTIA CALIFORNICA* (POACEAE) IN THE VERNAL POOLS OF THE SANTA ROSA PLATEAU RIVERSIDE COUNTY, CALIFORNIA

by Cluney M. Stagg

Ecological studies were conducted on the rare annual grass *Orcuttia californica* (Vasey), an endemic to California, from April to September, 1976 in 11 vernal pools located on the Santa Rosa Plateau in Riverside County. To help determine why Orcutt grass occurs in only 6 of the 11 pools and more specifically why it only occurs in patches within a given pool, biweekly measurements of frequency, density and phenology were taken within each of a total of 28 circular plots (r = 10 meters) in 5 pools. This data was related to concurrent biweekly measurements of soil moisture, soil texture and microrelief of each plot, area and order of desiccation of each pool. Frequency and density show no correlation to soil moisture, soil texture, and area. There is, however, a positive correlation between occurence of the study species and the (1) order in which the pools become desiccated; and (2) average depth of plot. This is probably related to the germination requirement of the seeds having to be submerged for a minimum amount of time. Also under different soil moisture conditions there seem to be differences in the time sequences of the phenological events.

LOMA LINDA UNIVERSITY

Graduate School

THE DISTRIBUTION OF *ORCUTTIA CALIFORNICA* (POACEAE) IN THE VERNAL POOLS OF THE SANTA ROSA PLATEAU, RIVERSIDE COUNTY, CALIFORNIA

by

Cluney M. Stagg

A Thesis in Partial Fulfillment
of the Requirements for the Degree
Master of Arts in the Field of Biology

May 1977

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Arts.

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INTRODUCTION

The geographical area that is enclosed within the political boundaries of the state of California is well known for its diversity of habitats, and its consequent diversity of species including many precinctive plant species. Numerous factors have interacted to create these varied habitats, with soil conditions and local topography being two important determinants in the formation of the vernal pool ephemeral habitat (Stebbins, 1976; Thorne, 1976). The vernal pools are the habitat for many of these precinctive species. Although relatively common in the California Central Valley, the only areas known to still have vernal pools in southern California are Kearney (Miramar) and Otay Mesas in San Diego County (Purer, 1939; Witham, 1971, 1973; Nadolski, 1974) and Mesas de Colorado, Burro, and la Punta on the Santa Rosa Plateau in western Riverside County (Lathrop and Thorne, 1968, 1976a, 1976b; Thorne and Lathrop, 1969, 1970; Kopecko and Lathrop, 1975; Collie and Lathrop, 1976; Lathrop, 1976). The eleven pools on these two mesas range in size from 0.25 to 10.16 ha (Lathrop and Thorne, 1976a). The soil of the mesas is Murrieta stony clay loam, which ranges in depth from 22 to 50 cm over the Pleistocene, olivine basalt bedrock (Lathrop and Thorne, 1976a).

Included in the 1974 Report on Endangered and Threatened Plant Species of the United States by the Smithsonian Institution is the annual grass Orcuttia californica Vasey (Poaceae), one of the rarest and more interesting of the California vernal pool species (Shevock, 1976). The genus includes six species and two subspecies; six of these taxa occur only in the vernal pools of the Central Valley (Griggs, 1976a). *Orcuttia* appears not to be related to any other members of the Poaceae except another vernal pool grass - *Neostapfia* (Griggs, 1976a), which has been included with it in the tribe Orcuttieae (Reeder, 1965). Stebbins indicates that the two genera are ancient genera or else relicts from other ancient genera that are now extinct. The representative of the genus *Orcuttia* that is present in the Riverside County vernal pools is *Orcuttia californica* var. *californica*, and it is limited to the southern California vernal pools.

Orcuttia californica (Orcutt grass) occurs on the dry and drying bottoms of vernal pools usually, and occasionally grows in standing water which inundates the bottom of a pool (Crampton, 1959; Munz, 1974). In the latter case the plants are generally larger. A more complete discussion of the life history strategies and development of *Orcuttia* is available (Griggs, 1976a). Orcutt grass at maturity can range from 5-25 culms. Except in the deepest pools where the species occurs in the center, Orcutt grass most often occurs around the edge of a vernal pool; if it occurs toward the center it is sparsely distributed. *O. californica* occurs in two of the five pools on Mesa de Colorado and in four of the six on Mesa de Burro.

Up until the time of this study no results have been reported on the field ecology of Orcutt grass. The purpose of the study reported here was to evaluate some of the factors that might have an effect on the distribution and occurrence of the study species in its natural habitat. It has an unusual distribution as mentioned above -- occuring in only six of the eleven pools, and not uniformly within any pool it occurs (Moran, 1969). The research was conducted in the field from April 8 until September 23, 1976. For the 1976 rainy season (September 1975 to April 1976), the total rainfall reported for the Loma Linda University weather station VMC located on Mesa de Colorado, and lying 4 km to the southwest of Mesa de Burro, was 33 cm (Lathrop and Thorne, 1976a).

Some pertinent questions relative to the problem are:

(1) Why does Orcuttia californica occur in some vernal pools on the Santa Rosa Plateau but not in similiar pools located in the same area?

(2) More specifically, why does it occur only in some areas of the same pool?

(3) At all sites where O. californica occurs, is the phenology similiar?

(4) At all sites where it occurs, is the frequency-density similiar?

(5) Is there any relationship between occurrence, frequency, density, phenology and certain physionomic parameters?

The following pages report the results of an attempt to answer these questions.

PROCEDURES

Beginning on April 8, 1976 all pools on both Mesas de Colorado and Burro were observed and periodic water depth measurements were made so as to give the order of desiccation for each pool. In May of 1976, after consultation with a biostatistician, five pools were chosen for further quantitative study. An experimental design incorporating the use of circular plots was devised. Seven plots were laid down in each of three pools, named Mesa de Colorado Nos. 1, 5 and 4 - a total of twenty-one plots (Figs. 1 and 2a-c). The plots were r = 10 m. The plots were arbitrarily laid out in areas where the species grew the year before, and also in areas where it had not occured the previous season. Drawing from the experience gained from working with the twenty-one plots on Mesa de Colorado, it was decided that r = 5 m plots might yield more meaningful results; therefore when seven additional plots were laid down on August 7 that radius was used. The seven plots were laid down on Mesa de Burro with four plots in Mesa de Burro No. 1 and three plots in Mesa de Burro No. 2 (Figs. 1 and 2d, e). The plots were numbered consecutively from one through twenty-eight in pools Mesa de Colorado Nos. 1, 5, 4 and Mesa de Burro Nos. 1 and 2 (Figs, 2a-e).

Biweekly (approximately) soil samples were taken at 15 and 30 cm depth increments from the center of each plot, from May 20 to July 16 on Mesa de Colorado and from August 5 to September 23 on Mesa de Burro. While the ground was still soft an open sided hand corer was used to extract the samples, but once the ground became hard a King soil tube was used. Soil samples were taken before there was any evidence of Orcutt grass and continued until the population was completely decadent. The soil samples were then brought back to the lab and soil moisture percentage determined by the oven-dry weight method (Gates, 1949). The soils were then stored for further analysis.

Concurrent with the soil moisture sampling, frequency, density and phenology of <u>Orcuttia californica</u> were measured in each of the pool plots, using a 183 x 30 cm quadrat frame divided into ninety-six 7.5 cm^2 divisions (Nord, 1965). The frame was positioned randomly eight times in each plot biweekly (approximately) from May 20 to July 16 for plots 1-21 and from August 5 to September 23 for plots 22-28. Frequency and density were calculated using the standard method (Cox, 1974). Phenological stages of the grass were recorded in twelve randomly selected 7.5 cm^2 divisions in each quadrat frame. The phenological stages recorded were: 1) vegetative -- from the time of sprouting until flowering; 2) flowering -- from the time the stamens were obvious until they had disappeared; 3) fruiting -- from the time of the loss of the stamens until the plants were decadent; 4) decadent -- no chlorophyll, golden-brown, brittle. The population of a plot was considered decadent when 75% were in stage 4.

After the vegetation was dead in the fall, and while the pools were still dry, they were surveyed by the alidade to give the exact boundaries of each pool, as well as to provide microrelief data (Compton, 1962). Depth changes were measured and recorded to the nearest 0.3 cm at 5 m intervals, from the center of the pool through the center of each plot and through to the edge of the pool (Figs. 2a-e). Area of the pools used in analysis was determined in a previous study (Lathrop, 1976).

Soil moisture retention curves were derived by the standard gravimetric method using the Soiltest Ceramic Plate Extractor and the Soiltest Pressure Membrane Extractor for the purpose of converting percent soil moisture to bars of soil tension (Reitemeier and Richards, 1944; Richards, 1947, 1948). The retention curves were produced for each pool based on a composite of soil from each plot in that pool at 15 and 30 cm increments. An individual retention curve was produced in one instance for an obviously distinct area within a pool (Figs, 3a-f).

Soil texture for each plot at both sampling increments was determined using the Bouyoucous method (Cox, 1974).

RESULTS

In looking at the order of desiccation of the eleven pools on Mesa de Colorado and Mesa de Burro, Orcutt grass was present in only one of the first five to become dry, but was present in five of the last six to undergo desiccation (Tables 1 and 2). It should be noted in connection with this that the frequency of Orcuttia californica in the last five pools to desiccate ranges from five to eleven times greater than the frequency of Orcutt grass in the single pool of the first group (Table 2). Although not conclusive, it seems apparent that there is a noticeable trend with regards to the relationship between the order of desiccation of a pool and the presence and abundance of Orcutt grass growing in it.

When we compare pool area with the frequency of Orcutt grass in the pool there seems to be no correlation. For example, one pool of 0.25 ha does not have any Orcutt grass, another pool of 0.25 ha has a frequency of 4.5%, while a pool of 0.54 ha has a frequency of 40% (Table 2). The largest pool of 10.16 ha does not contain the species but the next largest of 2.32 ha has a frequency of 44% (Table 2). When a regression-correlation analysis is run relating these two variables there is a negative correlation with a correlation coefficient of -0.21.

Within pools and between pools there is no significant difference in the moisture tension between plots that have Orcutt grass and those plots that do not have Orcutt grass (Table 3). In fact there is very little difference in the soil moisture tensions on the same sampling date between any plots in any pool, except in the case of pools Mesa de Burro Nos. 1 and 2. There is a relatively significant difference in soil moisture tensions however, between plots 26 and 27 in pool Mesa de Burro No. 2 and the remaining plots in pools Mesa de Burro Nos. 1 and 2, on comparable sampling dates. This difference does not, however, correlate to the frequency or density of Orcutt grass in those plots (Table 3). It should be noted though, that even though Mesa de Colorado Nos. 1, 5, and 4 have approximately the same soil moisture tensions from May 20 onward, it is more than likely that No. 4 reached that point (on May 20) earlier than Nos. 1 or 5 because it has a different soil moisture retention curve (Figs. 3a-d). Upon observation of the soil moisture retention curves for those three pools it is evident that Nos. 1 and 5 have a much better capacity for holding water at lower bars of suction than pool No. 4, but are approximately equal in this regard around the 15-bar range (Figs. 3a-d).

Although soil moisture tension is not apparently related to occurrence, frequency or density of Orcutt grass it does show some observable effects on the phenology of that species. Plots 3, 4, 8 and 10 have a very simiiliar phenology scheme, although plots 8 and 10 appear to be about two weeks ahead of plots 3 and 4. Plots 8 and 10 have >75% of the total number of plants in flower by June 16, but plots 3 and 4 do not reach that level of flowering until July 4, more than two weeks later. As a result, plots 8 and 10 are able to put about two or three times as many plants in fruit before the high soil moisture tension makes it impossible for the plant to remain alive (Figs, 4a-d). This may have some implications as to why two pools (Nos. 1 and 5), with such similiar soil moisture characteristics, would have such a difference in frequency and density of the same species. When we look at the soil moisture and phenology data for plots 22 and 23 from Mesa de Burro No. 1 and plots 26 and 18 from Mesa de Burro No. 2 we find that there is quite a difference from plots 3, 4, 8 and 10.

In plots 22, 23, 26 and 28 the grass had completed its vegetative stage, when collection of data began. Plot 22 on our first data point has a soil moisture tension of 6.5 bars (at 15 centimeters), implying that the soil is still relatively moist. One hundred percent of the plants were in flower then and were still in flower one week later. One week later than that however, when the soil moisture tension had been beyond 15.5 bars for at least a week, flowering had dropped off to 82% and 18% were decadent. Two weeks later when the soil moisture tension had reached 27 bars, 100% of the plants were decadent without having gone through the fruiting stage (Figs. 4e, f). Plot 23 was beyond the 15-bar soil moisture tension when data was first collected. Already 53% of the plants were decadent, but apparently the plot had a more uniform rise in the soil moisture tension as 44% of the plants were in the fruiting stage with only 3% in flower. The bars of tension continued rising gradually and the percent of decadent plants rose gradually with it, while the percentage of plants in fruit dropped off slowly. It is significant that plot 23 with its high bars of tension initially was several weeks ahead of plot 22 in its reproductive stages, plot 22 staying considerably more moist much longer (Figs. 4e, f).

In plot 25, which stayed near field capacity for the duration of the study, a majority of plants were in flower during the first two weeks but then with the soil moisture unchanged, the flowering dropped off to 12% and the fruiting rose to 51%. How it would have continued can only be postulated at this time since there was a heavy rainstorm the following week that inundated the entire plot for the next several weeks. Plot 28, which had a soil moisture tension of 34 bars at the time measurements began, had already 83% of the study species decadent, with 14% in flower and only 8% maturing to the fruiting stage. By the fourth week of observations, Orcutt grass was 100% decadent in plot 28 (Figs. 4g, h).

The analysis of soil texture (Table 4) shows that the majority of plots (24 out of 28) fall into the range of 50 to 70% clay content of their soil. The exceptions are plots 26, 27, and 28 of Mesa de Burro No. 2 which have soils that average about 50% sand and only about 20% clay. Clay soils retain water better than sandy soils (Meyer, et al, 1973). There is no correlation between soil texture of a plot and the occurrence, frequency or density of Orcutt grass within that plot (Table 4).

Of all the data collected in connection with this study, the one variable that seems most promising in answering the questions posed in the introduction, is the average depth of a plot computed from the maximum measured height at the edge of a pool to the depth at the center of that plot. This would give the relative depths of pools and plots within pools. Qualitatively this can be seen by observing the microrelief profiles through each plot and comparing with the frequency and density for that plot (Figs. 5a-f). However this information was tested quantitatively. The average literal depth of each plot was obtained by integration and a regression-correlation analysis of it was run against the frequency and density for that plot (Table 5). When this latter approach was used a correlation coefficient of 0.65 was obtained for the twenty-one plots on Mesa de Colorado for average depth versus frequency. This is significant at the 99% level. For the same two variables, the 28 plot total correlation coefficient was 0.34, 0.36 being the minimum correlation coefficient for significance at the 95% level. Average depth and density showed no significant relationship.

DISCUSSION

In the greenhouse, Orcuttia californica requires two to four weeks submergence under water at 50 to 60°F in order to germinate (Griggs, 1976b). It is not surprising therefore to find that in the field those pools that hold water the longest are the pools that first contain the study species, and have it at relatively high frequencies (Tables 1, 2). By the same reasoning it is evident that within a pool the areas that have the deepest depression, i.e., hold water the longest, are the areas that have Orcutt grass. This is true in almost every case on Mesa de Colorado and to a lesser extent on Mesa de Burro.

However, frequency measurements for plots 22 and 26 (Table 4) may be somewhat misleading -- Orcutt grass in those plots were larger, implying that the dominance of one of the larger plants is equal to the dominance of several of the small plants. It is concluded therefore, that all things considered, the depth of a pool and/or its ability to hold water are important determinants as to whether or not that pool will be a habitat suitable for Orcutt grass.

The data derived from the soil texture analysis indicated that soil texture was not related to the occurrence or distribution of _Orcuttia californica_. The information might have been more meaningful if there had been a wider range of textures, especially more variation in the clay content, but as it occured all of the soils with the exception of the soils of plots 26, 27 and 28 can be classified as high clay soils. The effect of a high sand soil on the occurrence of Orcutt grass could possibly have been derived from those plots had they not been in the deepest pool, with plot 26 being 1.6 meters deep. Its inability to retain water optimally because of its sandy soil was offset by its having standing water in it up until at least the middle of June -- with Orcutt grass already growing under the water. In a shallow pool with the soil texture similarly sandy, results may have been different. It is interesting to note that Mesa de Colorado No. 4 (even though it has a high clay soil) has approximately the same soil moisture retention curve as Mesa de Burro No. 2, but it is much shallower -- it does not contain _Orcuttia californica_ (Figs. 3d, f).

The phenological data would seem to suggest that soil moisture provides a cue for the initiation of the events in the life cycle of Orcutt grass; it is not entirely controlled by hours of daylight, temperature, etc.(Griggs, 1976b). The plots on Mesa de Colorado are not evidence for this but the plots on Mesa de Burro are. For example the two plots (22 and 26) that remained moist for several weeks after measurements began were still 75 to 100% in the flowering stage for the first couple data points. Just a few meters away in both pools the plots 23 and 28 which were already beyond the generally accepted permanent wilting point of 15 bars had by then gone through its flowering stage, and had 45% and 10% respectively in fruit at this time. Plants in plot 26 did not cease flowering or fruiting until four weeks later while the soil was still very moist. Just exactly how a mechanism of this sort works remains to be seen; that and other problems are being pursued in the laboratory and greenhouse in the life history strategy research of Tom Griggs at the University of California, Davis. Nevertheless there appears to be sufficient field data to indicate that soil moisture is a cue for each of the phenological events of Orcutt grass.

In conclusion therefore, of the parameters measured by the author, it would seem apparent that the capacity of a pool to retain water, either by its high clay soils or its depth or a combination of both is the parameter most likely to affect the occurrence and distribution of _Orcuttia californica_. Except as soil texture is related to this it does not appear to be of any consequence. Orcutt grass may have a sophisticated internal control system for its life cycle stages; the data suggests that this system is partially controlled by soil moisture tensions. One thing not mentioned thus far but which deserves mention is that several times in the author's field notes there are observations commenting that the plots that are devoid of Orcutt grass are often densely populated with other vernal pool species, especially _Eryngium_ and _Eleocharis_ (spike-rush). This suggests that competition from other vernal pool species is a significant factor in the distribution of Orcutt grass.

Fig. 1. Map showing the location of vernal pools on Mesa de Colorado (top inset) and Mesa de Burro with pools numbered. Modified from Lathrop (1976).

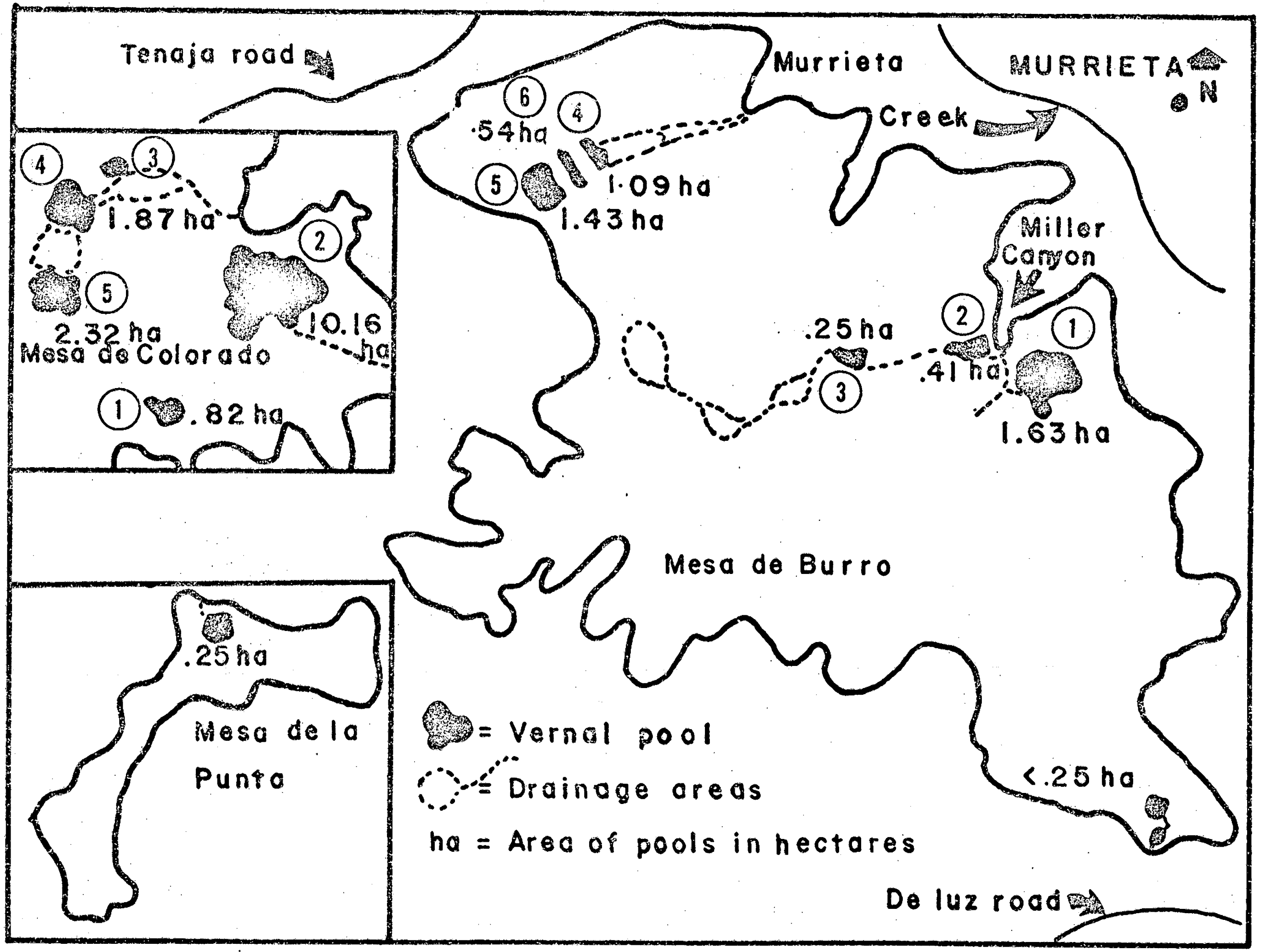
Tenaja road
MURRIETA
N
Murrieta
Creek
Miller
Canyon
⑥
.54 ha
④
⑤
1.09 ha
1.43 ha
.25 ha
②
①
.41 ha
③
1.63 ha
④
③
1.87 ha
②
⑤
2.32 ha
10.16 ha
Mesa de Colorado
①
.82 ha
Mesa de Burro
.25 ha
Mesa de la Punta
= Vernal pool
= Drainage areas
ha = Area of pools in hectares
<.25 ha
De luz road

Fig. 2a. Map showing location of study plots (numbered circles), drainage area (----) and direction of profile transects (— — — —) in pool Mesa de Colorado No. 1. The dotted line (....) separates significant topographic units within the pool.

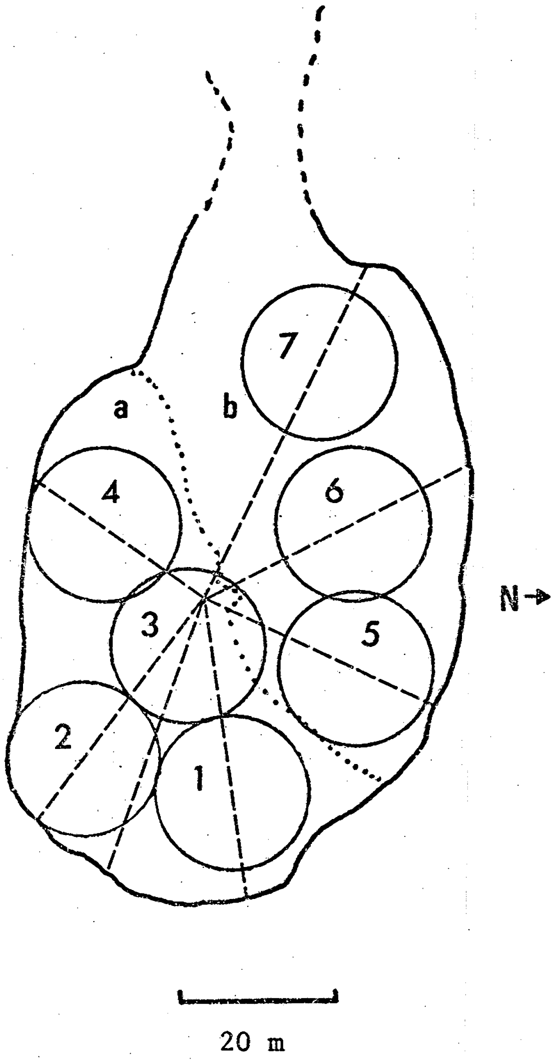
7
a
b
4
6
N →
3
5
2
1
20 m

Fig. 2b. Map showing location of study plots (numbered circles) drainage area (----) and direction of profile transects (— — — —) in pool Mesa de Colorado No. 5.

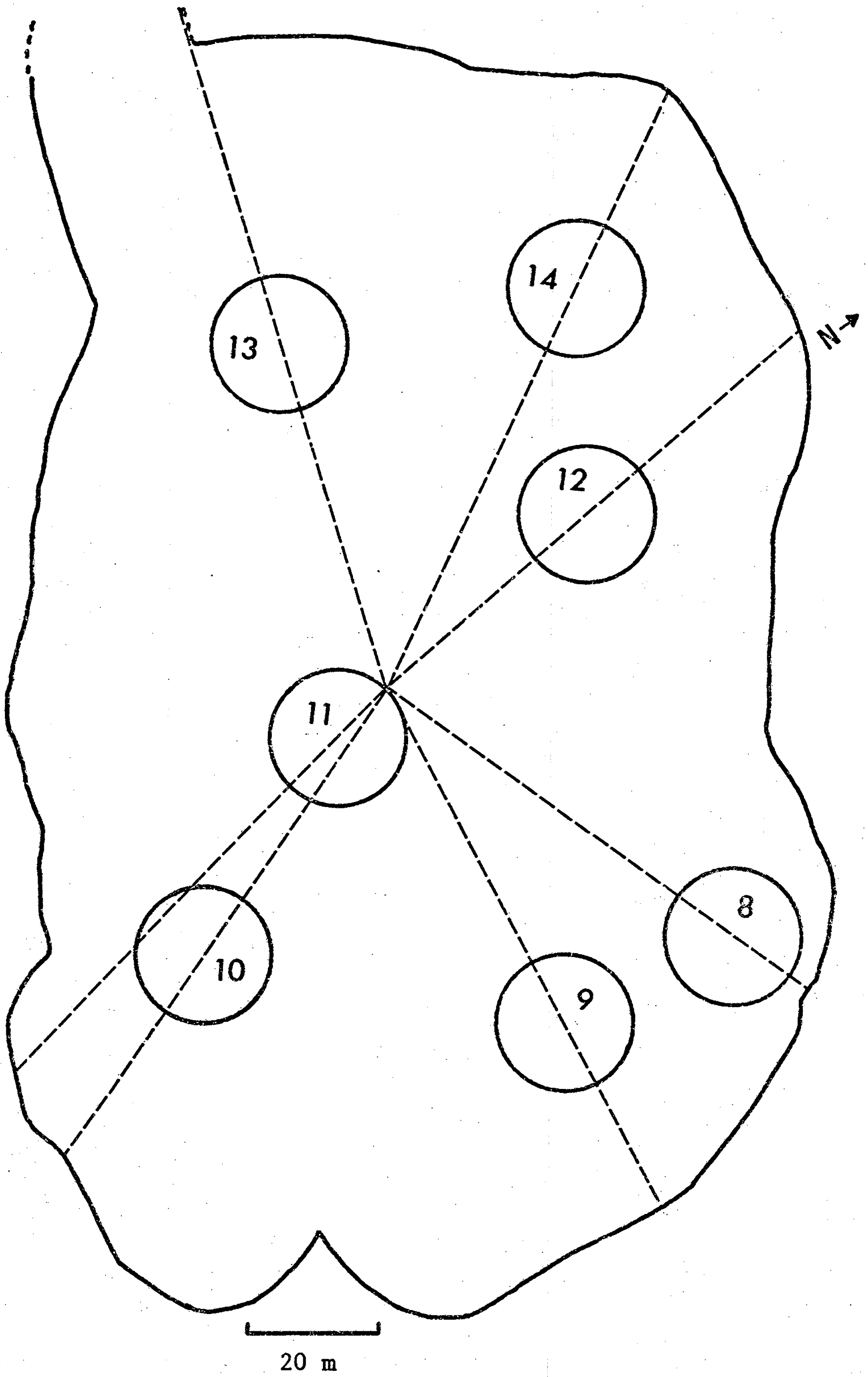
14
13
N
12
11
8
10
9
20 m

Fig. 2c. Map showing location of study plots (numbered circles), drainage area (----) and direction of profile transects (– – – –) in pool Mesa de Colorado No. 4.

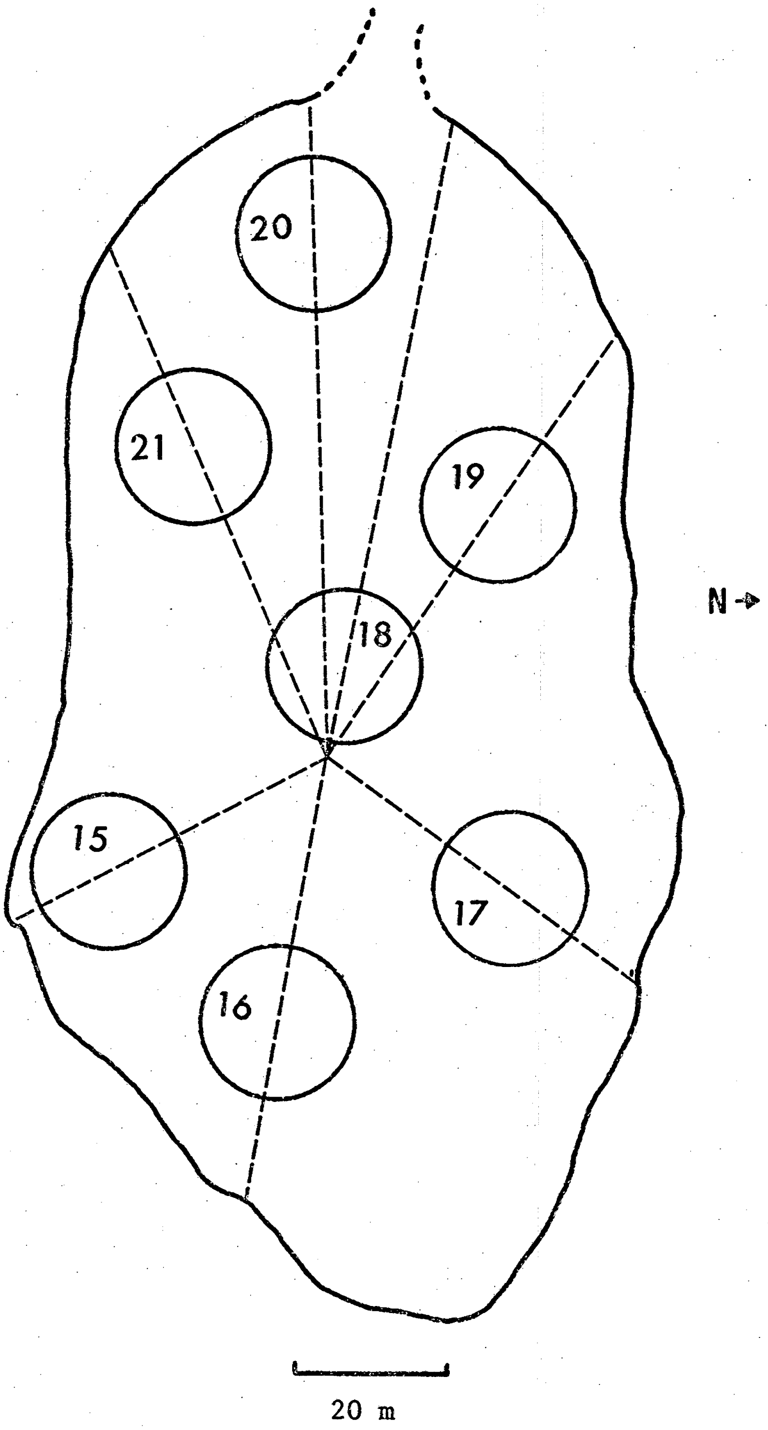
20
21
19
18
N →
15
17
16
20 m

Fig. 2d. Map showing location of study plots (numbered circles) and direction of profile transects (— — — —) in pool Mesa de Burro No. 1. The dotted line (....) separates significant topographic units within the pool.

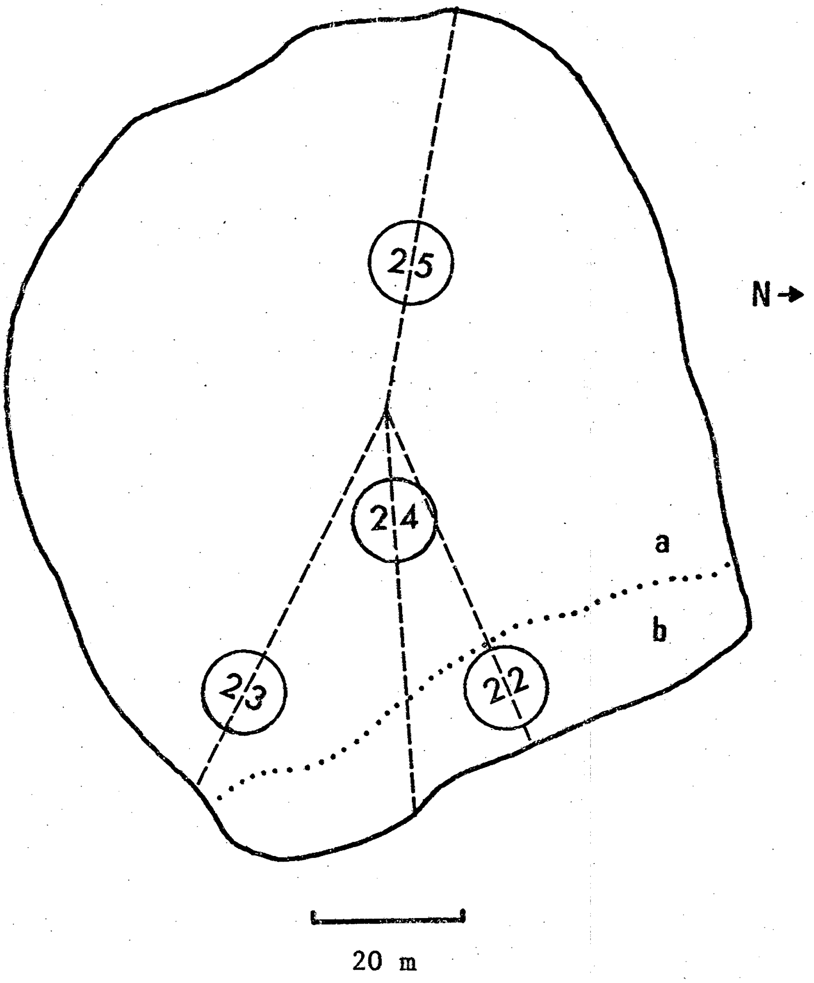
25
24
23
22
a
b
N
20 m

Fig. 2e. Map showing location of study plots (numbered circles) drainage area (----) and direction of profile transects (— — — —) in pool Mesa de Burro No. 2.

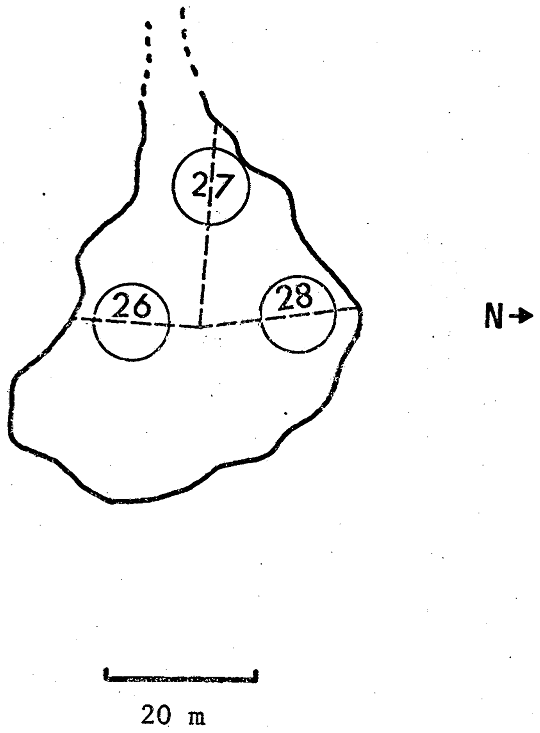
27
26
28
N→
20 m

Fig. 3a. Soil moisture retention curve for plots 1-4 in Mesa de Colorado No. 1.

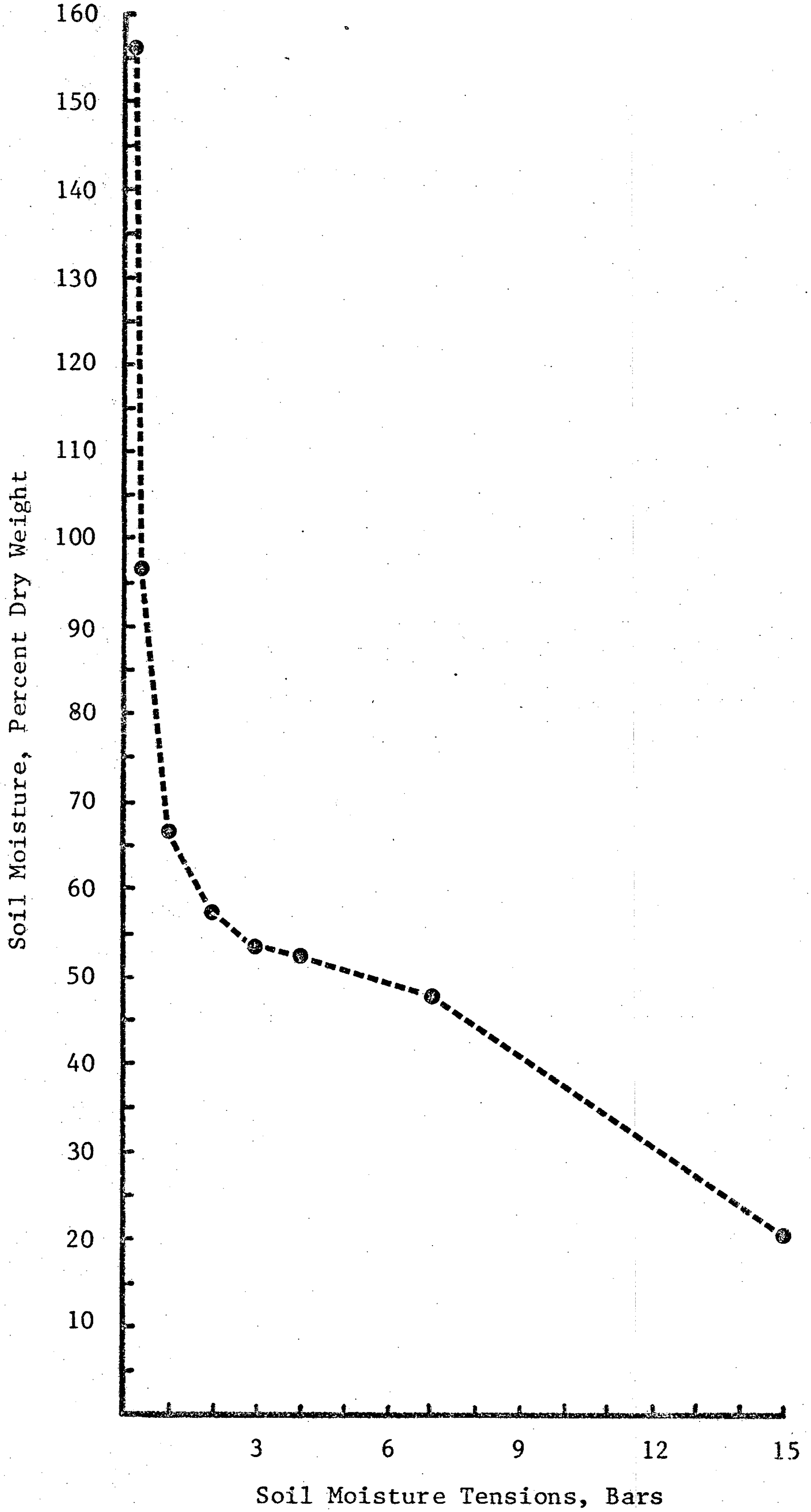
Soil Moisture, Percent Dry Weight
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
3
6
9
12
15
Soil Moisture Tensions, Bars

Fig. 3b. Soil moisture retention curve for plots 5-7 in Mesa de Colorado No. 1.

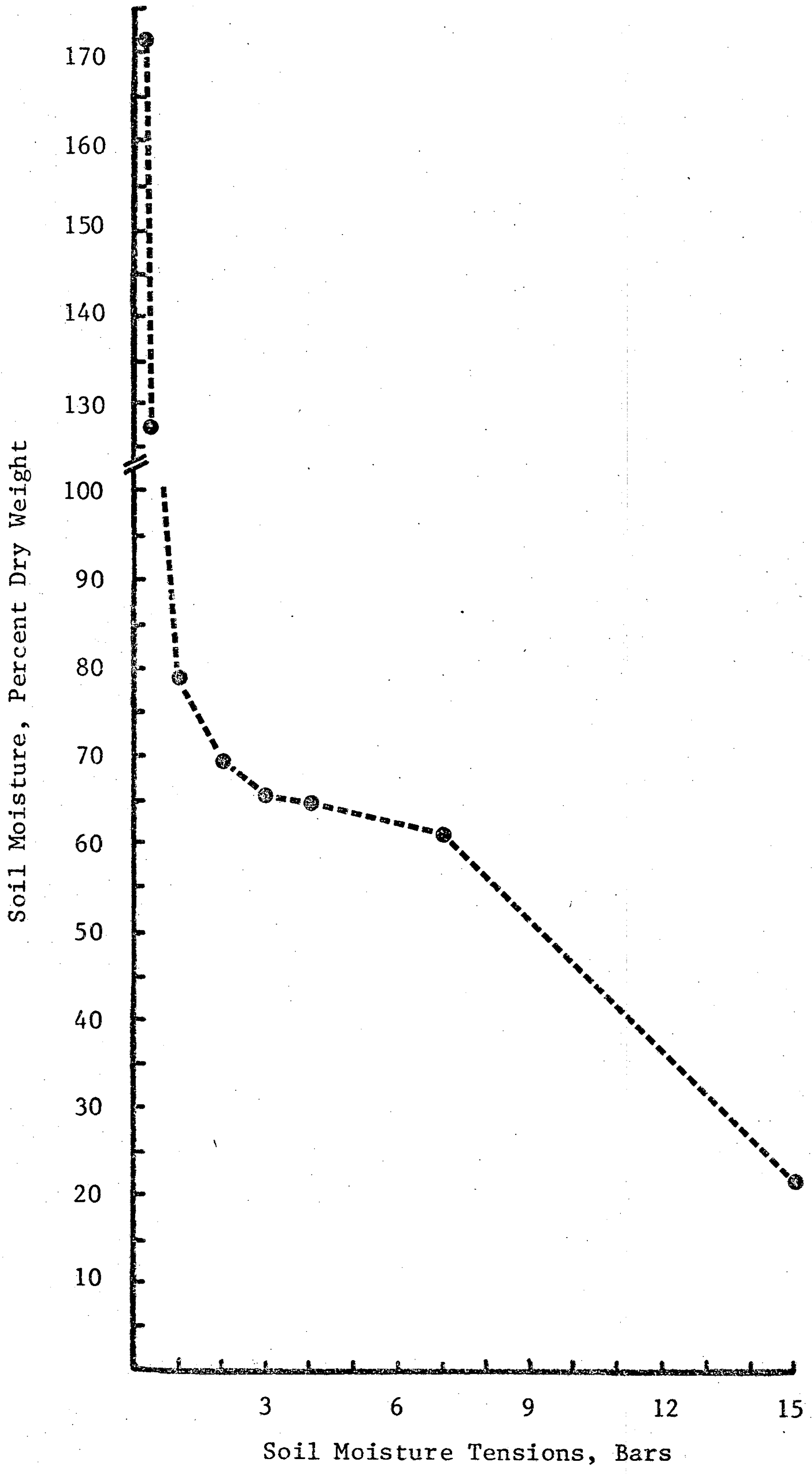
Soil Moisture, Percent Dry Weight
170
160
150
140
130
100
90
80
70
60
50
40
30
20
10
3
6
9
12
15
Soil Moisture Tensions, Bars

Fig. 3c. Soil moisture retention curve for plots 8-14 in Mesa de Colorado No. 5.

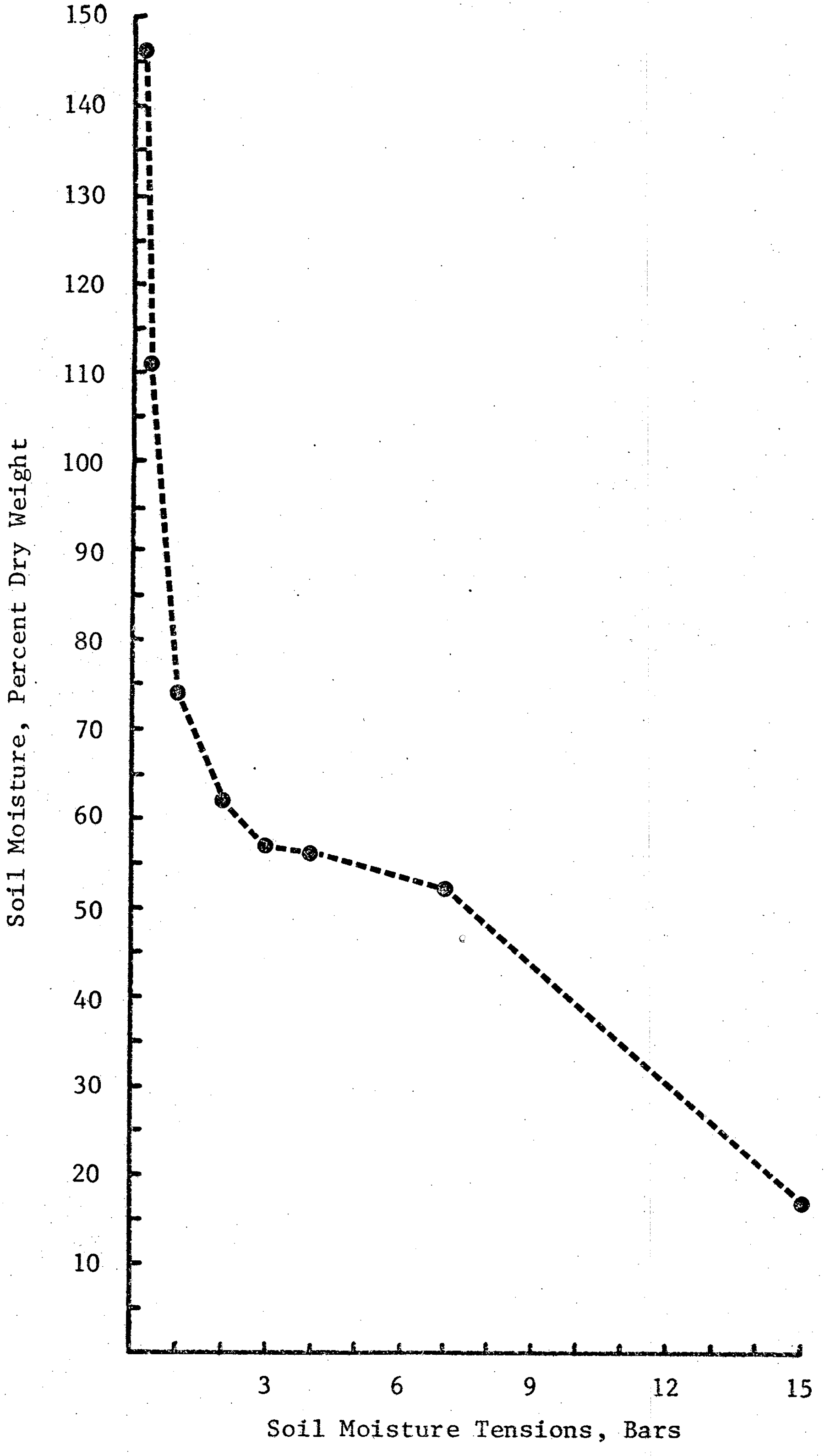
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Soil Moisture, Percent Dry Weight
3
6
9
12
15
Soil Moisture Tensions, Bars

Fig. 3d. Soil moisture retention curve for plots 15-21 in Mesa de Colorado No. 4.

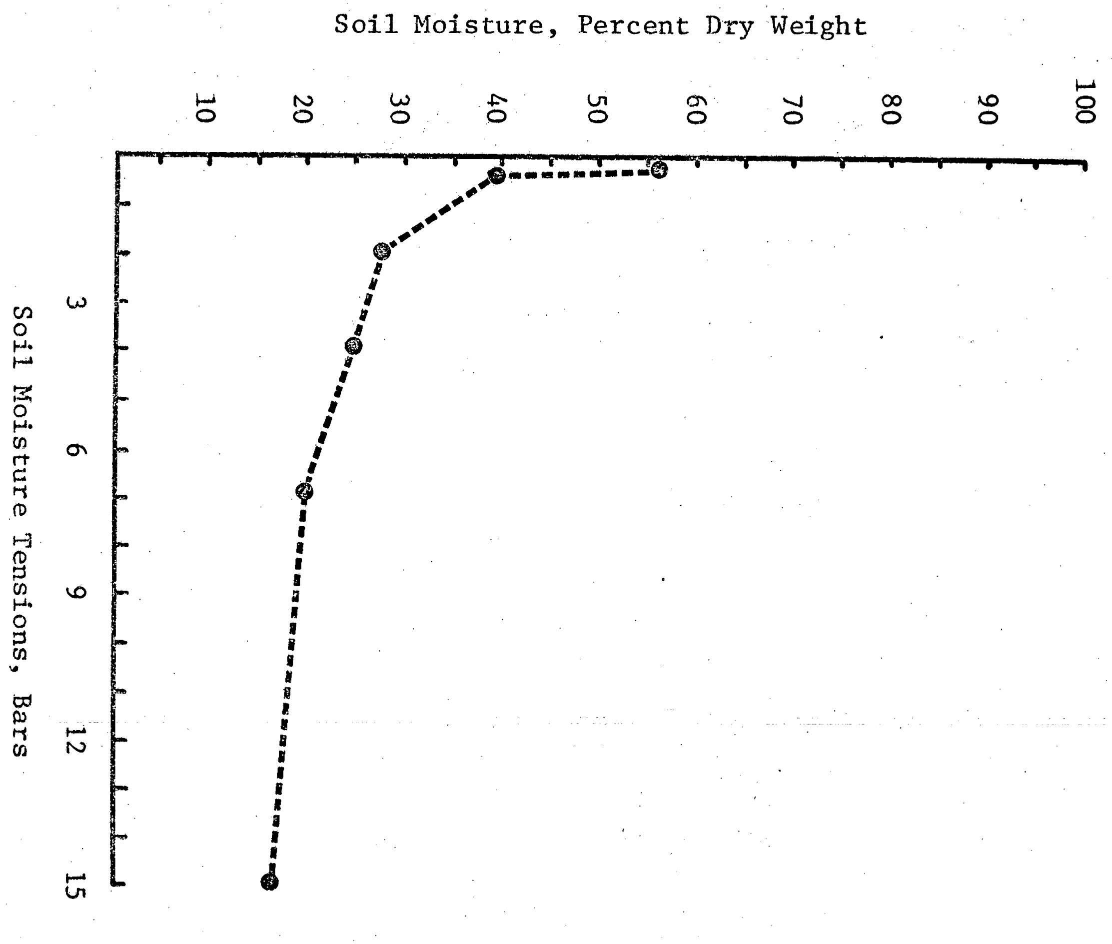
Soil Moisture, Percent Dry Weight
10
20
30
40
50
60
70
80
90
100
Soil Moisture Tensions, Bars
3
6
9
12
15

Fig. 3e. Soil moisture retention curve for plots 22-25 in Mesa de Burro No. 1.

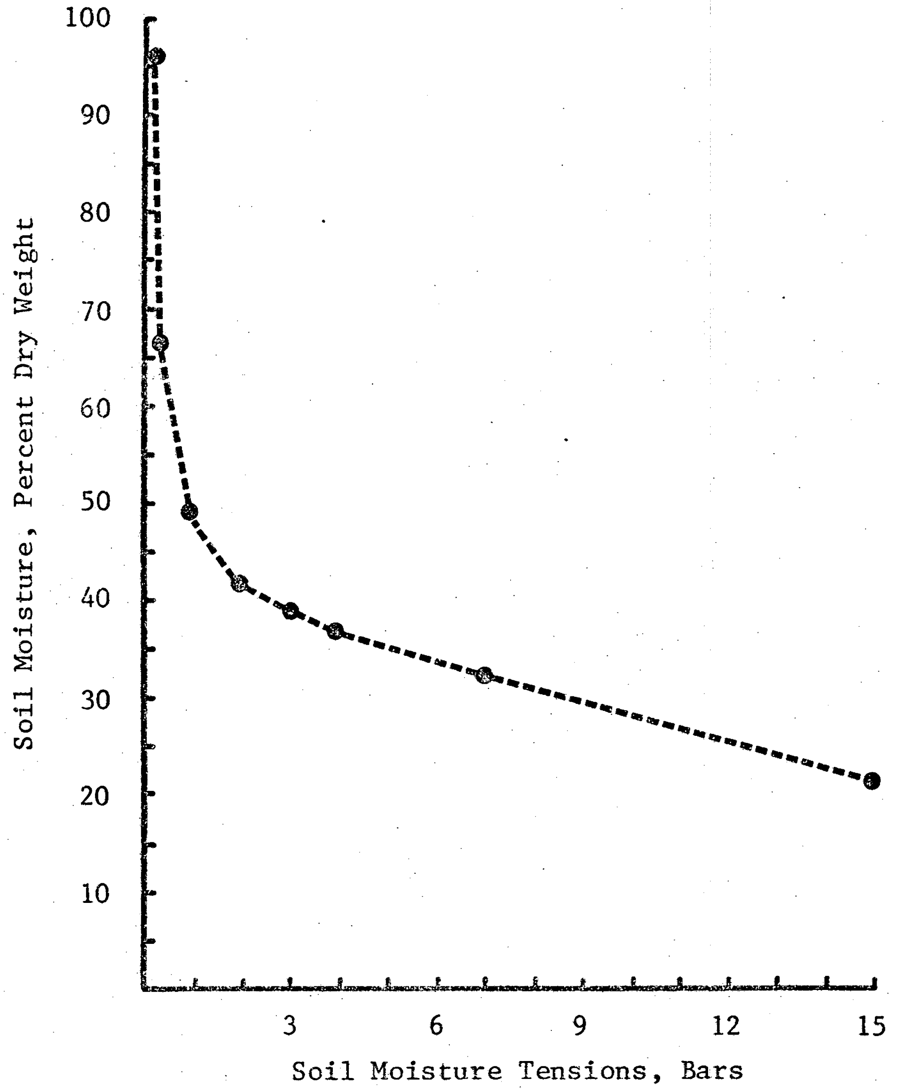
Soil Moisture, Percent Dry Weight
100
90
80
70
60
50
40
30
20
10
3
6
9
12
15
Soil Moisture Tensions, Bars

Fig. 3f. Soil moisture retention curve for plots 26-28 in Mesa de Burro No. 2.

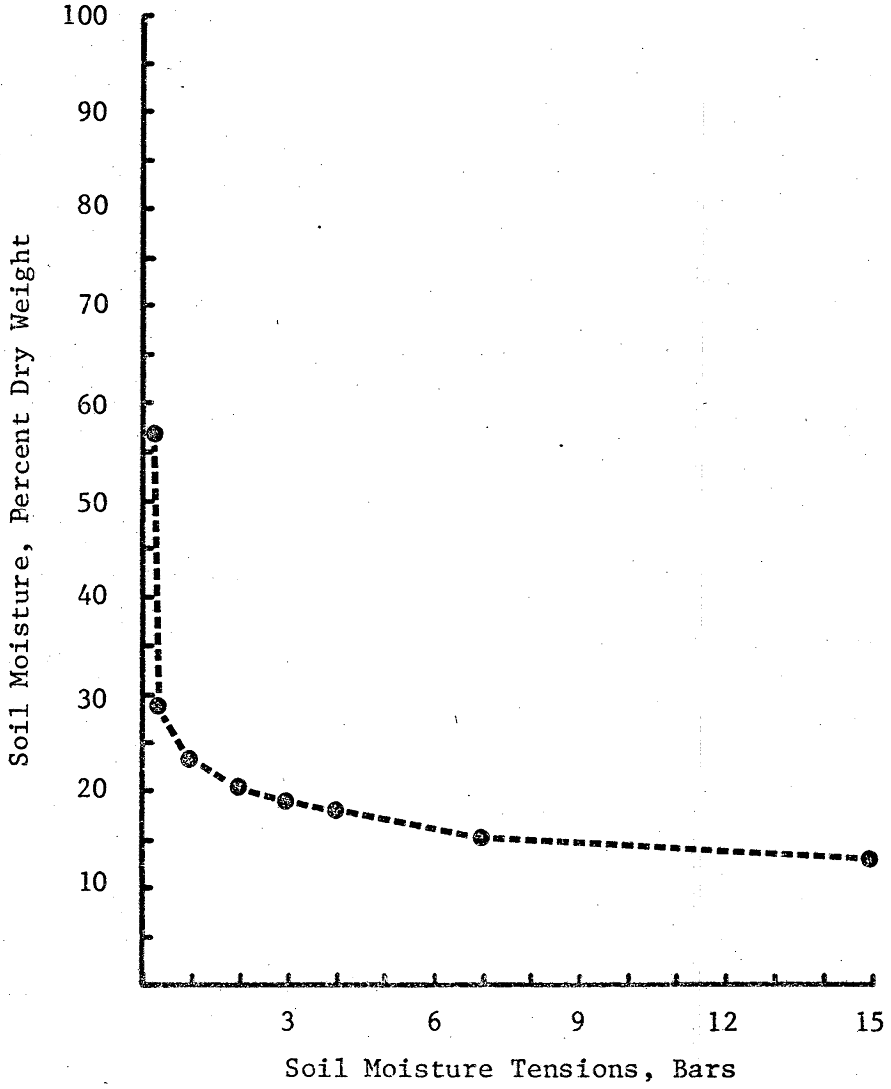
100
90
80
70
60
50
40
30
20
10
Soil Moisture, Percent Dry Weight
3
6
9
12
15
Soil Moisture Tensions, Bars

Fig. 4a. Relationships between soil moisture tension and the phenological growth stages of *Orcuttia californica* in plot 3 of Mesa de Colorado No. 1.

Key:

15 cm soil moisture tension	■ ▬ ▬ ▬ ▬ ▬
30 cm soil moisture tension	● ━━━━━━
Vegetative stage	▲ ▪▪▪▪▪▪▪▪
Flowering stage	□ ▬ ▬ ▬
Fruiting stage	△ • • • • • • • •
Decadent stage	◆ — — — — —

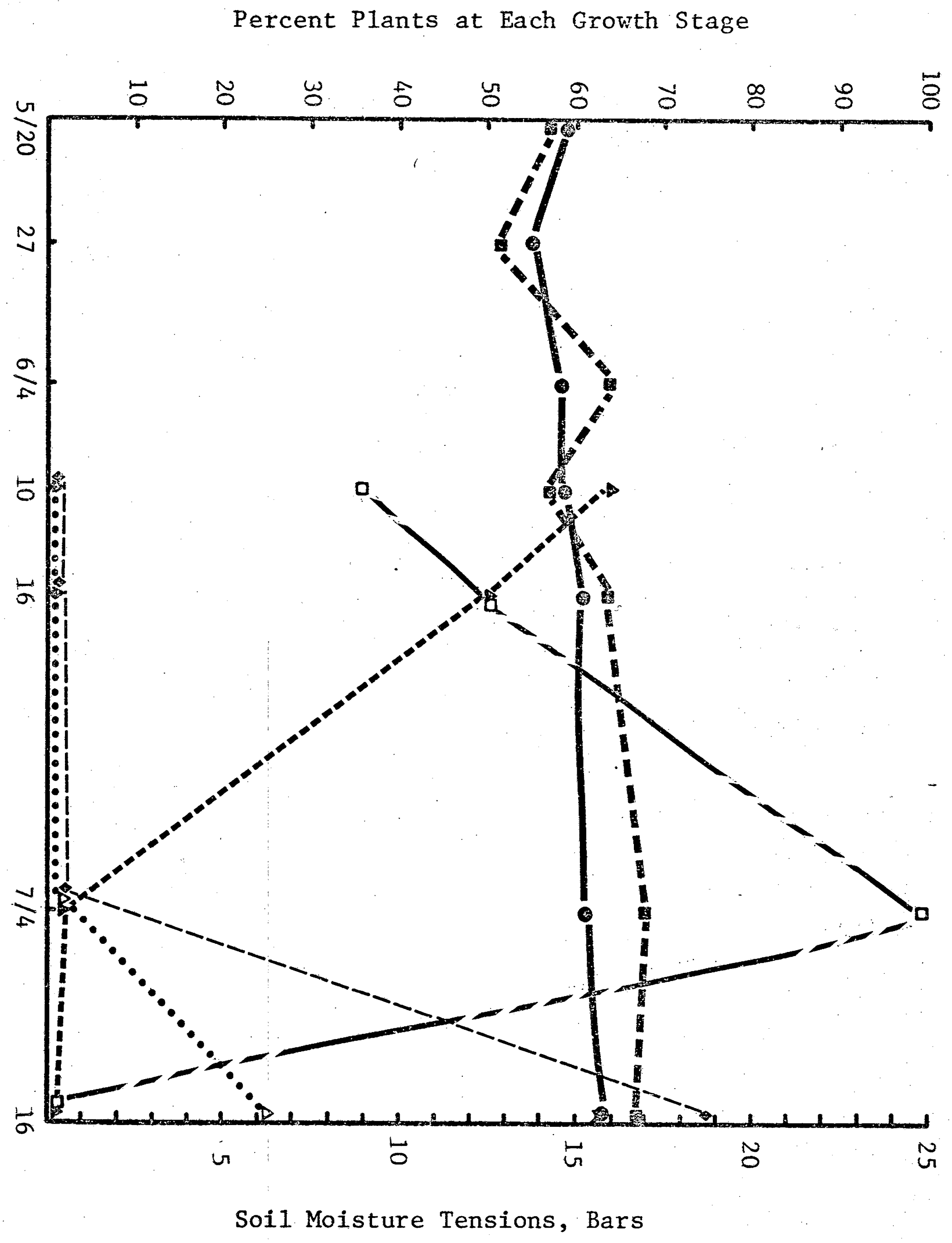
Percent Plants at Each Growth Stage
100
90
80
70
60
50
40
30
20
10
5/20
27
6/4
10
16
7/4
16
5
10
15
20
25
Soil Moisture Tensions, Bars

Fig. 4b. Relationships between soil moisture tension and the phenological growth stages of Orcuttia californica in plot 4 of Mesa de Colorado No. 1.

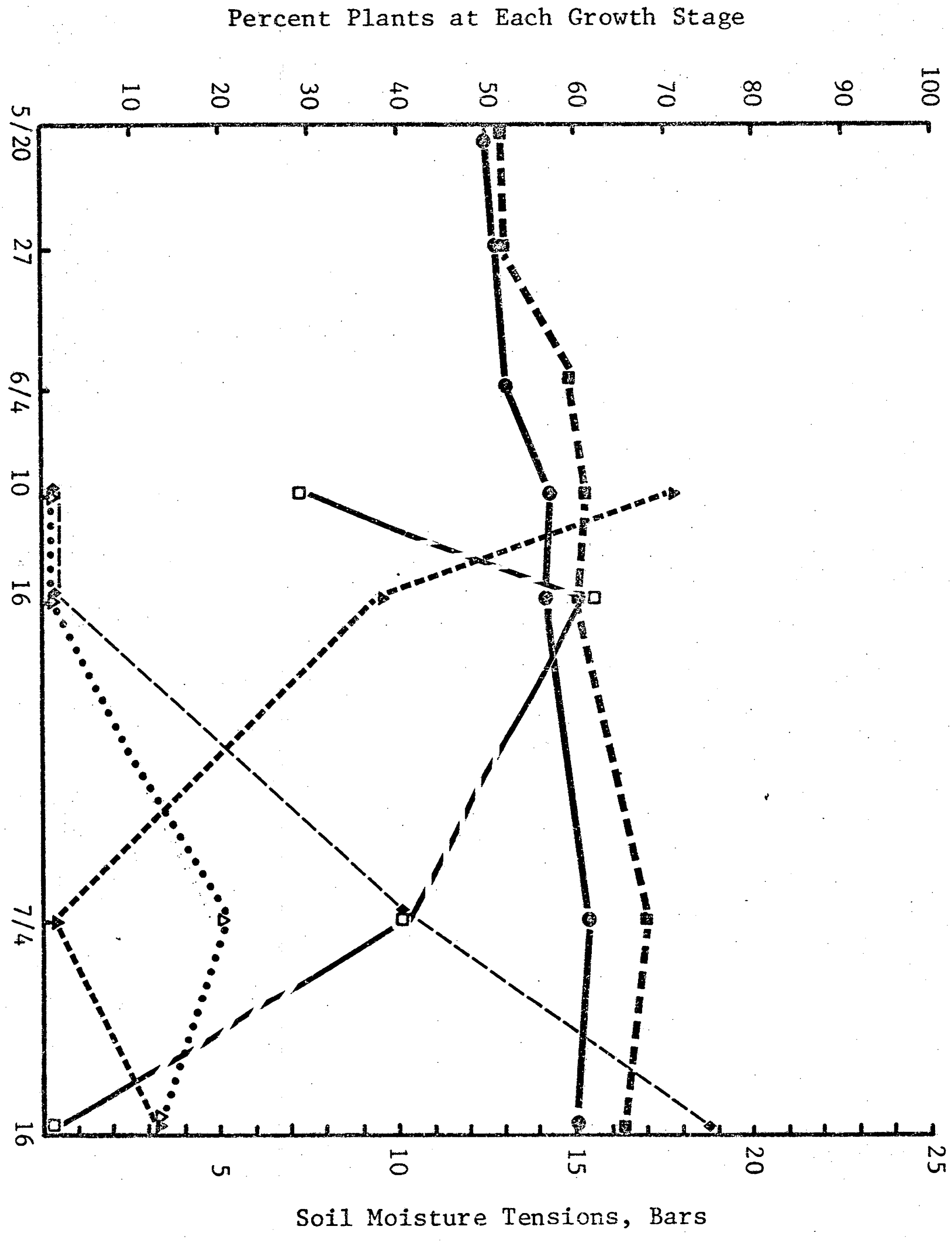
Percent Plants at Each Growth Stage
10
20
30
40
50
60
70
80
90
100
5/20
27
6/4
10
16
7/4
16
5
10
15
20
25
Soil Moisture Tensions, Bars

Fig. 4c. Relationships between soil moisture tension and the phenological growth stages of *Orcuttia californica* in plot 8 of Mesa de Colorado No. 5.

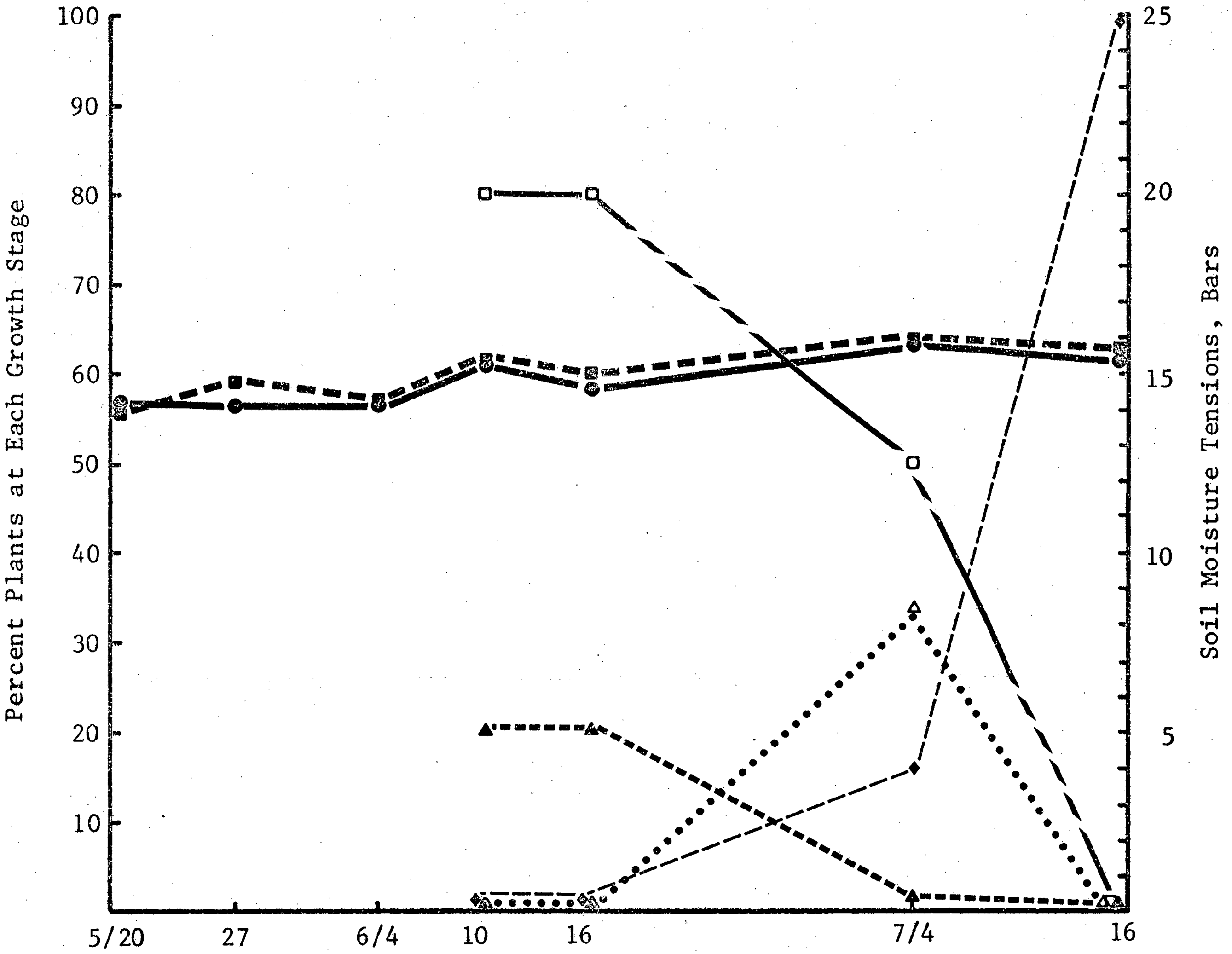
Percent Plants at Each Growth Stage
100
90
80
70
60
50
40
30
20
10
5/20
27
6/4
10
16
7/4
16
Soil Moisture Tensions, Bars
25
20
15
10
5

Fig. 4d. Relationships between soil moisture tension and the phenological growth stages of <u>Orcuttia californica</u> in plot 10 of Mesa de Colorado No. 5.

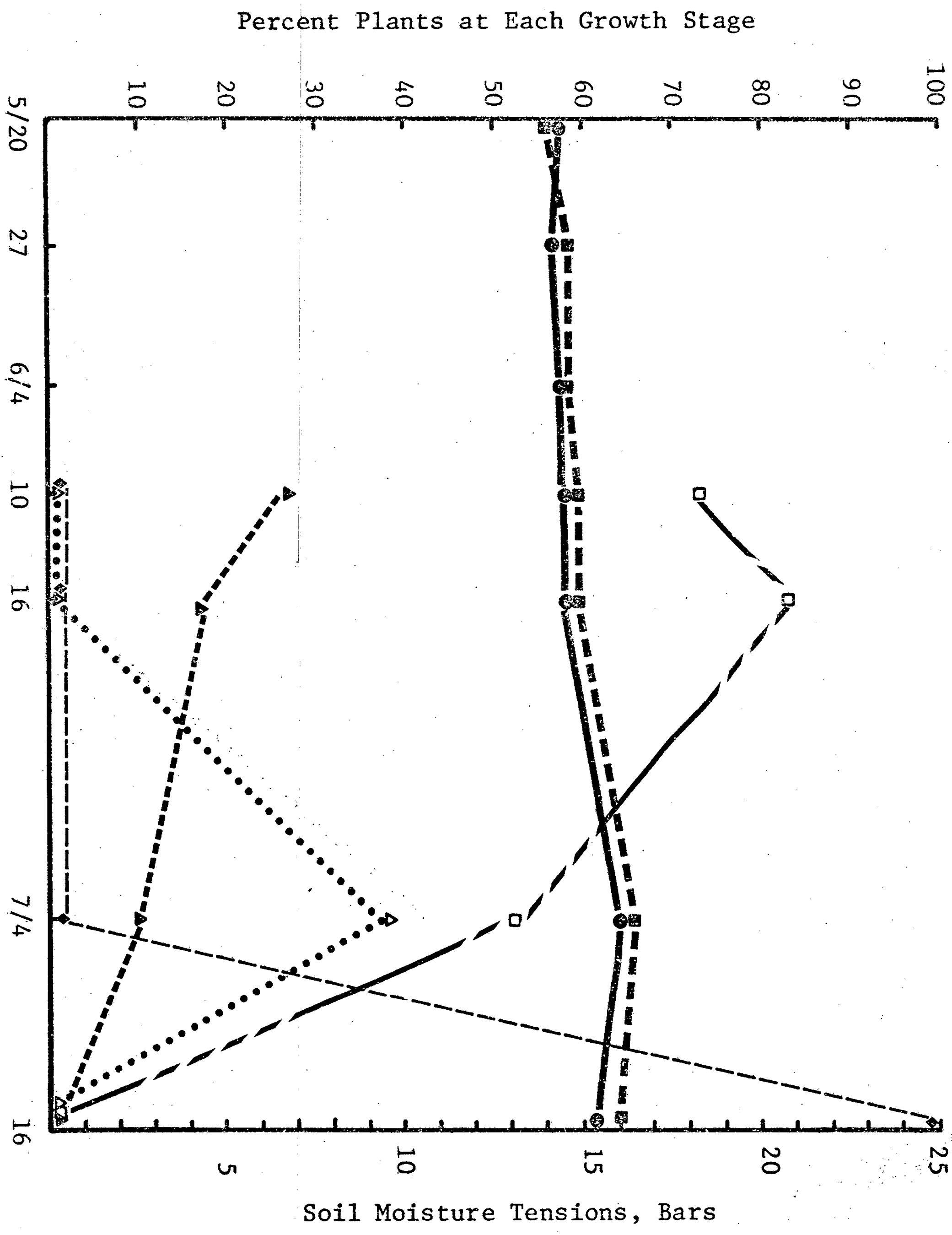
Percent Plants at Each Growth Stage
100
90
80
70
60
50
40
30
20
10
5/20
27
6/4
10
16
7/4
16
5
10
15
20
25
Soil Moisture Tensions, Bars

Fig. 4e. Relationships between soil moisture tension and the phenological growth stages of Orcuttia californica in plot 22 of Mesa de Burro No. 1.

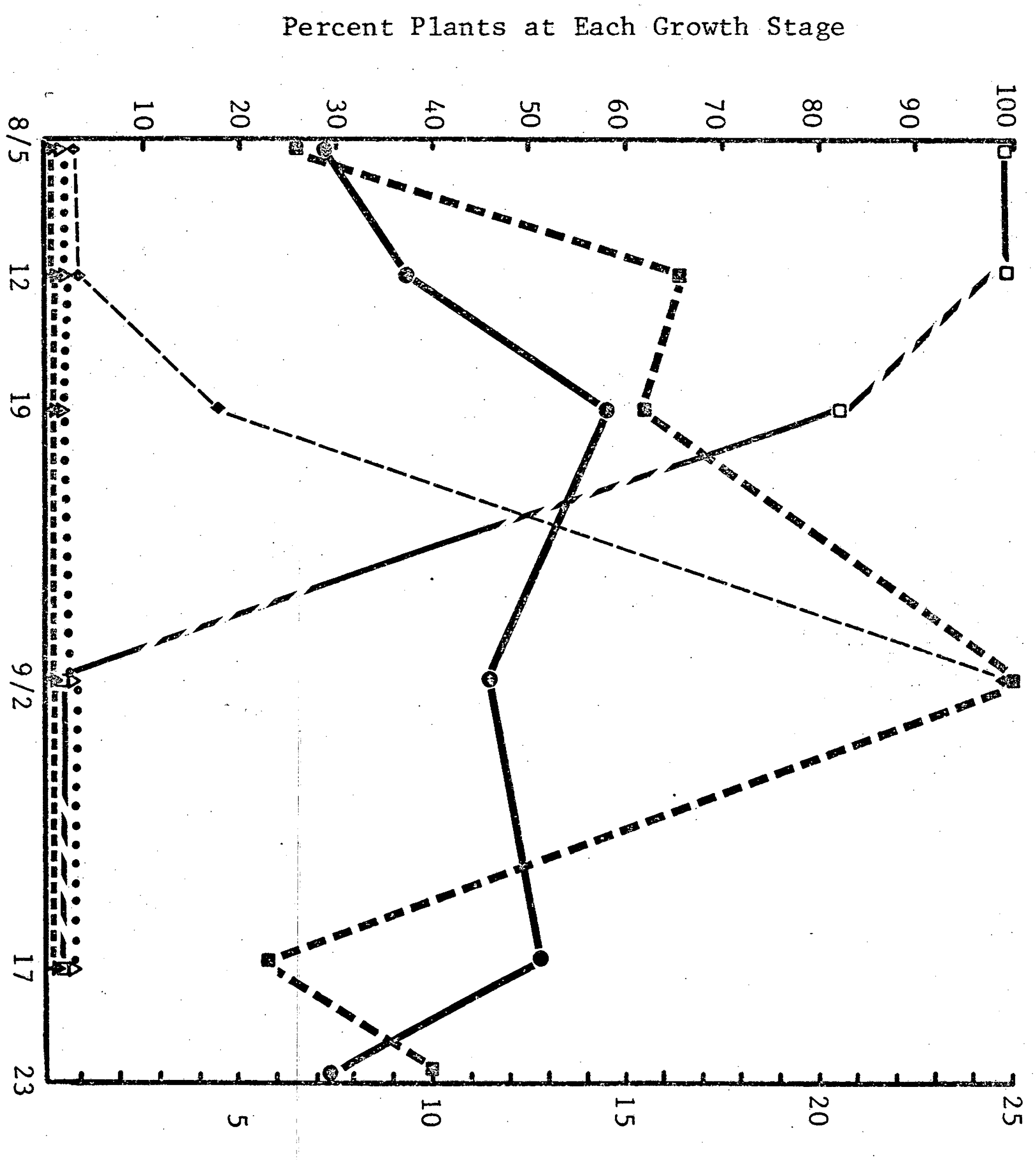
Percent Plants at Each Growth Stage
100
90
80
70
60
50
40
30
20
10
8/5
12
19
9/2
17
23
5
10
15
20
25
Soil Moisture Tensions, Bars

Fig. 4f. Relationships between soil moisture tension and the phenological growth stages of <u>Orcuttia californica</u> in plot 23 of Mesa de Burro No. 1.

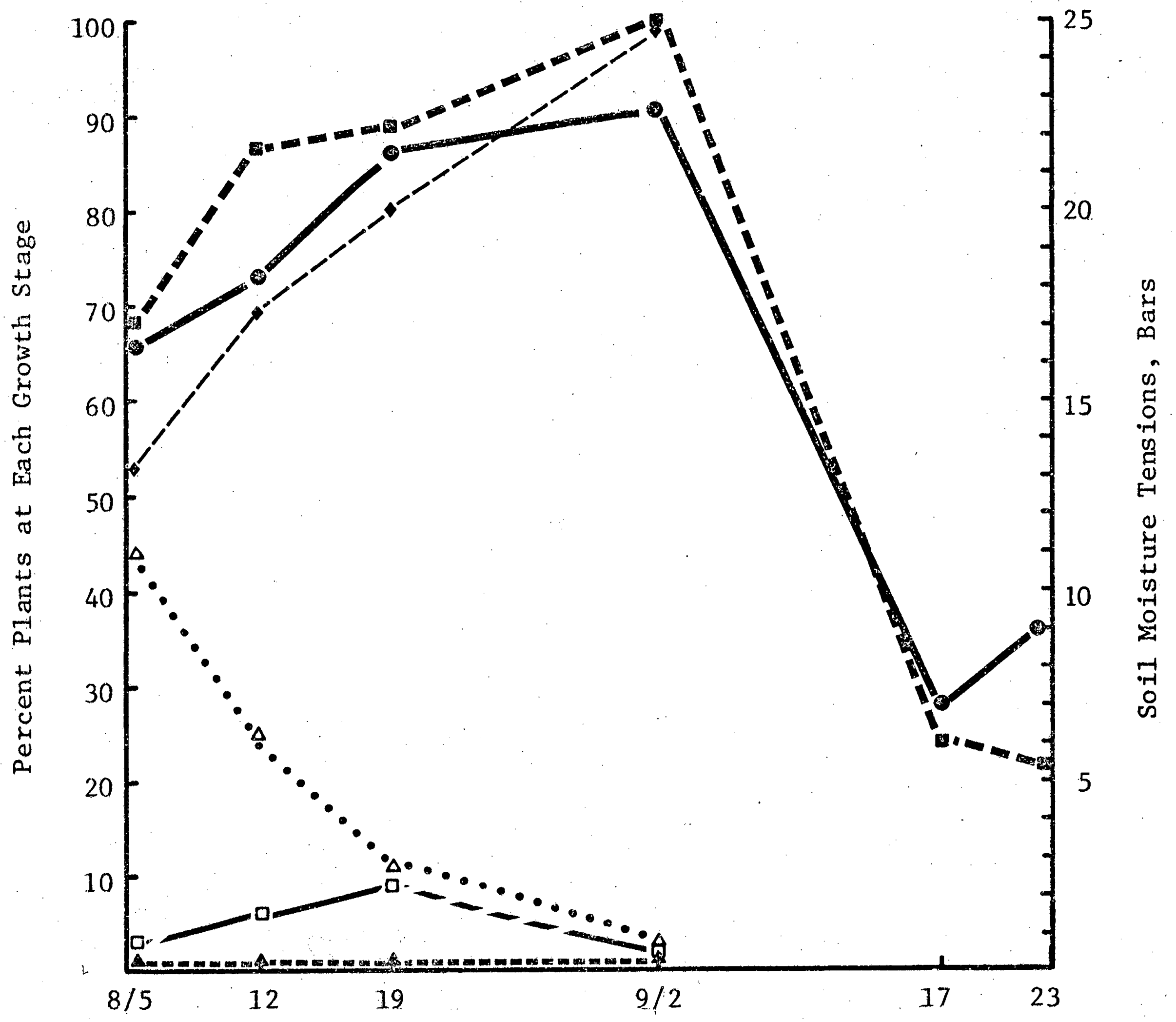
Percent Plants at Each Growth Stage
100
90
80
70
60
50
40
30
20
10
8/5
12
19
9/2
17
23
Soil Moisture Tensions, Bars
25
20
15
10
5

Fig. 4g. Relationships between soil moisture tension and the phenological growth stages of Orcuttia californica in plot 26 of Mesa de Burro No. 2.

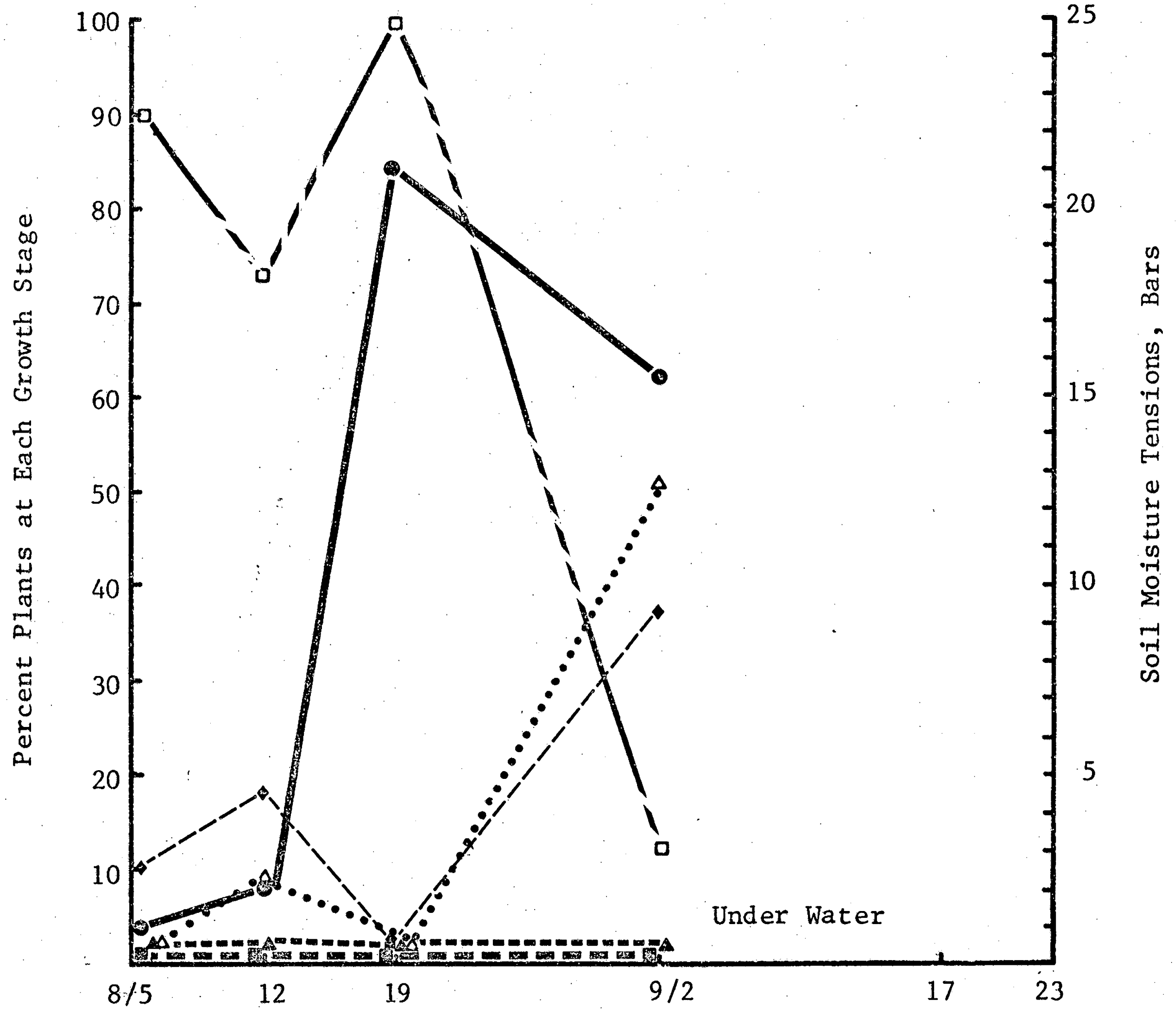
Percent Plants at Each Growth Stage
100
90
80
70
60
50
40
30
20
10
Soil Moisture Tensions, Bars
25
20
15
10
5
8/5
12
19
9/2
17
23
Under Water

Fig. 4h. Relationships between soil moisture tension and the phenological growth stages of <u>Orcuttia californica</u> in plot 28 of Mesa de Burro No. 2.

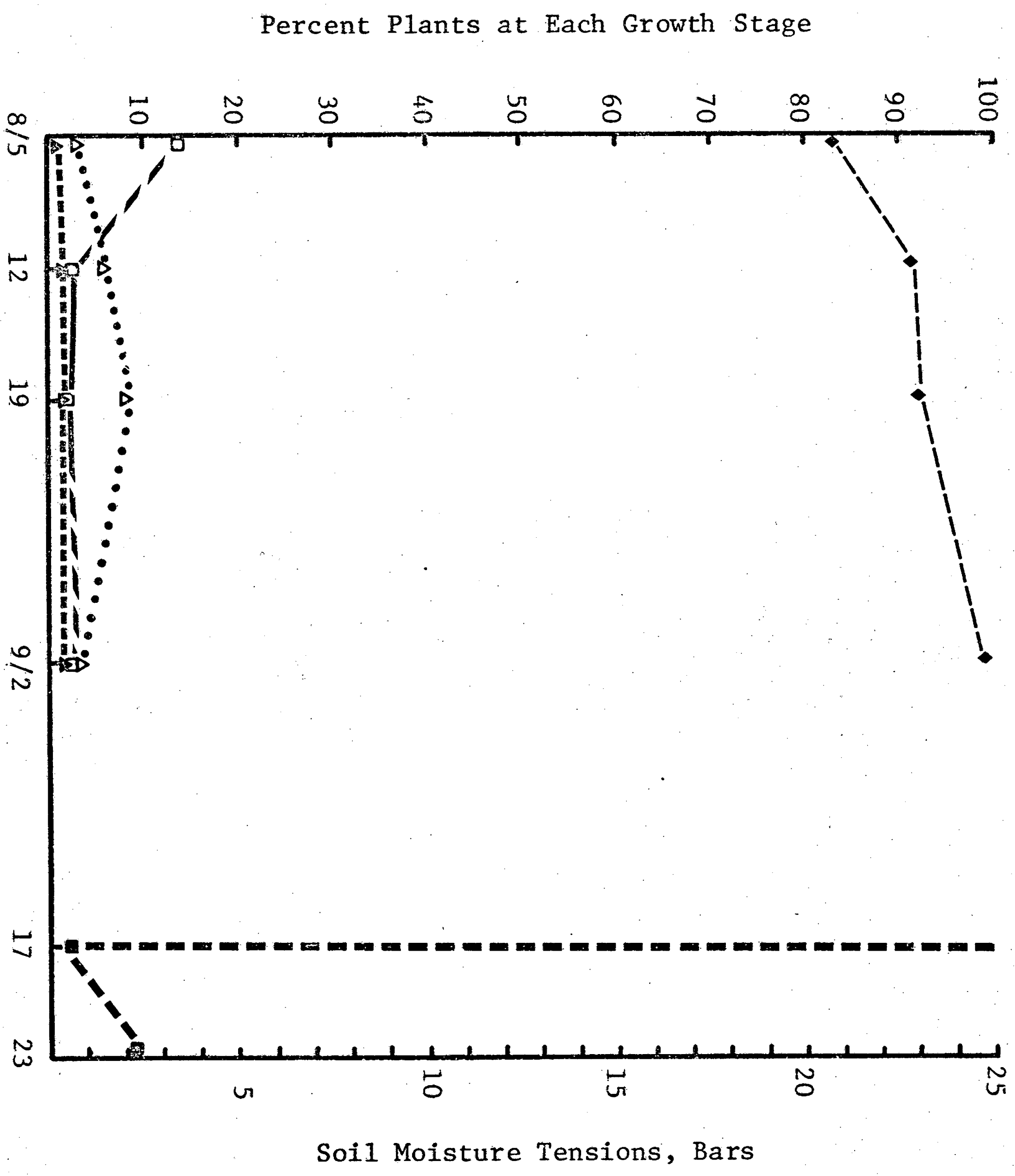
Percent Plants at Each Growth Stage
100
90
80
70
60
50
40
30
20
10
8/5
12
19
9/2
17
23
5
10
15
20
25
Soil Moisture Tensions, Bars

Fig. 5a. Horizontal profiles through the center of plots 1-7 in Mesa de Colorado No. 1. (See Figs. 2a-e for direction of profiles).

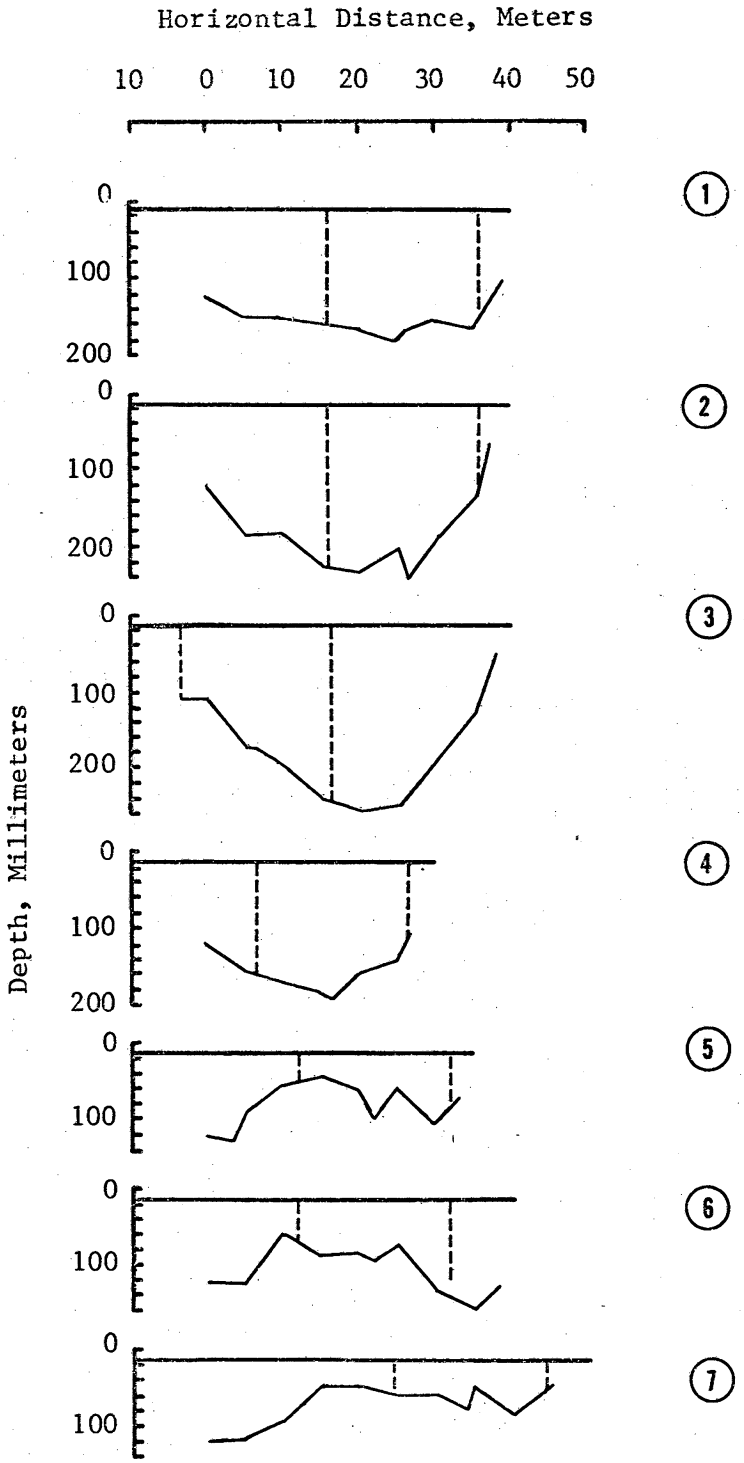
Horizontal Distance, Meters
10
0
10
20
30
40
50
Depth, Millimeters
0
100
200
①
②
③
④
⑤
⑥
⑦

Fig. 5b. Horizontal profiles through the center of plots 8-11 in Mesa de Colorado No. 5. (See Figs. 2a-e for direction of profiles).

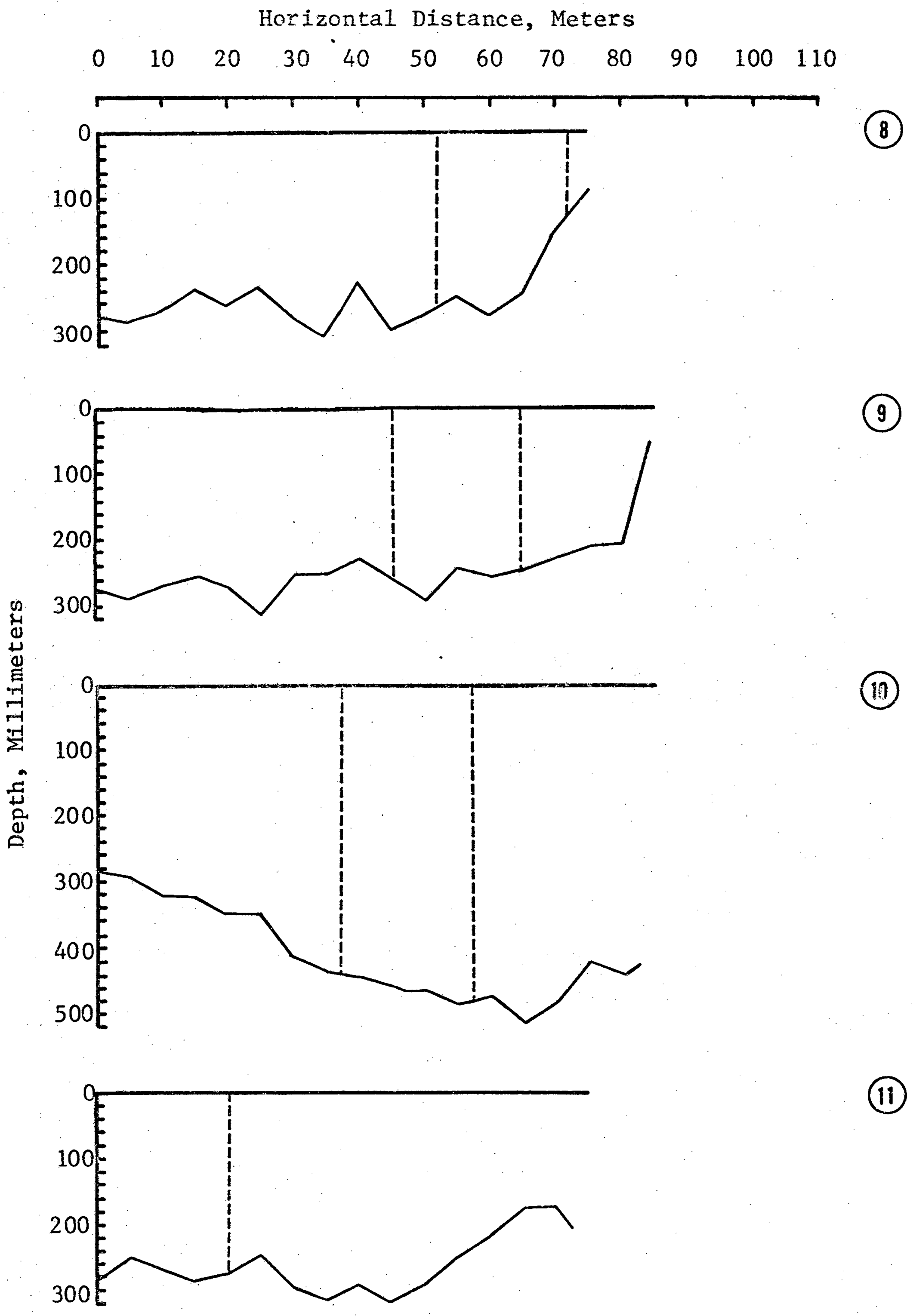
Horizontal Distance, Meters
0
10
20
30
40
50
60
70
80
90
100
110
Depth, Millimeters
⑧
0
100
200
300
⑨
0
100
200
300
⑩
0
100
200
300
400
500
⑪
0
100
200
300

Fig. 5c. Horizontal profiles through the center of plots 12-14 in Mesa de Colorado No. 5. (See Figs. 2a-e for direction of profiles).

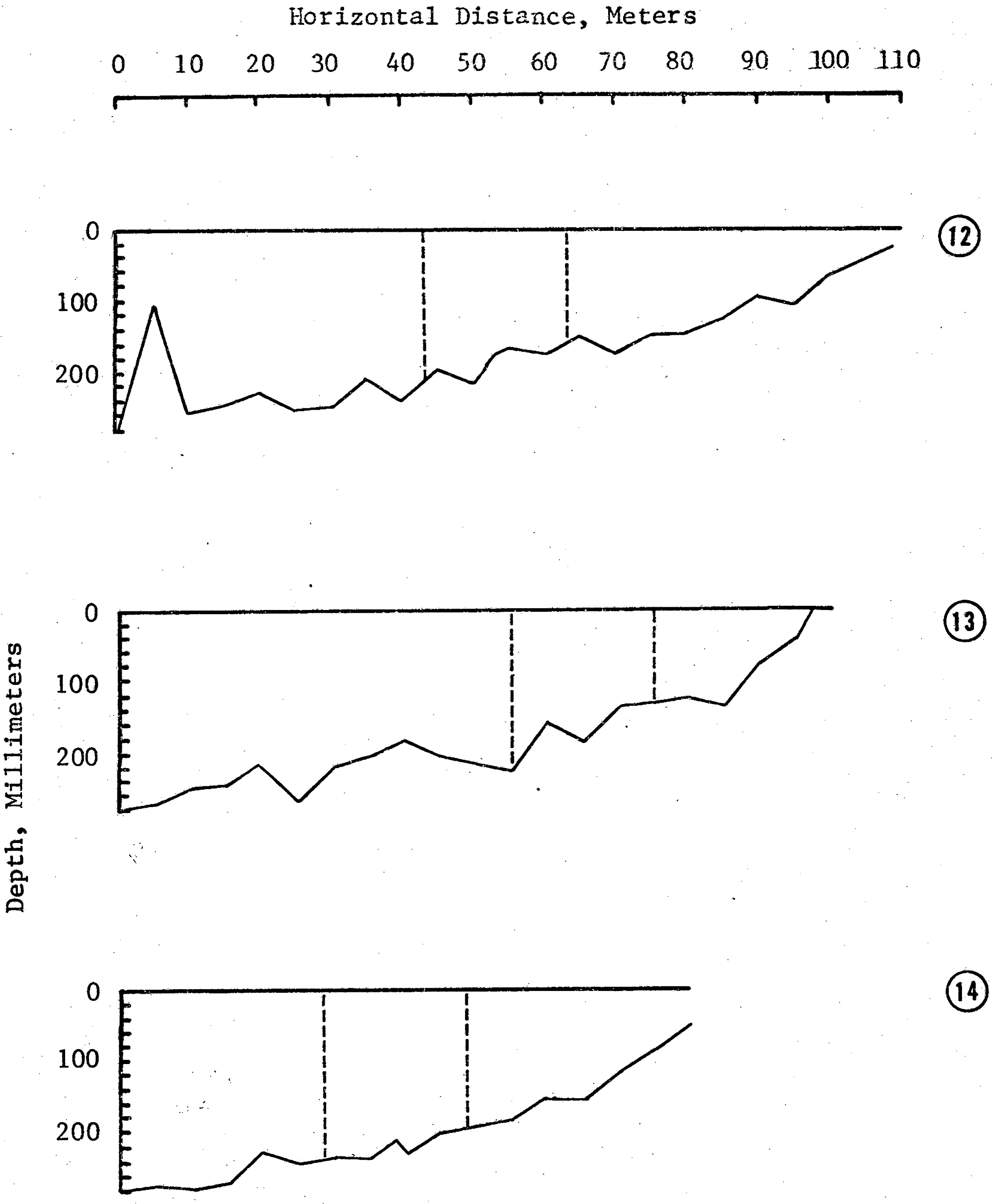
Horizontal Distance, Meters
0
10
20
30
40
50
60
70
80
90
100
110
Depth, Millimeters
0
100
200
⑫
0
100
200
⑬
0
100
200
⑭

Fig. 5d. Horizontal profiles through the center of plots 15-21 in Mesa de Colorado No. 4. (See Figs. 2a-e for direction of profiles).

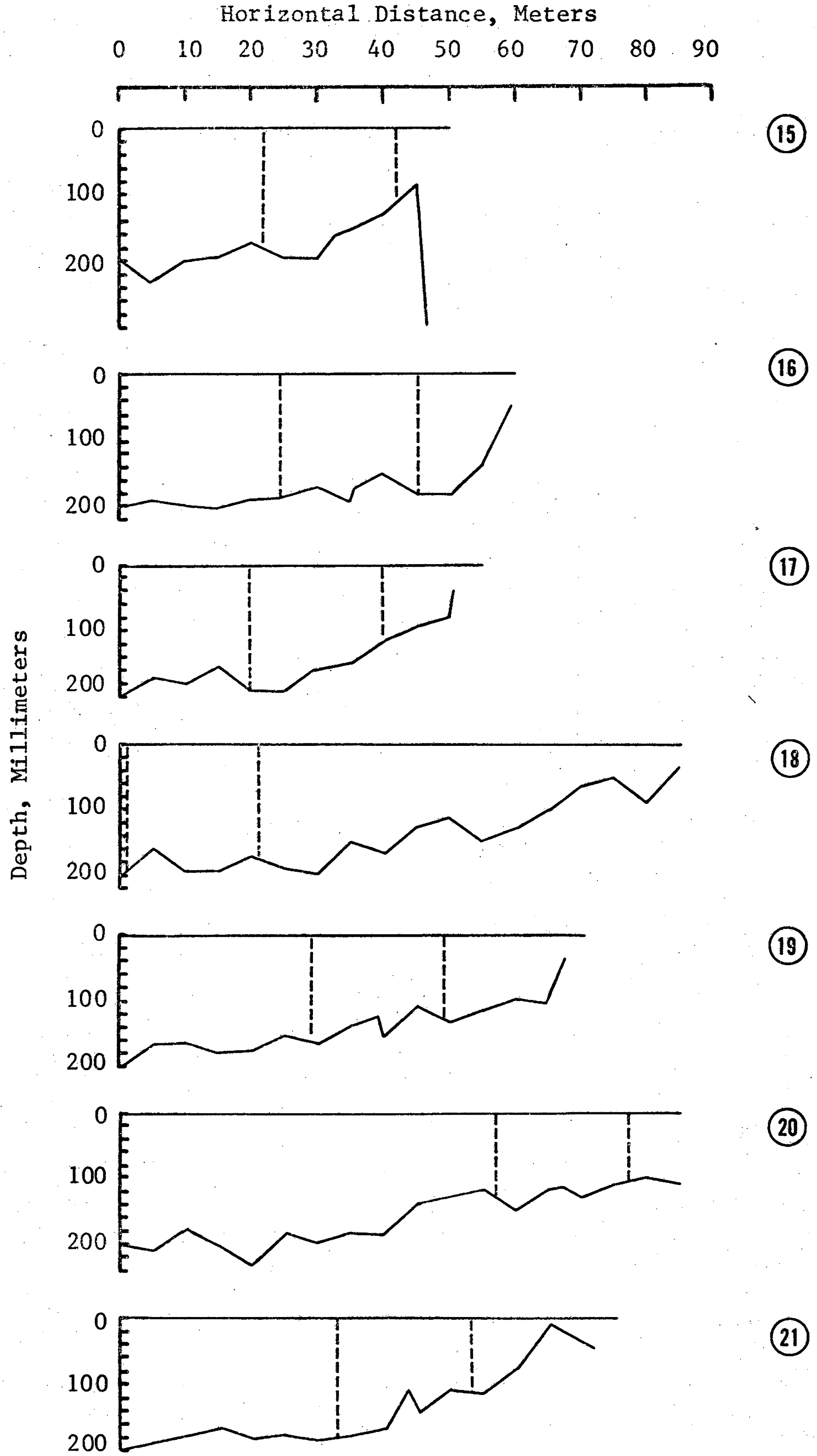
Horizontal Distance, Meters
0
10
20
30
40
50
60
70
80
90
Depth, Millimeters
0
100
200
⑮
0
100
200
⑯
0
100
200
⑰
0
100
200
⑱
0
100
200
⑲
0
100
200
⑳
0
100
200
㉑

Fig. 5e. Horizontal profiles through the center of plots 22-25 in Mesa de Burro No. 1. (See Figs. 2a-e for direction of profiles).

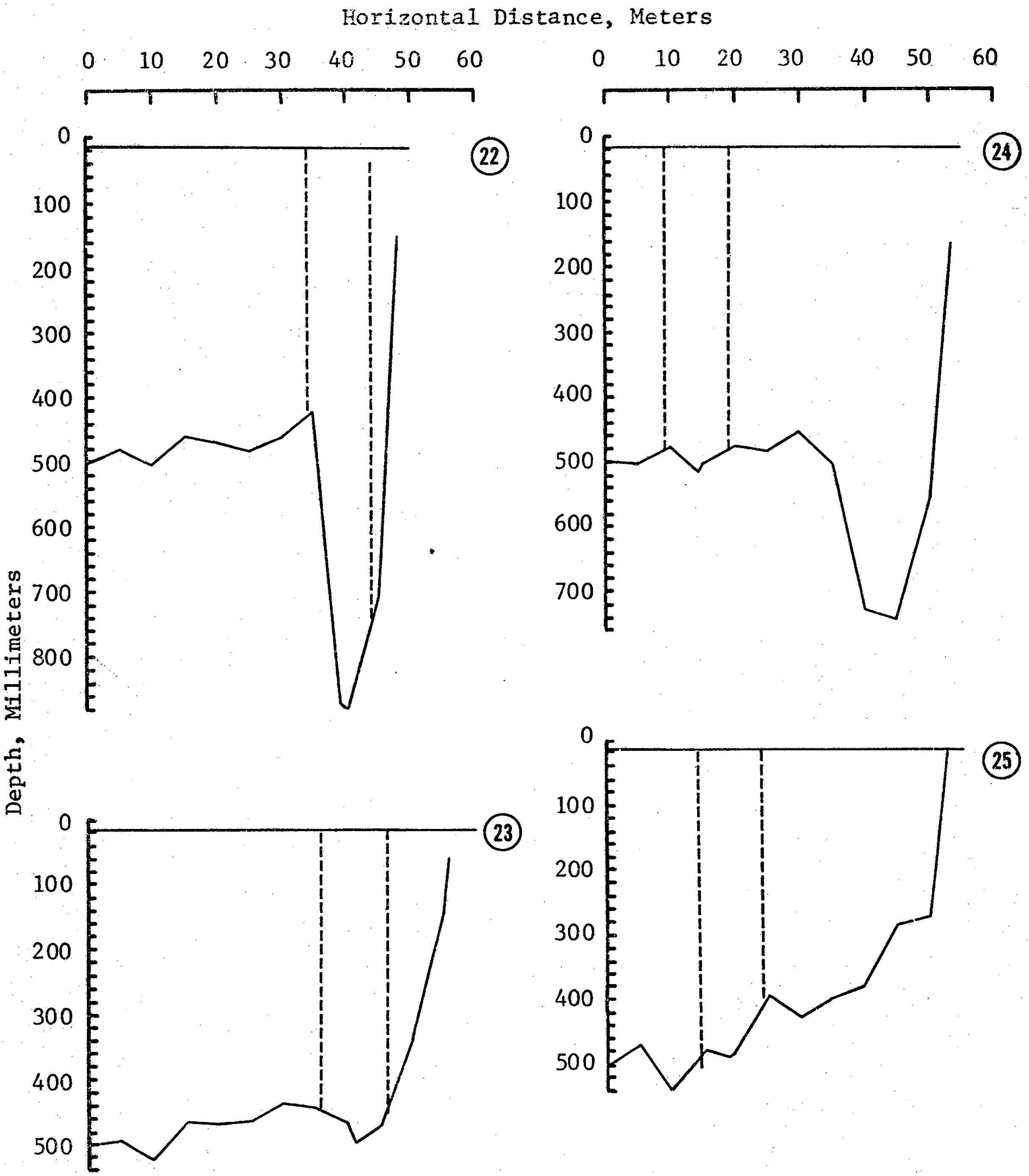
Horizontal Distance, Meters
0
10
20
30
40
50
60
Depth, Millimeters
0
100
200
300
400
500
600
700
800
㉒
㉓
㉔
㉕

Fig. 5f. Horizontal profiles through the center of plots 26-28 in Mesa de Burro No. 2. (See Figs 2a-e for direction of profiles).

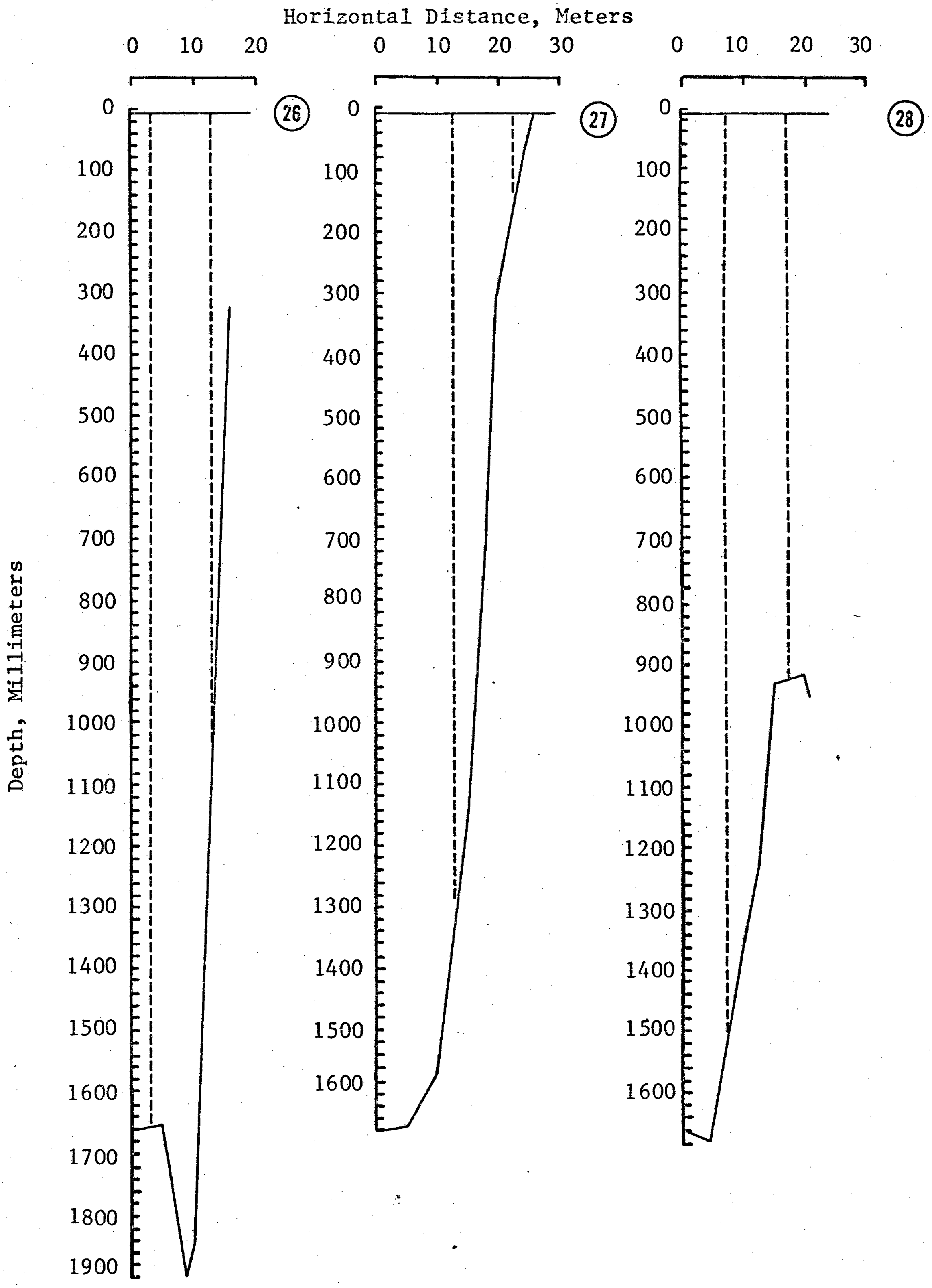
Horizontal Distance, Meters
0 10 20
0 10 20 30
0 10 20 30
㉖
㉗
㉘
Depth, Millimeters
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900

Table 1. Water Depth in all Vernal Pools on
Mesa de Colorado (C) and Mesa de Burro (B)
from April 8 to August 5, 1976

	Dates/Depth of Water, cm						
Pool No.	4/8	4/22	4/29	5/6	5/13	6/16	8/5
C-1a	†	*	*	*	*	*	*
C-1b	†	*	*	*	*	*	*
C-2	15	15	15	6	†	*	*
C-3	*	*	*	*	*	*	*
C-4	5	*	*	*	*	*	*
C-5	15	15	8	*	*	*	*
B-1a	33	32	31	26	19	*	*
B-1b	68	68	68	59	55	>0	*
B-2	>90	>90	90	80	76	>0	*
B-3	13	†	*	*	*	*	*
B-4	†	*	*	*	*	*	*
B-5	12.5	5	†	*	*	*	*
B-6	27.5	18	15	5	†	*	*

† no standing water but too wet to take soil samples (muddy)

* dry (not muddy)

Table 2. Relationships Between Order of Desiccation and Area of All Pools on Mesa de Colorado (C) and Mesa de Burro (B) and Maximum Frequency of *Orcuttia californica* in the Pools

No.	Order of Desiccation	Area ha	Maximum Frequency percent
C-3	1	0.25	0
B-4	2	1.63	0
C-1	2	0.25	~4.5
C-4	2	1.87	0
B-3	3	0.82	0
B-5	4	1.09	>40.0
C-5	5	2.32	~44.0
B-6	6	0.54	>40.0
C-2	7	10.16	0
B-1	8	1.63	~40.0
B-2	8	0.41	~21.0

Table 3. Relationships between Soil Moisture Tension in Bars at the 15 and 30 cm Depth Increments and Periodic Measurements of Frequency and Density of *Orcuttia californica* in all Plots, 1976

Plot No.	Depth cm	Dates/Soil Moisture Tension, Bars							Frequency percent	Density no/m^2
		5/20	5/27	6/4	6/10	6/16	7/4	7/16		
1	15	13.5	13.75	15.8	15.0	14.5	16.9	16.9	0	0
	30	13.5	13.75	14.8	14.5	14.2	14.9	15.1		
2	15	13.5	13.8	16.7	15.3	16.75	16.8	17.0	0.39	0.46
	30	13.25	13.8	14.8	14.25	15.5	15.8	16.0		
3	15	14.2	12.8	15.9	14.2	15.8	16.9	16.75	4.3	16.67
	30	14.75	13.7	14.6	14.4	15.1	15.2	15.7		
4	15	12.8	13.0	14.9	15.2	15.0	16.9	16.35	5.4	20.37
	30	12.5	13.0	13.8	14.25	14.2	15.3	15.0		
5	15	14.0	13.5	14.25	14.25	13.75	15.8	15.6	0	0
	30	12.4	13.7	14.2	14.2	14.2	14.8	15.0		
6	15	14.2	14.5	14.0	14.75	13.9	16.2	14.7	0	0
	30	14.3	14.5	15.0	14.2	13.3	15.0	14.5		
7	15	13.7	13.75	14.5	15.5	15.0	16.3	15.2	0	0
	30	14.3	13.9	14.5	14.9	14.8	15.0	14.6		

Table 3. continued

Plot	Depth	5/20	5/27	6/4	6/10	6/16	7/4	7/16	Frequency	Density
8	15	13.9	14.8	14.25	15.3	15.0	15.9	15.7	44.7	305.56
	30	14.1	14.1	14.25	15.3	14.55	15.8	15.4		
9	15	14.5	14.25	14.95	14.7	15.3	16.0	15.95	0.52	0.46
	30	14.25	14.3	13.9	14.8	15.1	16.0	15.25		
10	15	13.8	14.5	14.55	14.8	14.8	16.4	16.0	22.3	112.04
	30	14.25	14.1	14.4	14.5	14.5	16.0	15.3		
11	15	14.25	14.05	14.1	15.05	14.25	15.4	15.9	2.4	10.18
	30	14.2	13.6	14.5	14.1	14.2	15.3	15.25		
12	15	14.2	14.5	14.95	15.75	15.1	15.9	16.3	0	0
	30	14.2	14.25	14.8	14.8	15.05	16.0	15.8		
13	15	14.55	14.8	14.7	15.3	15.1	15.9	15.9	0	0
	30	14.4	14.5	14.7	14.95	15.05	15.95	15.65		
14	15	14.25	14.7	15.0	15.1	15.05	15.75	15.45	0.3	0.46
	30	13.9	14.4	14.8	14.7	15.0	15.65	15.4		

Table 3. continued

Plot	Depth	5/20	5/27	6/4	6/10	6/16	7/4	7/16	Frequency	Density
15	15	14.25	†	20.0	24.0	23.0	†	32.5	0	0
	30	12.0	†	19.8	19.5	19.7	†	24.2		
16	15	13.3	†	17.0	27.0	23.0	†	27.8	0	0
	30	12.5	†	15.8	18.0	25.9	†	24.9		
17	15	18.0	†	20.0	19.5	24.0	†	28.0	0	0
	30	15.2	†	19.7	17.5	23.0	†	24.4		
18	15	13.3	†	23.0	18.0	21.6	†	29.0	0	0
	30	12.3	†	22.0	17.6	21.5	†	27.0		
19	15	14.5	†	27.5	19.5	24.8	†	29.0	0	0
	30	13.3	†	19.5	18.4	19.6	†	24.0		
20	15	23.0	†	23.0	21.5	27.0	†	30.5	0	0
	30	23.0	†	22.0	22.0	25.3	†	27.0		
21	15	16.0	†	23.5	20.0	23.0	†	32.0	0	0
	30	13.5	†	22.0	19.75	23.0	†	26.6		

†No samples collected

Table 3. continued

Plot	Depth	8/5	8/12	8/19	10/2	10/17	10/23	Frequency	Density
22	15	6.5	16.4	15.5	27.0	5.7	10.0	9.6	29.17
	30	7.2	9.3	14.5	11.5	12.8	7.3		
23	15	17.0	21.6	22.2	26.0	6.0	5.4	41.6	170.83
	30	16.4	18.2	21.5	22.6	7.0	9.0		
24	15	19.0	18.4	21.4	23.4	10.1	10.0	1.1	4.17
	30	17.0	17.2	17.3	18.5	14.0	12.9		
25	15	†	17.15	17.3	20.0	9.1	14.7	0	0
	30	†	15.1	15.0	16.6	9.2	9.7		
26	15	0.2	0.2	0.2	0.2	*	*	12.0	38.89
	30	0.9	2.0	21.0	15.5	*	*		
27	15	1.7	5.5	6.5	28.0	1.8	2.8	1.6	8.33
	30	0.8	2.6	1.8	28.0	0.3	20.5		
28	15	34.0	44.0	35.0	40.0	0.4	2.2	20.3	103.7
	30	†	†	†	42.0	†	†		
Average all Plots								5.95	29.33
Average in plots with orcutt grass								11.89	58.66

*Under water following storm

† No samples collected

Table 4. Relationships Between Soil Texture of each Plot and the Frequency and Density of *Orcuttia californica* in each Plot

Plot No.	Depth cm	Sand	Silt	Clay	Frequency percent	Density no/m^2
1	15	18	20	62	0	0
	30	12	22	66		
2	15	12	24	64	0.39	0.46
	30	26	16	58		
3	15	14	22	64	4.3	16.67
	30	26	18	56		
4	15	12	20	68	5.4	20.37
	30	30	18	52		
5	15	20	22	58	0	0
	30	30	10	60		
6	15	18	20	62	0	0
	30	12	22	66		
7	15	18	20	62	0	0
	30	12	24	64		
8	15	32	14	54	44.7	305.56
	30	34	12	54		
9	15	30	20	50	0.52	0.46
	30	26	22	52		
10	15	18	18	64	22.3	112.04
	30	24	18	58		
11	15	24	12	64	2.4	10.18
	30	22	28	50		
12	15	18	26	56	0	0
	30	20	24	56		
13	15	20	24	56	0	0
	30	24	20	56		
14	15	22	22	56	0.3	0.46
	30	28	18	54		

Table 4. continued

Plot	Depth	Sand	Silt	Clay	Frequency	Density
15	15	24	18	58	0	0
	30	40	12	48		
16	15	28	22	50	0	0
	30	20	26	54		
17	15	20	24	56	0	0
	30	28	20	52		
18	15	18	30	52	0	0
	30	26	24	50		
19	15	22	26	52	0	0
	30	20	24	56		
20	15	30	22	48	0	0
	30	28	22	50		
21	15	30	20	50	0	0
	30	28	22	50		
22	15	14	20	66	9.6	29.17
	30	12	20	68		
23	15	18	24	58	41.6	170.83
	30	14	26	60		
24	15	10	24	66	1.1	4.17
	30	32	16	52		
25	15	12	18	70	0	0
	30	28	10	62		
26	15	34	34	32	12.0	38.89
	30	56	20	24		
27	15	54	26	20	1.6	8.33
	30	58	18	24		
28	15	66	16	18	20.3	103.7
	30	*	*	*		

*Insufficient sample

Table 5. Relationships Between Average Depth of Plot and Frequency and Density of Each Plot

Plot No.	Average Depth mm	Frequency percent	Density no/m^2
1	151	0	0
2	186	0.39	0.46
3	174	4.3	16.67
4	147	5.4	20.37
5	55	0	0
6	79	0	0
7	47	0	0
8	231	44.7	305.56
9	269	0.52	0.46
10	453	22.3	112.04
11	268	2.4	10.18
12	187	0	0
13	163	0	0
14	218	0.3	0.46
15	166	0	0
16	173	0	0
17	162	0	0
18	159	0	0
19	139	0	0
20	131	0	0
21	151	0	0

Table 5. continued

Plot	Average Depth	Frequency	Density
22	730	9.6	29.17
23	466	41.6	170.83
24	486	1.1	4.17
25	469	0	0
26	1598	12.0	38.89
27	684	1.6	8.33
28	1199	20.3	103.7

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