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Consumptive Use of Water by Major Crops in the Southwestern United States

Acknowledgment

This publication summarizes, in part, studies made of consumptive use of water by crops produced in the Salt River Valley of Arizona. Studies were conducted in cooperation with the University of Arizona on the Mesa Experiment Station, Mesa, Ariz., and on the Cotton Research Center, Phoenix, Ariz. Some of the measurements were made at various private farms in the valley. Special acknowledgment is made to W.D. Pew, Superintendent of the Mesa Branch Experiment Station; C.W. Fitzgibbon, Superintendent of the University of Arizona Cotton Research Center; members of the Soils, Water, and Engineering Department, University of Arizona; and to other Federal and State personnel for their critical review and comments.

Abstract

Erie, L.J., O.F. French, D.A. Bucks, and K. Harris. 1981. Consumptive Use of Water by Major Crops in the Southwestern United States. United States Department of Agriculture, Conservation Research Report No. 29, 42 p., illus .

This publication identifies and clarifies aspects of water use by the most common field crops in the Southwestern United States. Estimates of consumptive use in the Salt River Valley of Arizona, as measured by soil moisture depletion, are reported. A method is described for using the reported data to develop consumptive use estimates for other irrigated areas. This USDA Conservation Research Report updates an earlier bulletin, "Consumptive Use of Water by Crops in Arizona," by Erie et al., including both additional crops and years of data.

Keywords: Consumptive use, peak consumptive use rate, evapotranspiration, irrigation water requirement, irrigation water management, irrigation scheduling, Blaney-Criddle formula.

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Consumptive Use of Water by Major Crops in the Southwestern United States

By L.J. Erie, O.F. French, D.A. Bucks, and K. Harris[1]

Introduction

Water is a limiting factor in the expansion of irrigated areas and in the production of food for all Western States. As the population increases, greater competition for the water supply makes conservation and efficient use of water imperative.

Savings in irrigation water seldom exist where water is plentiful. Where the water supply is diminishing, scarce, or expensive, conservation methods are most apt to be practiced. New sources of irrigation water supplies are limited, and water and operating costs are increasing.

To get the most out of each unit of water, we must know how much water to apply, when to apply it, and where to apply it, and how to design and manage an irrigation system. Consumptive use is defined as the unit amount of water used on a given area in transpiration, building of plant tissues, and evaporation from adjacent soil. Knowledge of consumptive use is necessary in planning farm irrigation and drainage systems, for improving irrigation practices, conserving energy, and assisting in irrigation scheduling.

Factors Influencing Consumptive Use

Consumptive use is affected by many management and natural factors. Important natural factors are climate, soils, and topography. Climatic factors include temperature, precipitation, solar radiation, humidity, wind movement, and length of growing season.

Management factors can usually be controlled although many are interrelated with the natural factors. They include water supply, water quality, planting date, crop variety, fertility, plant spacing, irrigation scheduling, cultivation, and chemical spraying.

All these factors may influence plant growth and, thereby, the amount of water used. Consumptive uses may vary from farm to farm, season to season, and day to day. When plants are young, the rate of water use is low. The consumptive use increases with plant growth, reaches a peak during some part of the growth period, then tapers off by harvesttime. Nevertheless, for maximum production at a specific location, a specific crop requires a fairly definite amount of water during the growing season.

Irrigation Water Requirement

The net irrigation water requirement represents the amount of water necessary for a particular crop's consumptive use (consumptive water requirement) and miscellaneous water requirements, which include water for leaching, frost protection, crop cooling and other beneficial purposes. Part of this water can be supplied by water previously stored in the soil, growing season precipitation, and ground water within reach of the plant roots. The sum of ground water contribution, effective precipitation, and available moisture stored in the root zone can be subtracted from the consumptive water requirement to determine the net amount of irrigation water to satisfy consumptive use during the growing or irrigation season.

The amount of water to be pumped or purchased depends on the efficiency with which it can be delivered, applied to the field, and stored within the plant root zone. The efficiency of farm water application is often defined as the percentage of irrigation water delivered to the farm that is stored in the soil to meet the net irrigation water requirement of the crop. If highly permeable soils are overirrigated, considerable water may penetrate below the root zone and be unavailable for immediate consumptive use. This deep percolation water is difficult to measure in terms of irrigation efficiency, yet it is supplied to the field and must be taken into account.

Miscellaneous Irrigation Requirements

Many other irrigation water requirements exist that are usually not associated with the consumptive water requirements. When excessive salts exist, extra water must be passed through the soil to leach salts out of the root zone. Additional irrigations are sometimes necessary for attaining adequate germination, crop cooling, or frost protection. In sorghum, water is sometimes used to control the lesser corn stalk borer, *Elasmopalpus lignosellus* (Zeller). Some crops, such as lettuce, require a high level of soil moisture during harvest to improve quality or preserve crispness. All of these beneficial requirements, in addition to consumptive use, are a reality, and they should be considered in farm management and project design.

Consumptive Use Investigations

Consumptive use by various agricultural crops has been investigated at many locations for nearly 80 years. The most common methods of measuring the amount of water consumed by crops have been (1) lysimeters, (2) water balance, and (3) soil moisture depletion.

Lysimeters are tanks, either weighing or nonweighing, filled with soil. Weighing lysimeters are usually accurate

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and can be used for estimating short-term water use; however, lysimeters have some disadvantages. They are difficult to maintain: Plants, once established, must be used for the entire growing season, regardless of their vigor; roots are confined to the lysimeter dimensions; and soils are disturbed when lysimeters are installed, which may create growing conditions different from those of undisturbed soil.

The water balance technique requires that water be accurately measured into a small field plot or nonweighing lysimeter where the water can be uniformly distributed. Consumptive use is then determined by total water applied plus rainfall and the change in soil water storage over the growing season. No information is obtainable on soil moisture conditions, such as short-term use, profile use, peak use, deep percolation, and soil water content at the time of an irrigation.

The soil moisture depletion method is the measurement of changes in the soil water content over a period of time under actual field conditions using soil sampling and gravimetric analysis or the neutron meter. This method is well adapted where water tables are not involved; precipitation is low and good control of irrigation water is possible; short-term measurements are not feasible, and precautions must be taken to prevent or minimize deep percolation losses. With the gravimetric procedure, soil sampling sites with respect to plants can be changed if desired. Equipment costs are generally low, but considerable labor is required.

This report presents consumptive use data for various cash, oil, hay, bermuda lawn, small grain, forage, fruit, vegetable, and green manure crops as grown in central Arizona. Since good consumptive-use measurements have not been made in many areas, numerous attempts have been made to calculate consumptive use or transpose existing data to other areas (*1, 5, 6, 7, 8, 10*).[2] None of these methods is completely satisfactory, but several have proved useful. We will present one method for transposing the data to other localities in the report.

Experimental Method and Procedures

During the past 50 years, consumptive-use studies were conducted by the authors on private farms and on University of Arizona Experiment Station farms near Tempe and Mesa, Ariz. Consumptive use was computed from gravimetric soil water content measurements on soil samples taken at depths and locations that could be expected to evaluate the average soil moisture distribution and depletion by the plants under study.

To study the soil moisture depletion within the soil profile, root distribution, plant and row spacing, kind of crop, and direction of rows were considered. For example, six soil-sampling locations on the north and six on the south side of each grapevine were considered adequate to determine the consumptive use. A different, healthy grapevine was selected after each irrigation.

Three sampling locations in the field with two or three samples per location might be considered adequate on close-growing crops, such as barley, alfalfa, and wheat, where plants were evenly spaced and growing normally and where irrigation water was distributed uniformly into small, level-basin plots. On row irrigation, at least two samples at each of three locations in the field were used. On wide cantaloup beds, where horizontal movement of water during an irrigation was not always complete, at least three samples per location and three locations were used. Sample locations were changed for all crops after each irrigation, and additional soil samples were sometimes taken in the upper 2 feet at critical growth stages.

Soil samples were taken at 1-foot intervals throughout the root zone with a King tube or Oakfield probe. The samples were weighed to a hundredth of a gram, dried for at least 24 hours at 105°C. in a forced air oven, and the amount of moisture was calculated. Soil moisture samples were taken at planting and harvesting dates, before and after (3 to 4 days) irrigations, and at intermediate dates as necessary.

The gravimetric procedure for measuring soil moisture was selected because the soil moisture status of various crops was required in conjunction with other field experiments. For example, when irrigation scheduling was studied on certain crops, the irrigation timing was determined from soil moisture measurements, and it was then possible to calculate the consumptive use for the crop for various irrigation schedules. By using the soil moisture depletion method, measurements could be made on various farms and on plots not specifically set aside for consumptive-use studies. If plants were broken, diseased, or appeared below normal, sampling locations were changed.

Vegetables such as lettuce, dry onions, and green onions, because of their shallow root systems, use most of their water from the top foot of soil. Thus, moisture needs per application are small and some deep percolation is inevitable. On these crops, irrigation water was controlled in an effort to minimize these deep-percolation losses. Although most irrigation systems are not designed to deliver light applications of water, newer practices such as level-basin, trickle, and low-pressure sprinkler irrigation have this capability (*3, 4*).

Experimental Results

The consumptive-use curves included in this report were developed from the averages for several years. They do not show short-time fluctuations in water use, and the data were selected from irrigation treatments, which resulted in high (near or at maximum) crop production.

Consumptive-use curves for 33 cash, oil, hay, bermuda lawn, small grain, forage, fruit, vegetable, and green manure crops are presented in Appendix I. Each figure contains estimates of seasonal use, semimonthly use,

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[2]Italic numbers in parentheses refer to Literature Cited, p. 3.

and soil profile moisture depletion. Peak-use rates may be estimated from the curves. Seasonal moisture depletion from each foot of rooting depth is presented by bar graphs in the upper left-hand corner of each figure. These graphs include use in inches per foot and percentage of the total. Since field measurements by gravimetric means do not differentiate between the moisture used by plants and that moving from one level to another, profile use values may be better described as the net profile depletion values.

Several estimates of consumptive use are presented for sugarbeets depending upon the harvest date; estimates of seasonal consumptive use for alfalfa with and without a summer dormancy period are given; and consumptive use from bud break to harvest (grape-producing season) is presented for early and late maturing grape varieties.

Use of Data

Tentative irrigation schedules can be calculated directly from the consumptive use curves. As an example, refer to Appendix I, figure 1, on castor beans (p. 5). For ease of calculation, assume that each semimonthly period contains 15 days. Suppose that on June 15, the soil profile contains 6 inches of available water and we wish to irrigate when two-thirds of the available water, or 4 inches ($6 \times 2/3 = 4$), is used. Average daily consumptive use for the last half of June is 0.29 inch (4.41 inches semimonthly use, divided by 15 days = 0.29 inch per day). The 4 inches of water will be gone in 14 days ($4 \div 0.29 = 14$), and we should irrigate on or before June 29 ($15 + 14 = 29$).

Consider a second example for a shallow-rooted crop, such as dry onions (fig. 27, p. 31). Assume that the top 2 feet of soil hold 3 inches of available water on November 1, and we wish to irrigate when half of that, or 1-1/2 inches, is used. Adding semimonthly use figures, we find that by January 15, the onions have used 1.22 inches ($0.05 + 0.09 + 0.20 + 0.37 + 0.51 = 1.22$), and we have 0.27 inch left in the root zone. Average daily use for the last half of January is 0.05 inch per day ($0.74 \div 15 = 0.05$). The 0.27 inch will be gone in 5 days ($0.27 \div 0.05 = 5$). To keep from running out of water, we should irrigate in 5 days, or about January 20 ($15 + 5 = 20$).

Data from the figures can be used for irrigation scheduling in areas having growing seasons comparable to those in the Salt River Valley of Arizona. Small differences in growing season length and planting dates can be taken care of by shifting the curves forward or backward on the time scale, as required. Within similar limitations, the seasonal consumptive use totals and peak consumptive use rates can be used for planning irrigation projects or farm irrigation systems.

The profile-use diagrams show the percentage of water used at the respective soil depths. If 5 percent is used at a certain depth, and the total consumptive use is 30 inches, 5 percent of 30 = 1.5 inches. Many soils will hold 1.5 inches or more of available water per foot; therefore, this amount of water could possibly be stored early in the season for later use, and replenishment of this water would not be necessary during the growing season.

Several methods have been developed for predicting or estimating consumptive use (5). All these methods require local or regional coefficients to obtain reliable estimates. Direct transfer of the measured consumptive-use data in this report to an area of similar latitude, temperature, humidity, cloud cover, and wind as Phoenix is possible. In addition, a simple method of utilizing our information in different but somewhat similar areas is the Blaney-Criddle formula (*1*). The main advantage of this method is that only temperature and sunshine hours are required. These are probably the most important climatic factors and are readily available for most locations. A brief description of the Blaney-Criddle method along with empirical consumptive-use crop coefficients is presented in Appendix II (p. 38). Our crop coefficients (K factors) would not be valid for areas of high humidity, high windspeeds, and excessive cloud cover. In these situations, crop coefficients should be determined from actual consumptive-use measurements.

A list of common conversion factors from English to metric units for using this data in other countries and making related computations is given in Appendix III (p. 42).

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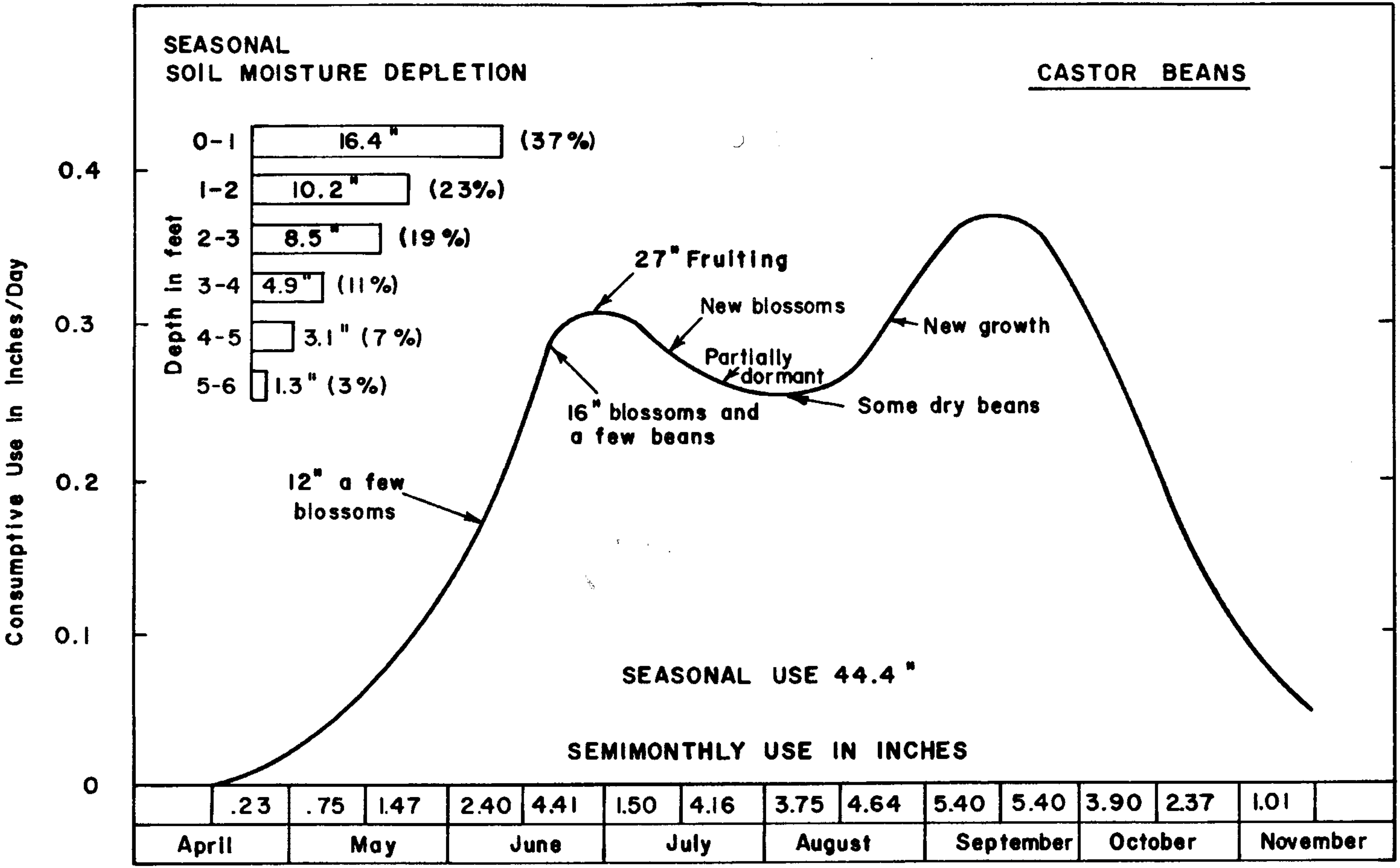

Figure 1.—Mean consumptive use for castor beans at Mesa, Ariz., 1958.

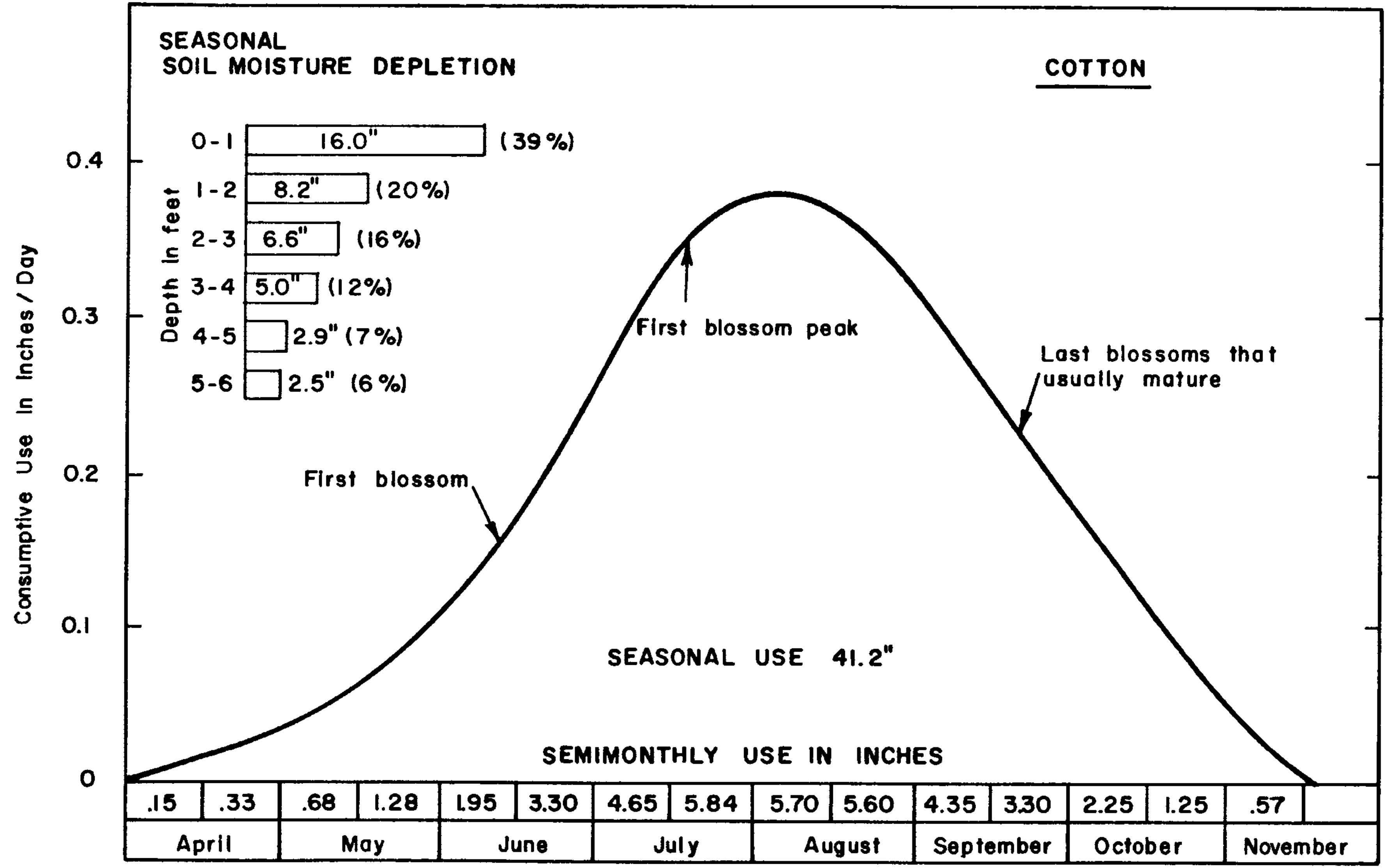

Figure 2.—Mean consumptive use for cotton at Mesa and Tempe, Ariz., 1954-62.

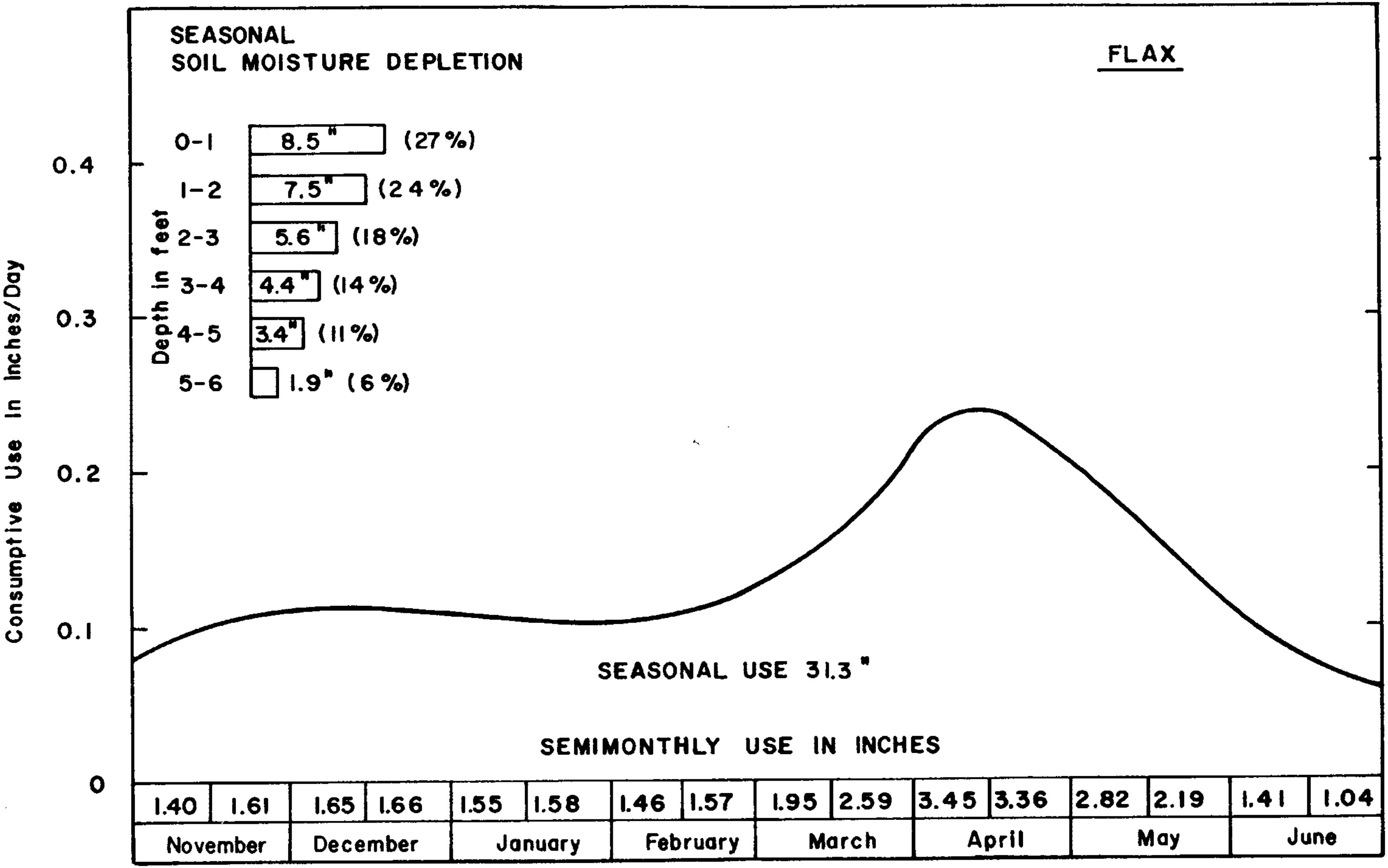

Figure 3.—Mean consumptive use for flax at Mesa, Ariz., 1943-44.

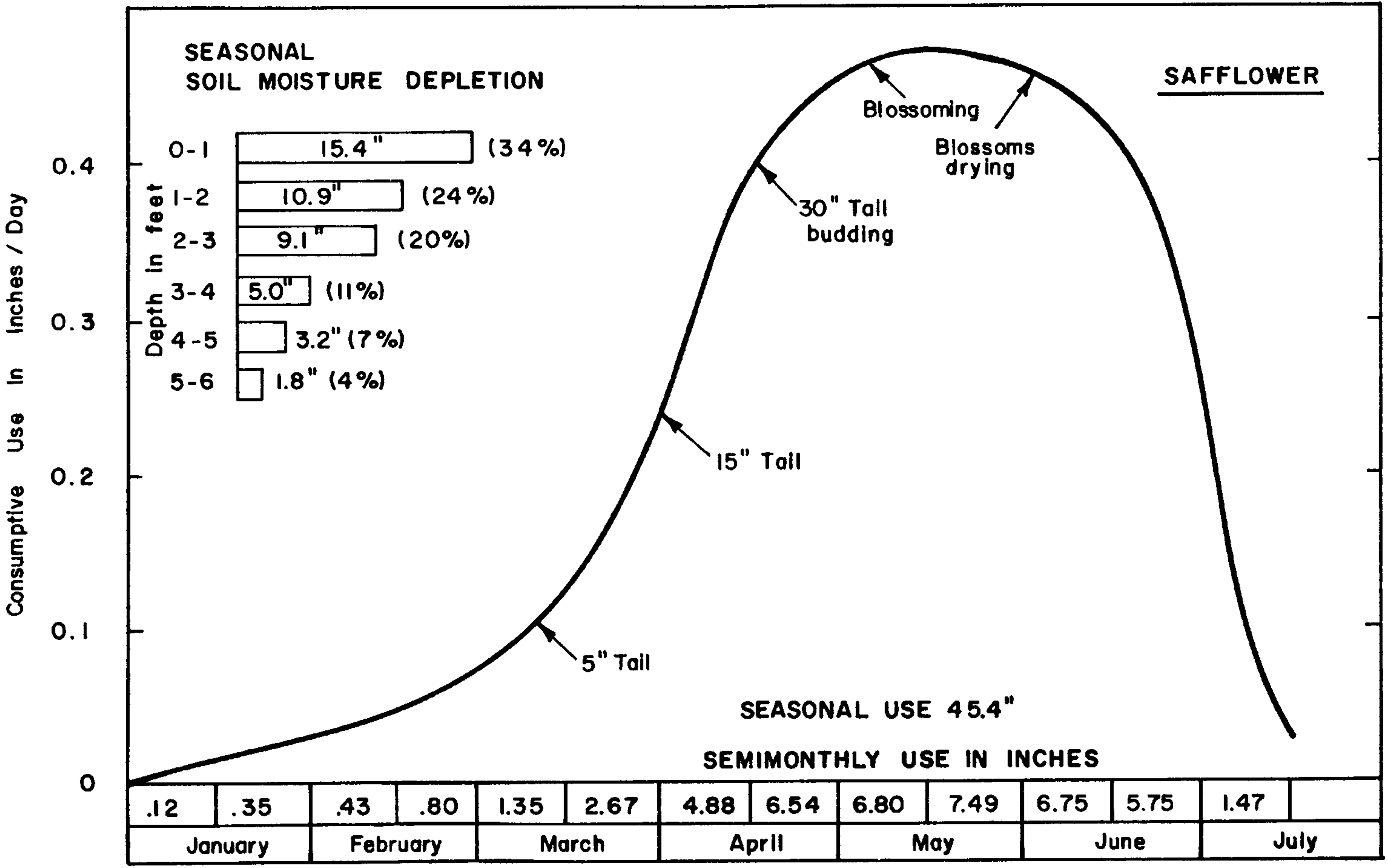

Figure 4.—Mean consumptive use for safflower at Mesa, Ariz., 1958-60, 1963-64.

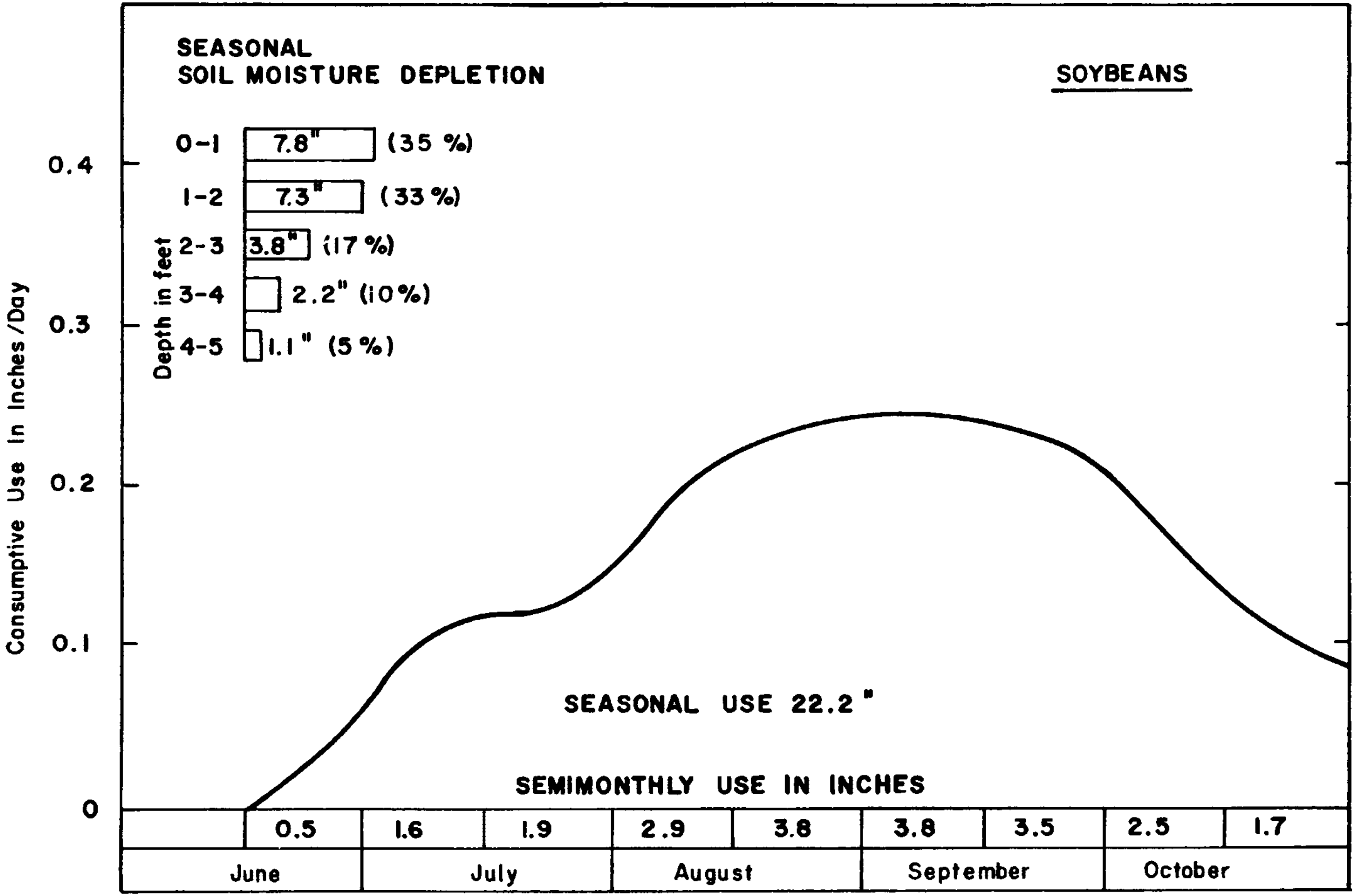

Figure 5.—Mean consumptive use for soybeans at Mesa, Ariz., 1944.

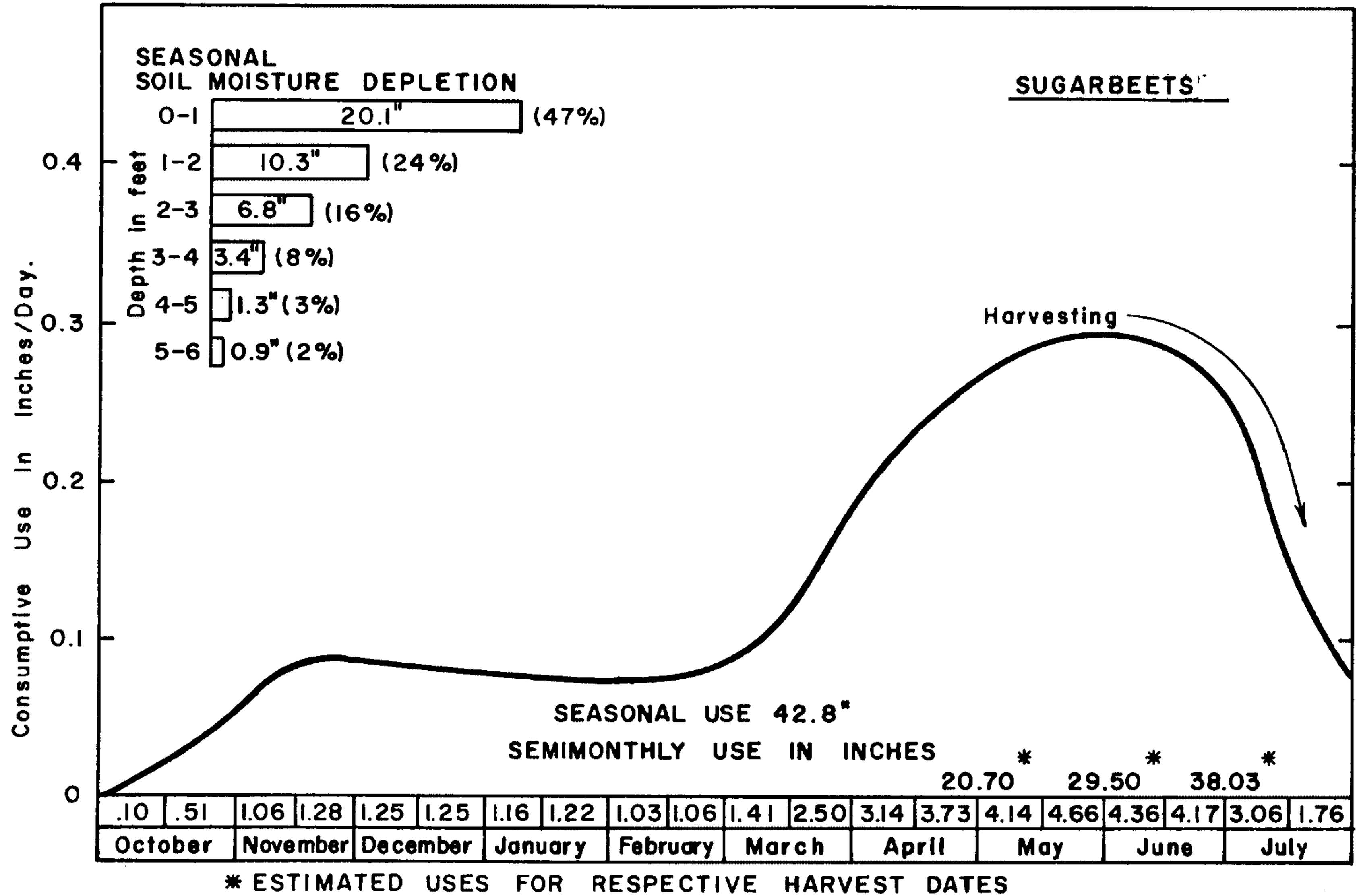

Figure 6.—Mean consumptive use for sugarbeets at Mesa, Ariz., 1956-66.

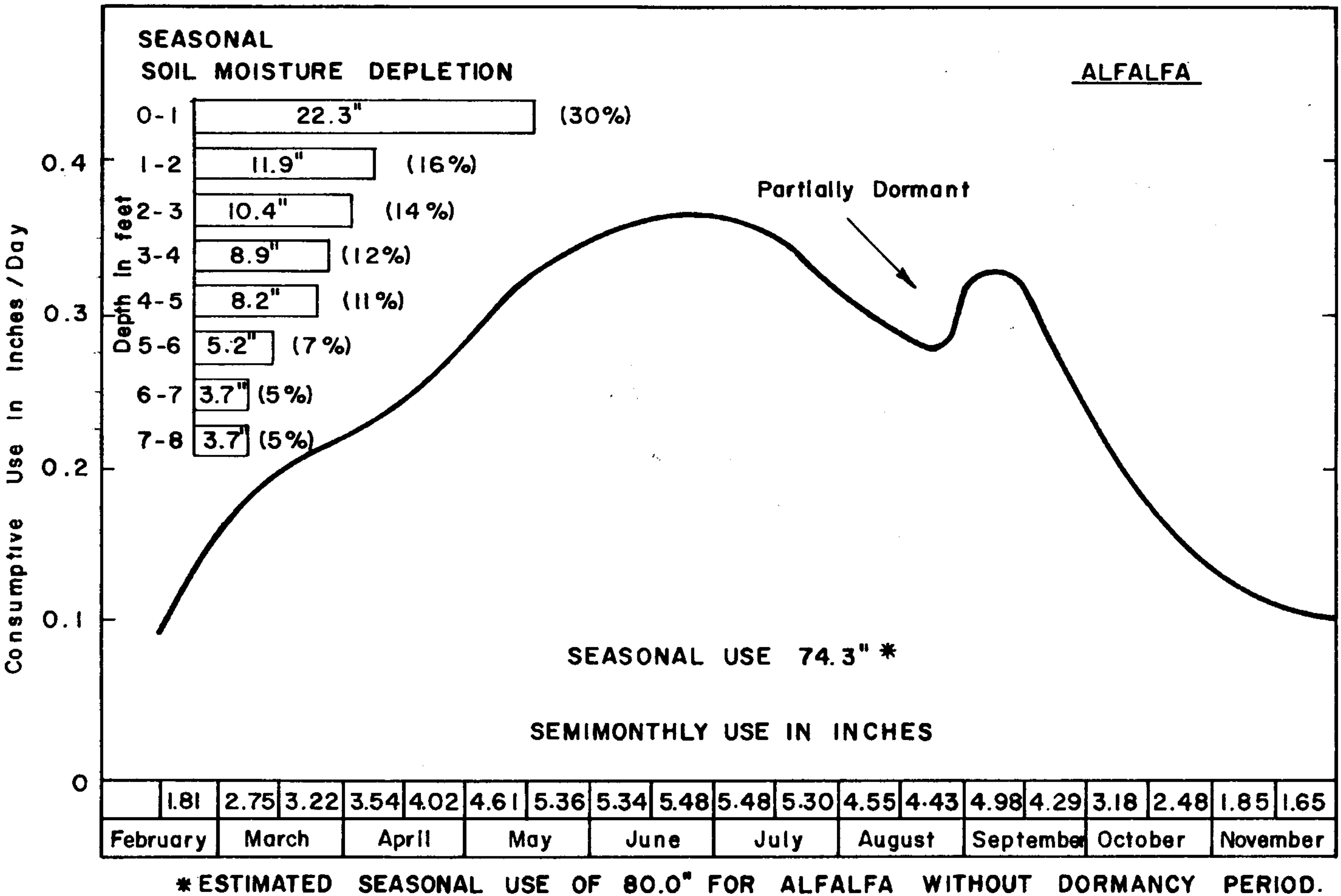

Figure 7.—Mean consumptive use for alfalfa at Mesa and Tempe, Ariz., 1946, 1950, 1962-63.

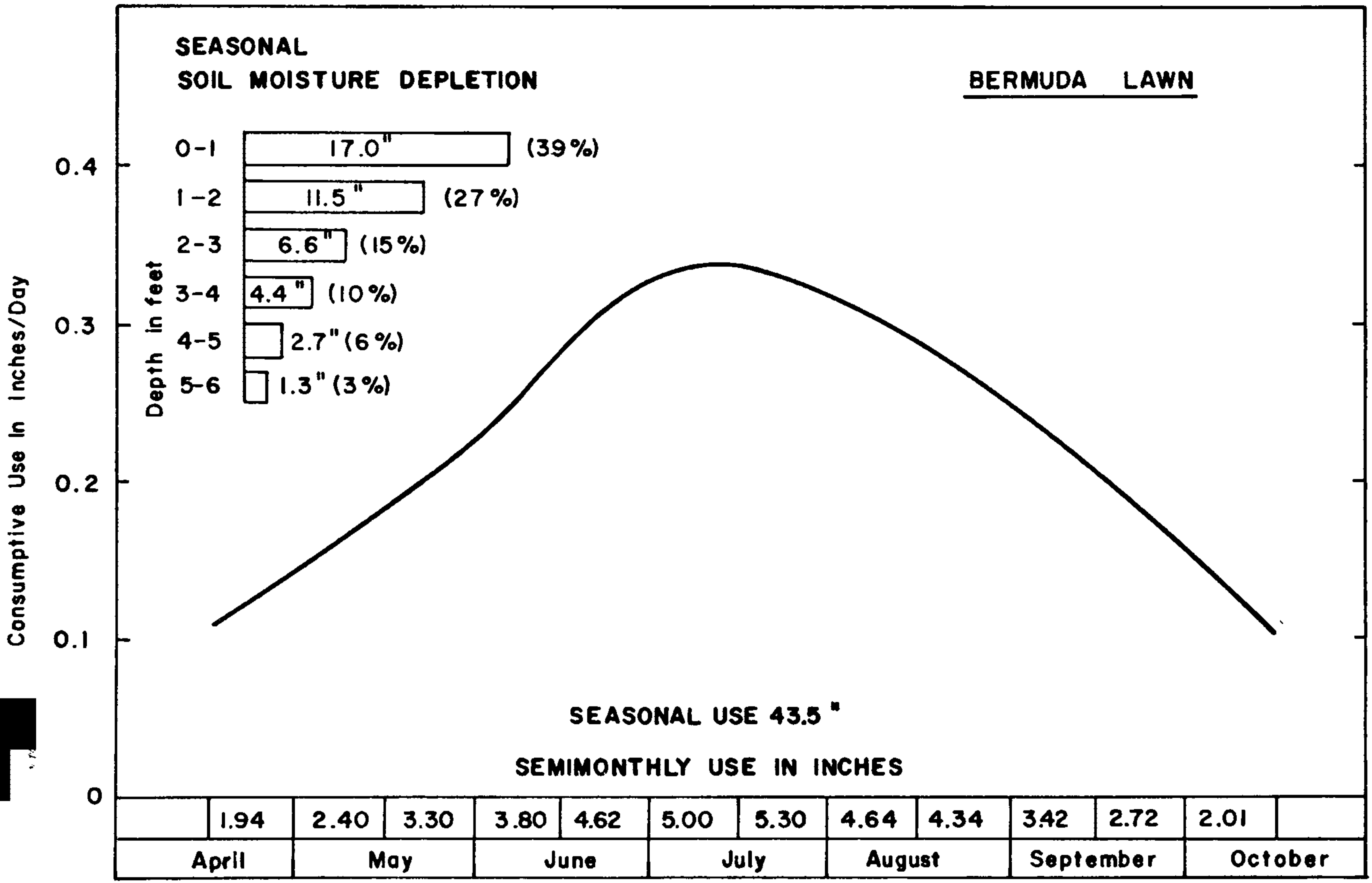

Figure 8.—Mean consumptive use for Bermuda lawn at Mesa and Tempe, Ariz., 1959-60, 1962-64.

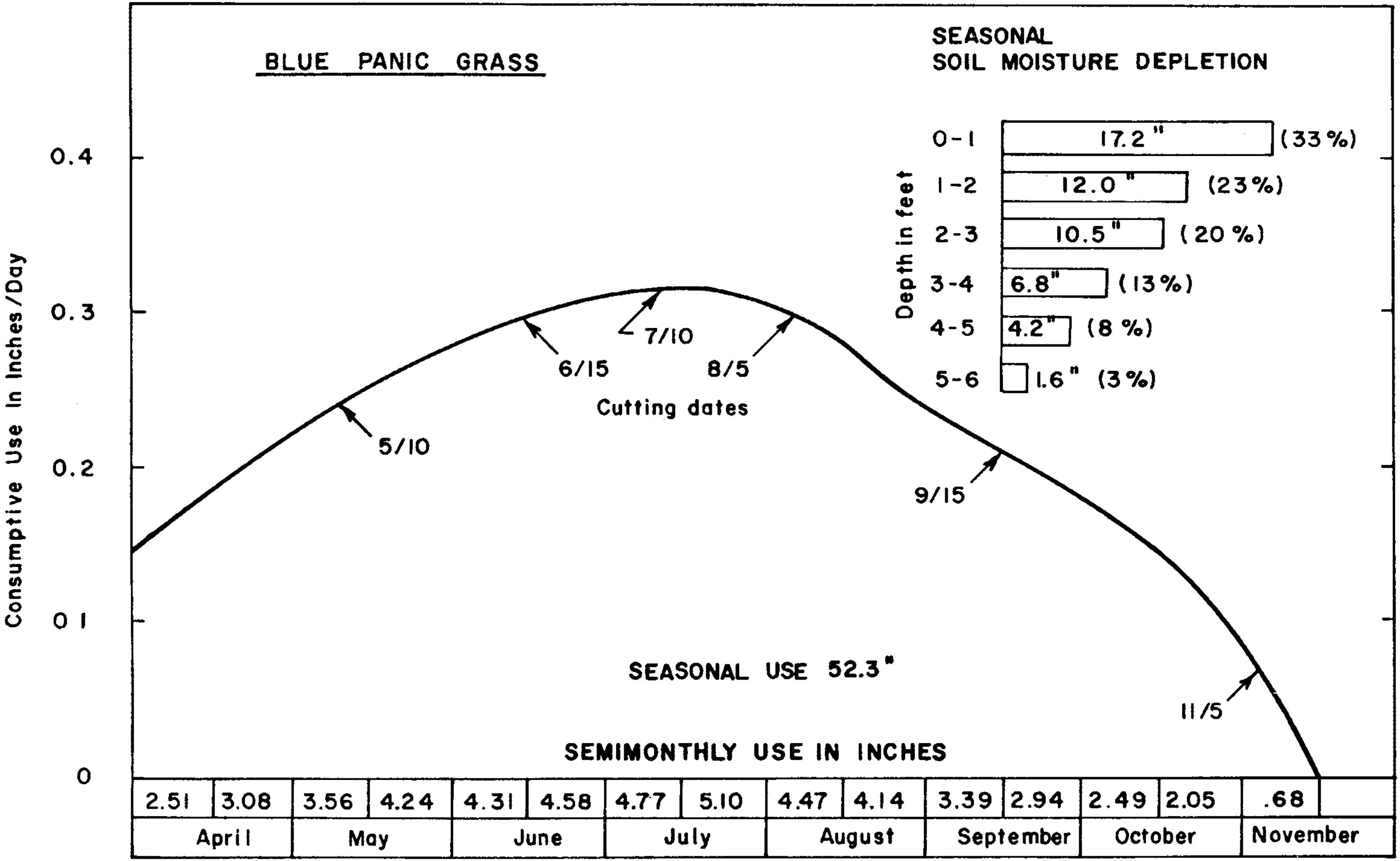

Figure 9.—Mean consumptive use for blue panic grass at Mesa, Ariz., 1960-61.

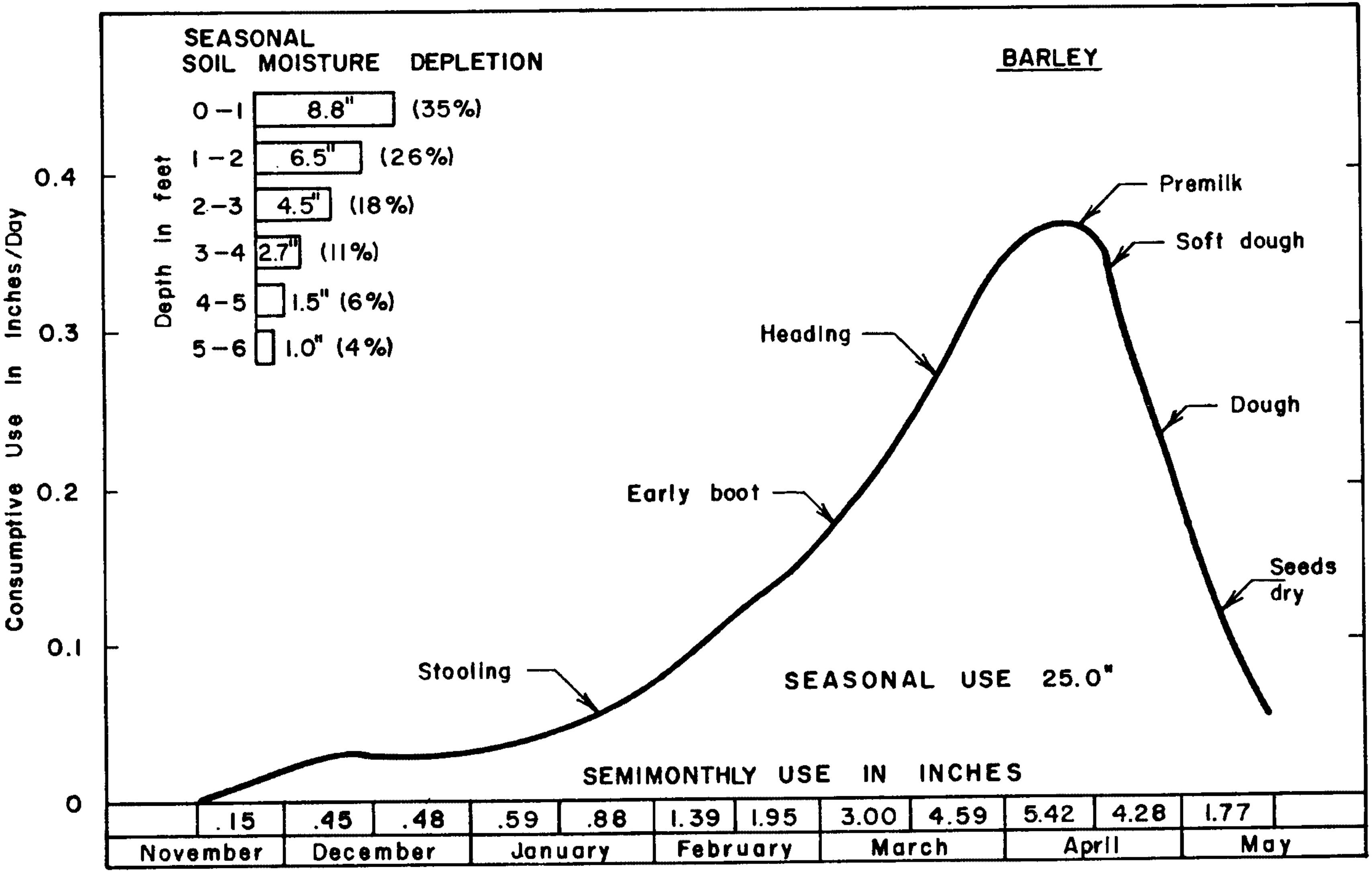

Figure 10.—Mean consumptive use for barley at Mesa, Ariz., 1952-53, 1956, 1969-70.

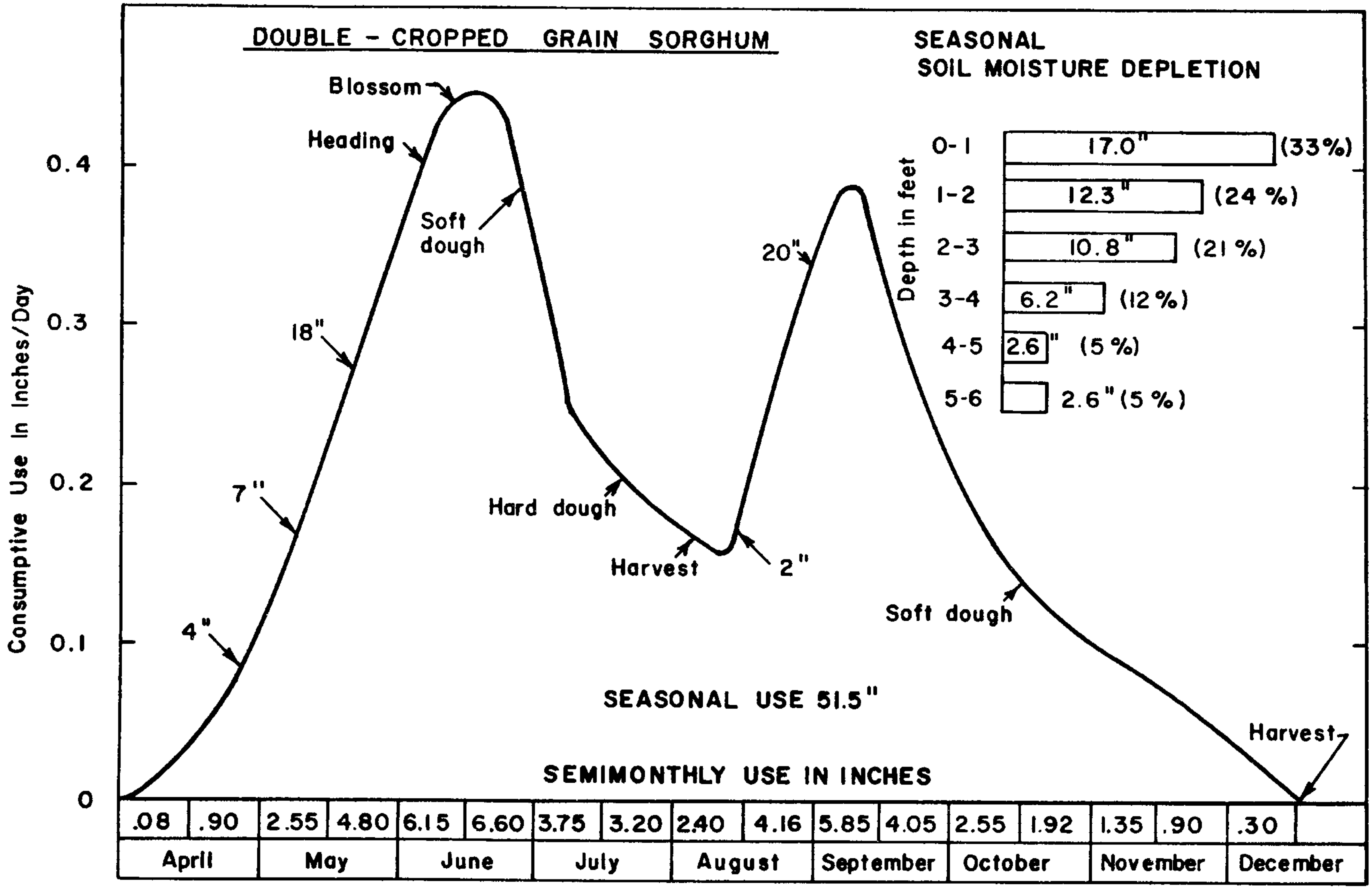

Figure 12.—Mean consumptive use for double-cropped grain sorghum at Mesa, Ariz., 1962.

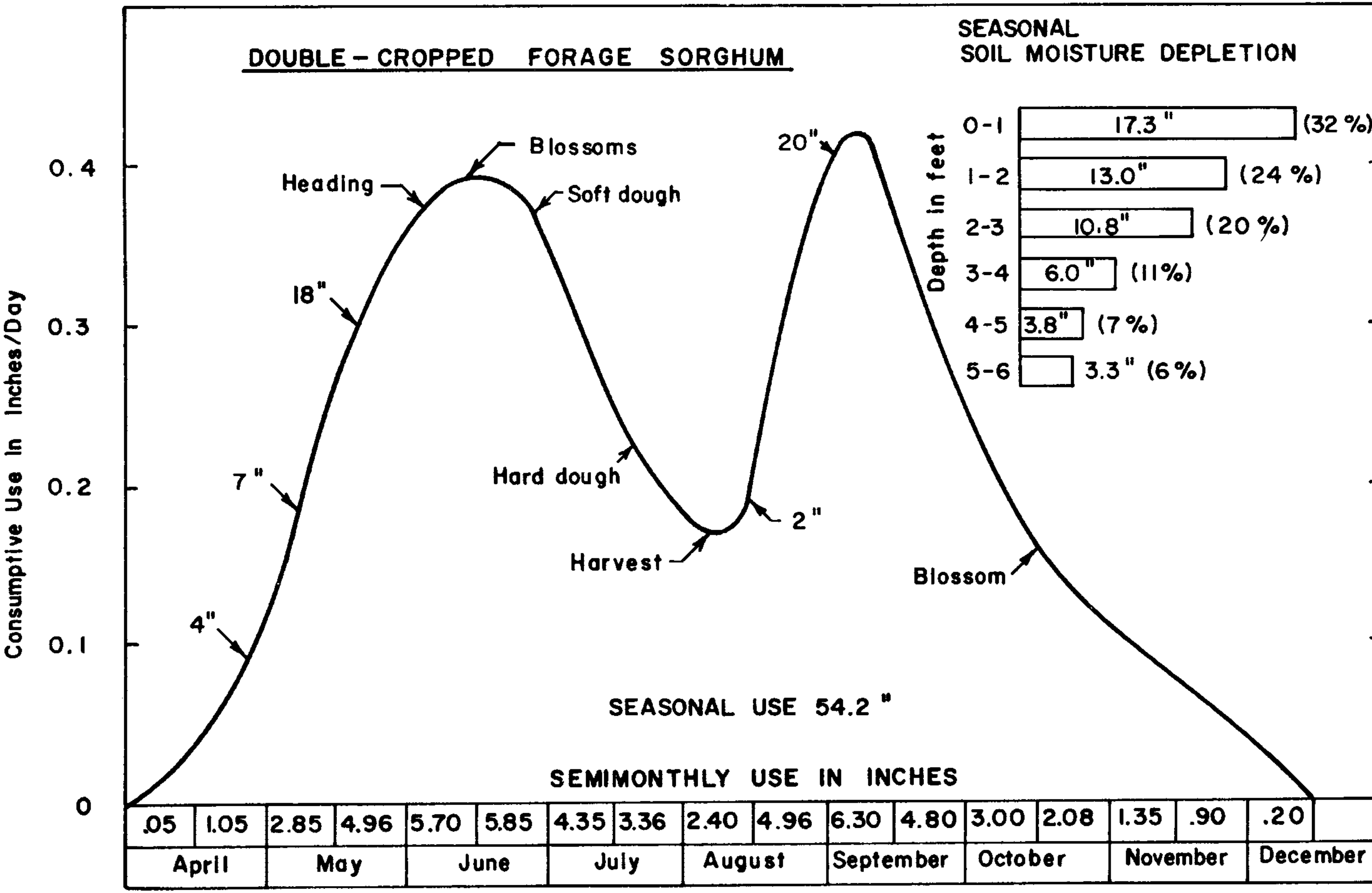

Figure 13.—Mean consumptive use for double-cropped forage sorghum at Mesa, Ariz., 1962.

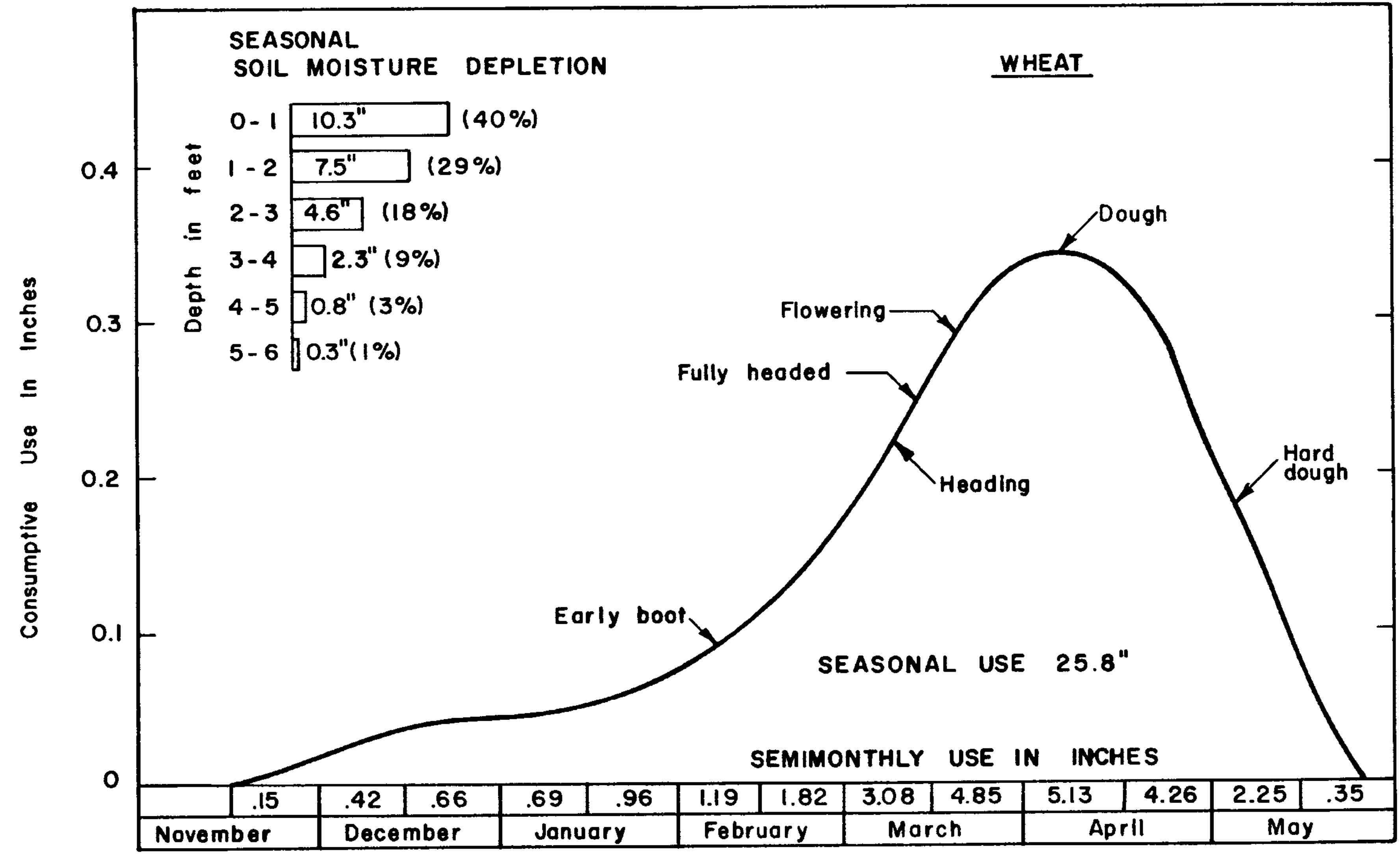

Figure 14.—Mean consumptive use for high-yielding wheats at Mesa, Ariz., 1969-70.

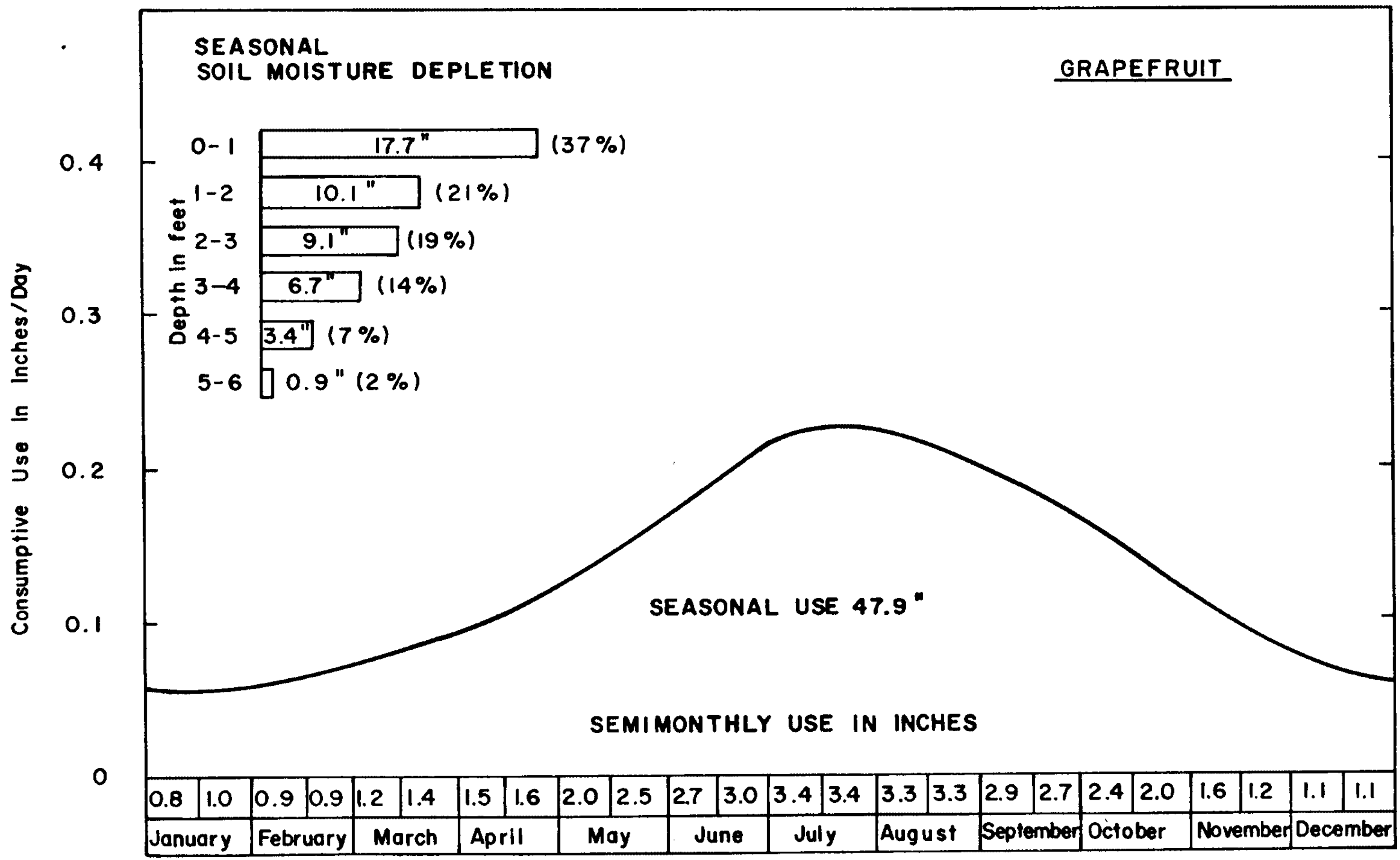

Figure 15.—Mean consumptive use for grapefruit at Phoenix, Ariz., 1931-34.

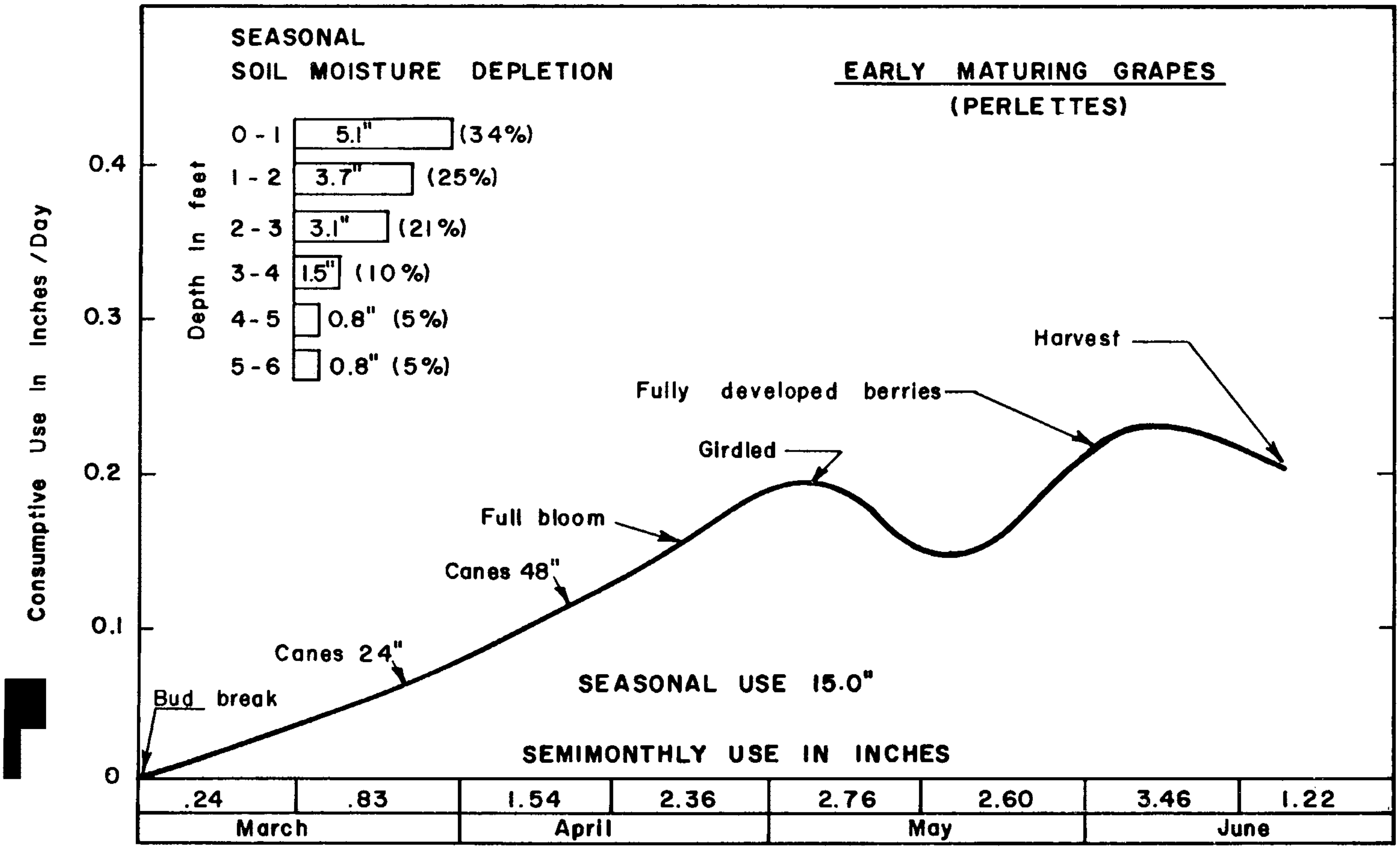

Figure 16.—Mean consumptive use for early maturing grapes at Litchfield Park, Ariz., 1973-77.

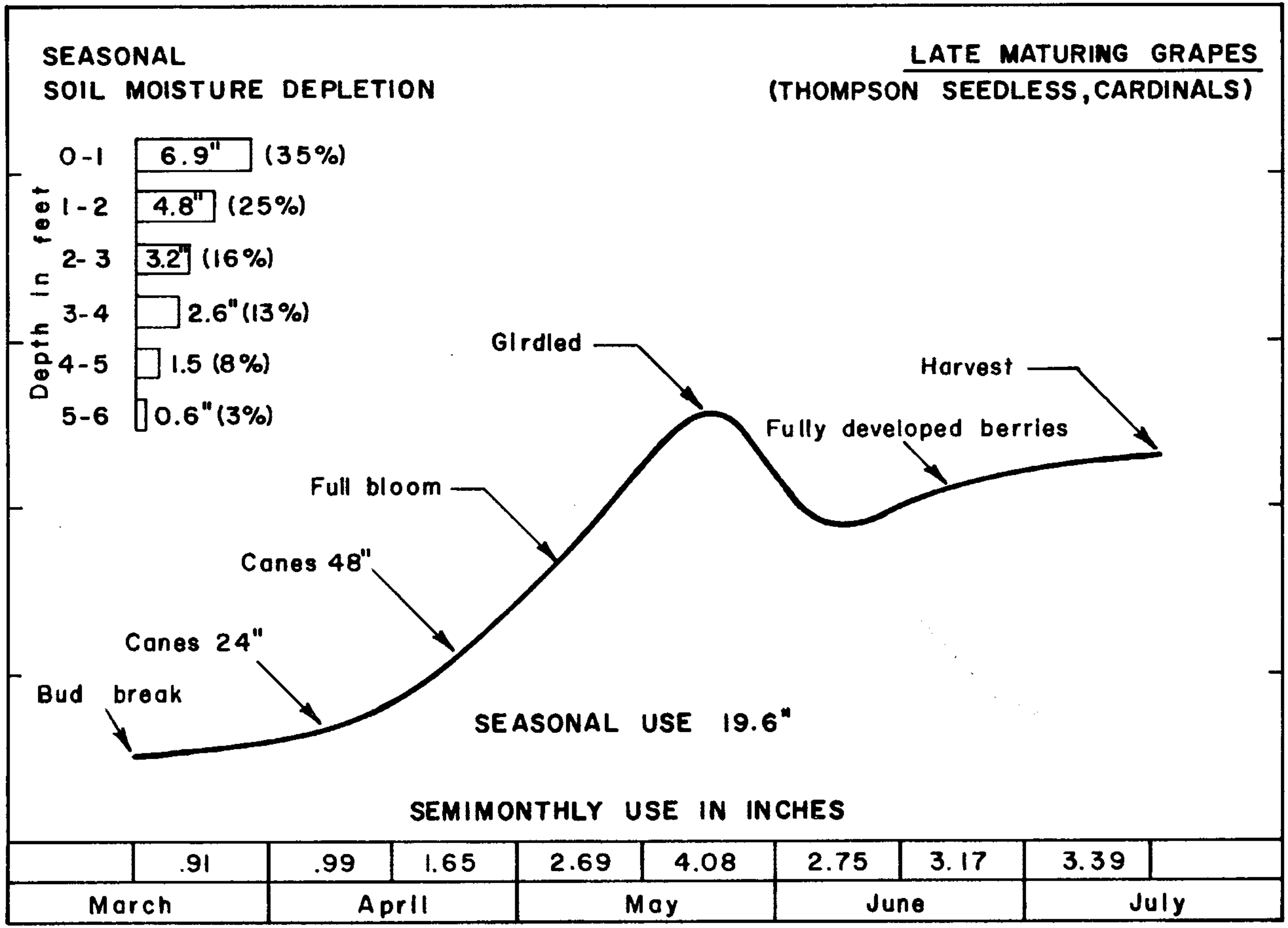

Figure 17.—Mean consumptive use for late maturing grapes at Mesa and Litchfield Park, Ariz., 1961-64.

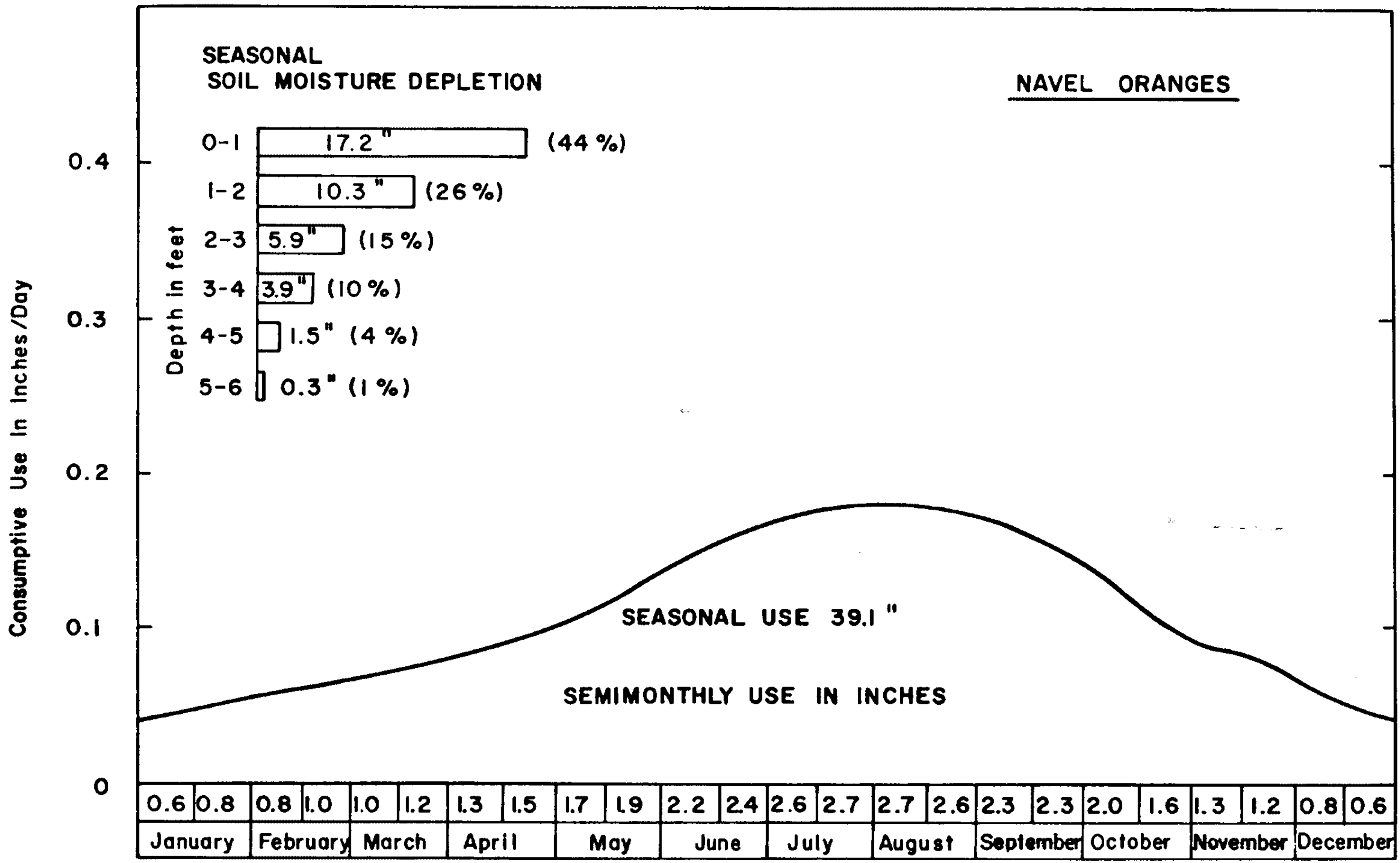

Figure 18.—Mean consumptive use for navel oranges at Phoenix, Ariz., 1931-34.

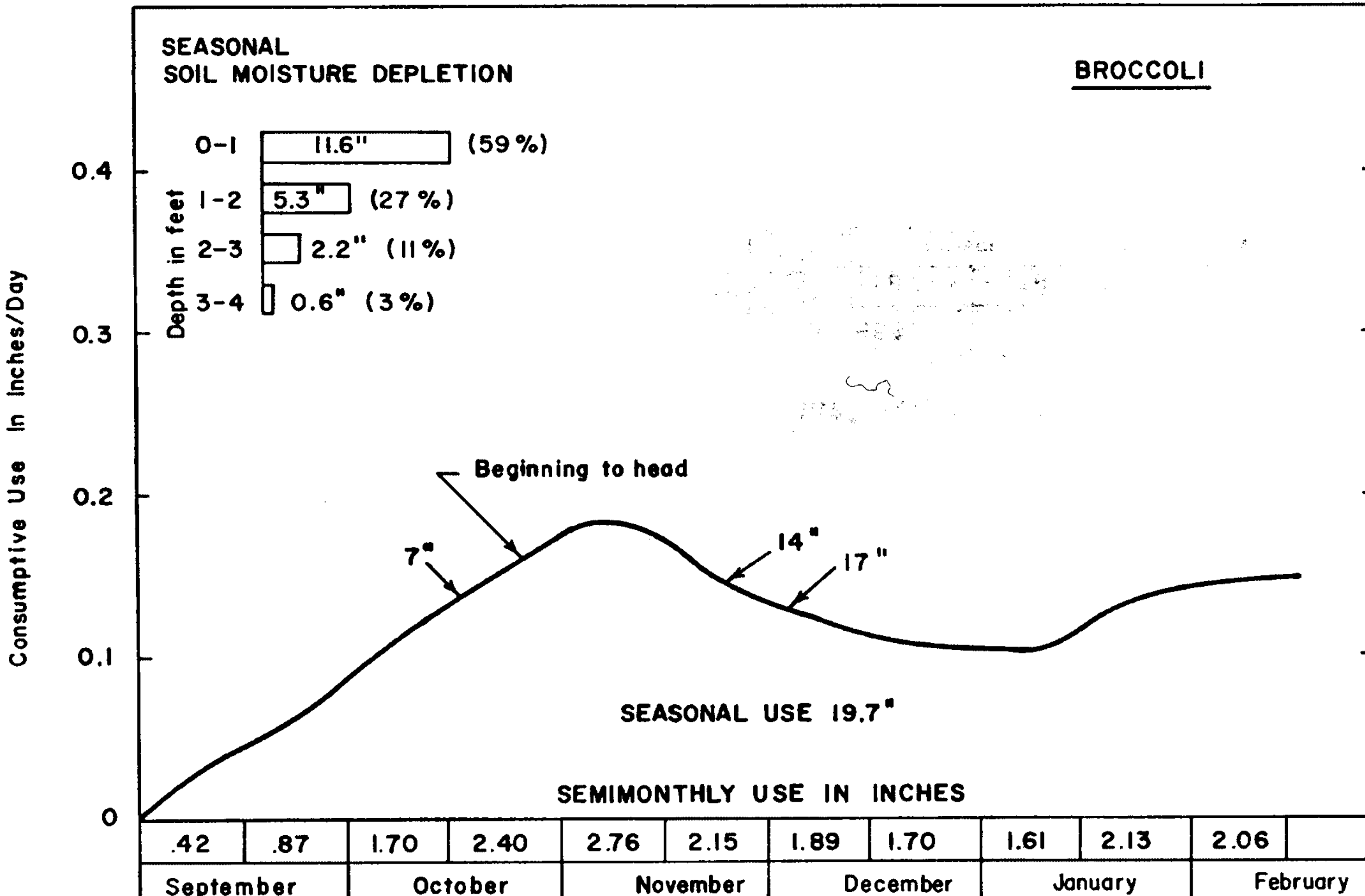

Figure 19.—Mean consumptive use for broccoli at Mesa, Ariz., 1960-62.

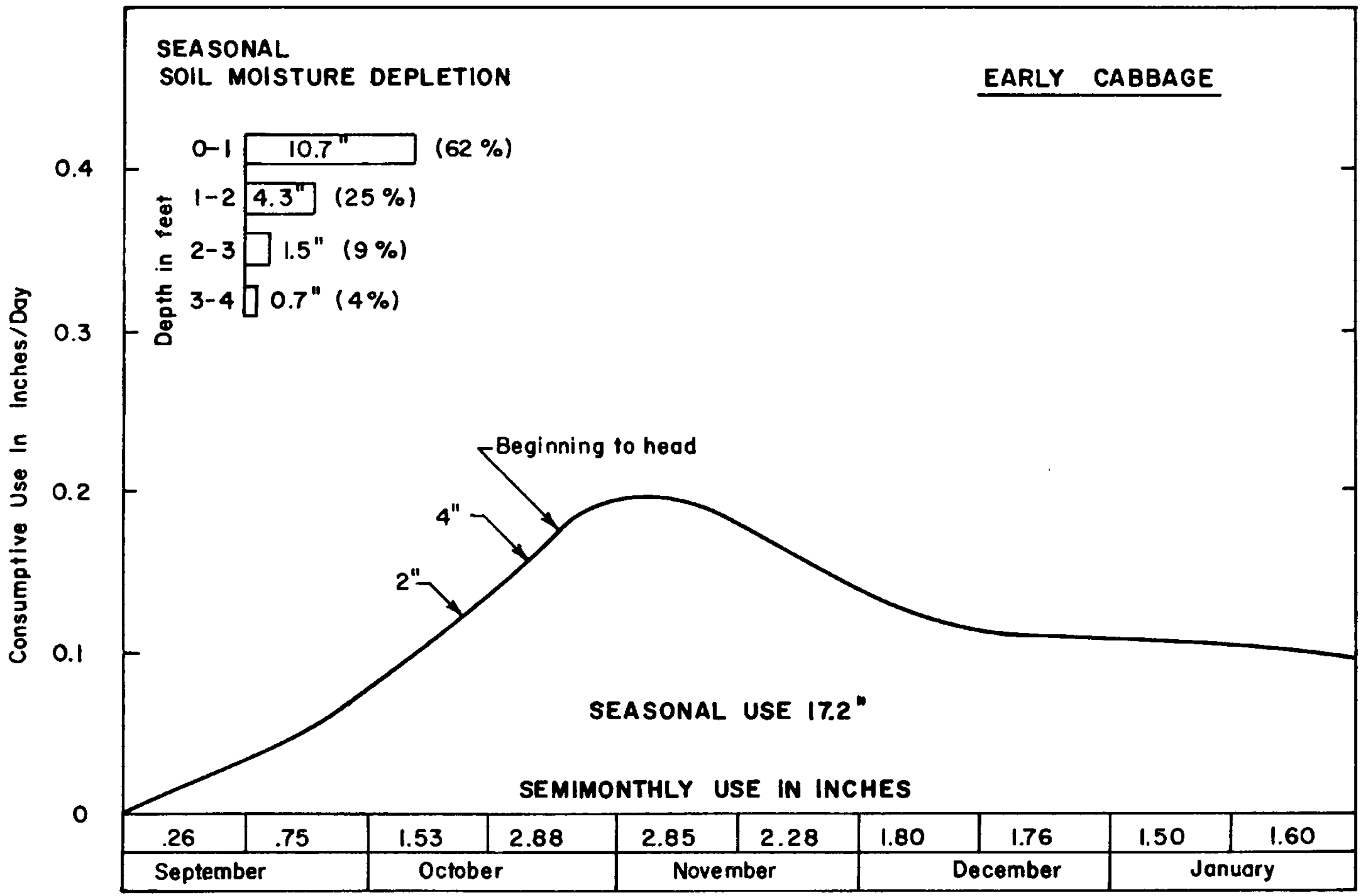

Figure 20.—Mean consumptive use for early maturing cabbage at Mesa, Ariz., 1960-62.

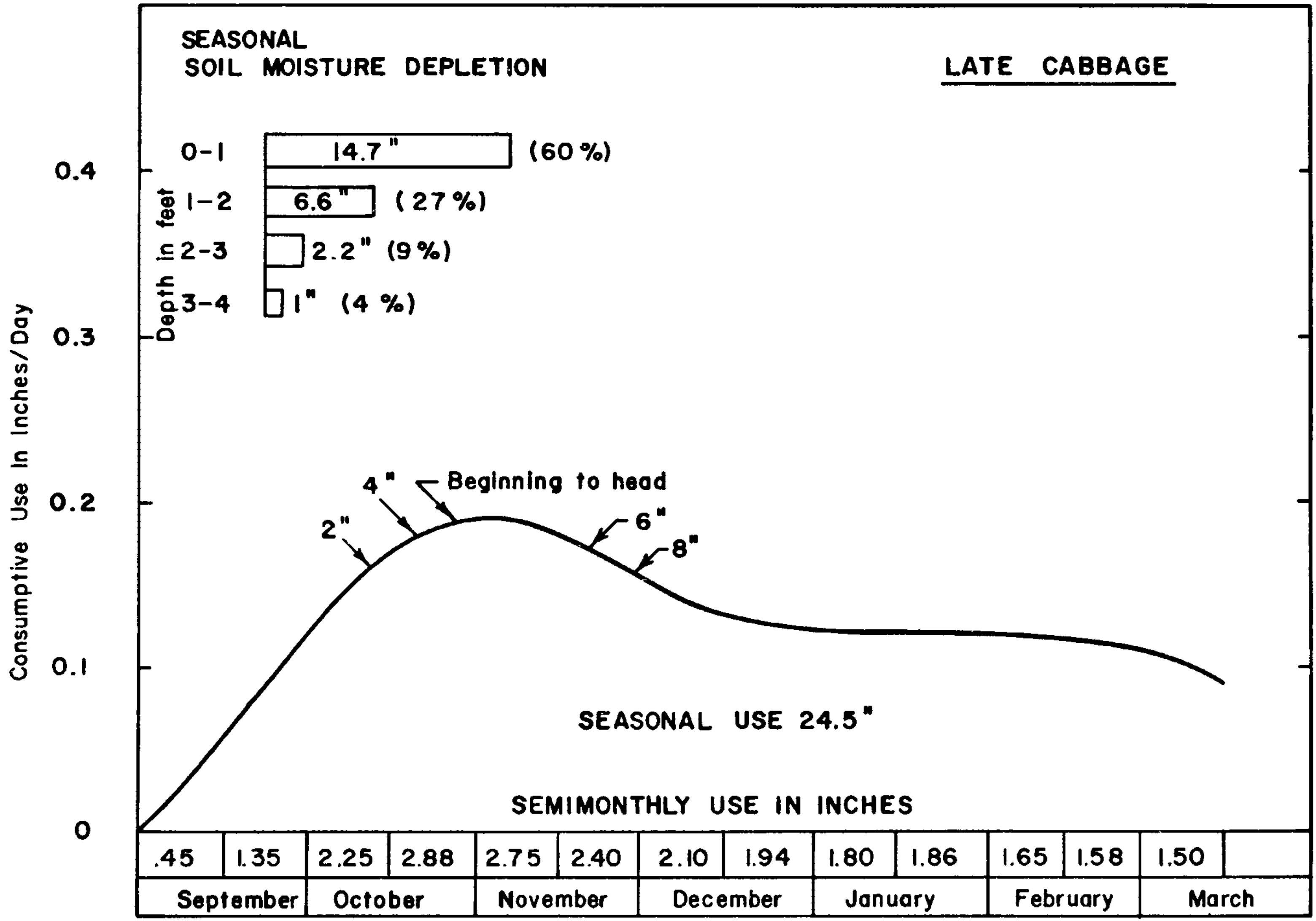

Figure 21.—Mean consumptive use for late maturing cabbage at Mesa, Ariz., 1960-62.

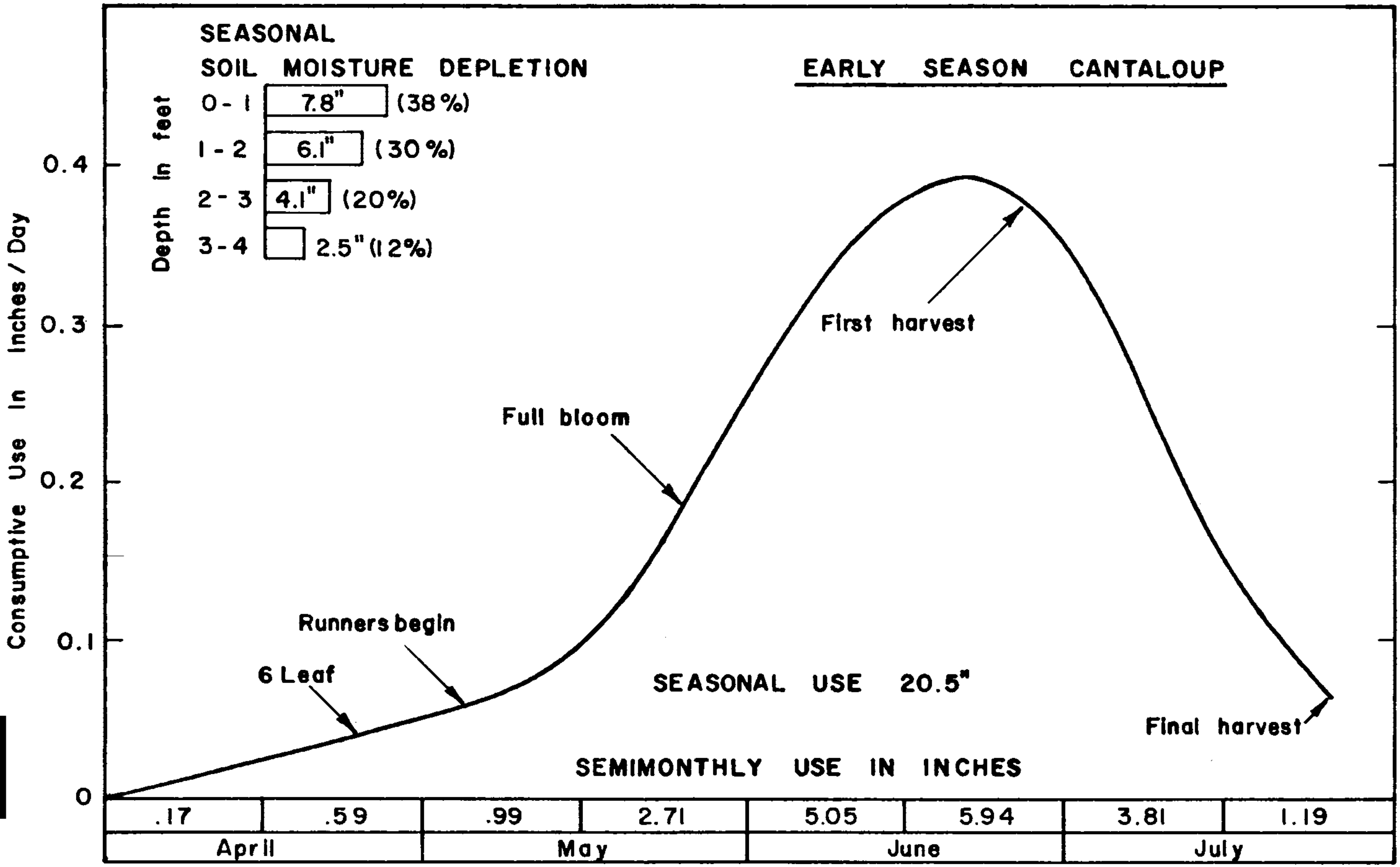

Figure 22.—Mean consumptive use for early season cantaloup at Mesa, Ariz.

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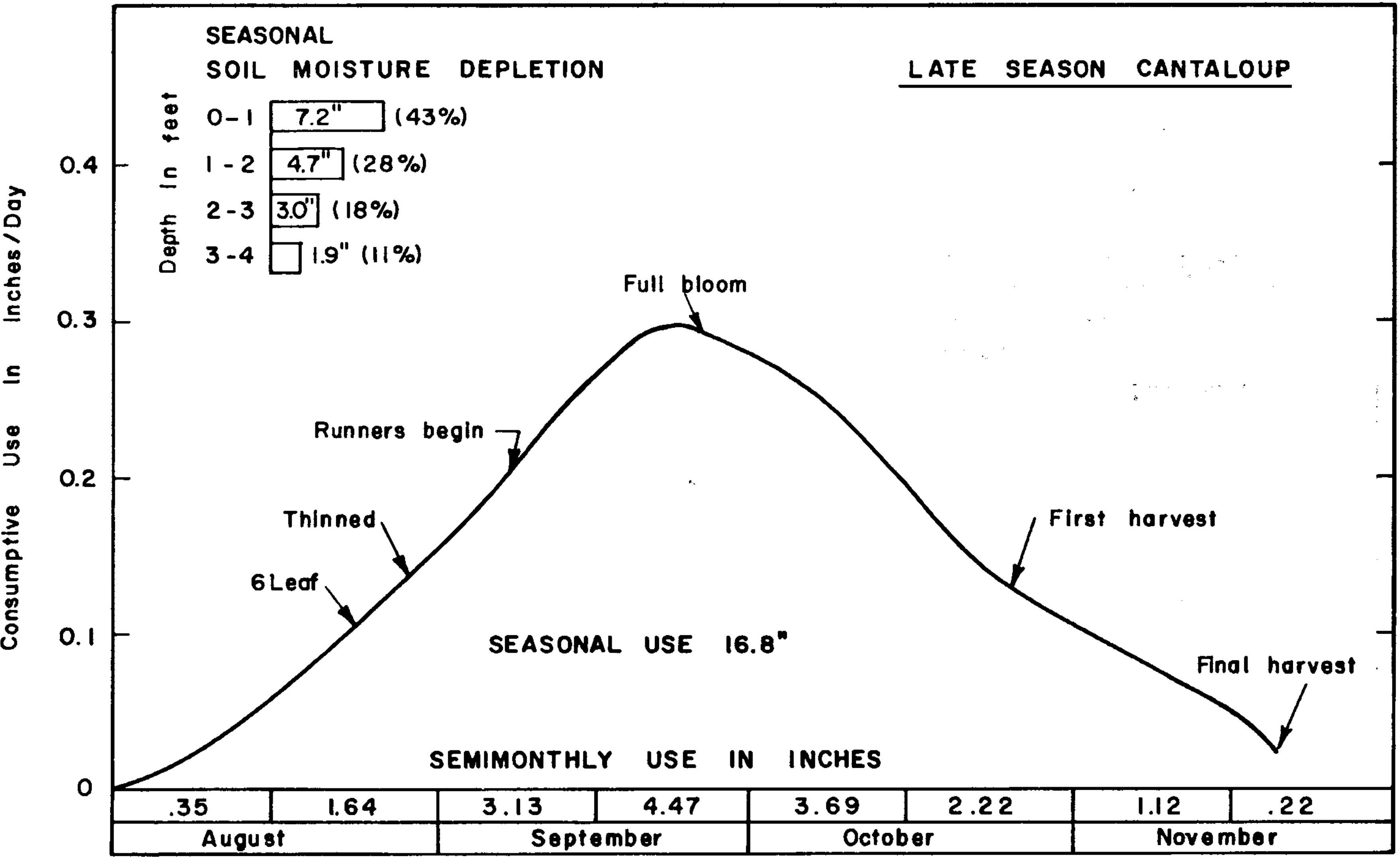

Figure 23.—Mean consumptive use for late season cantaloup at Mesa, Ariz., 1977-79.

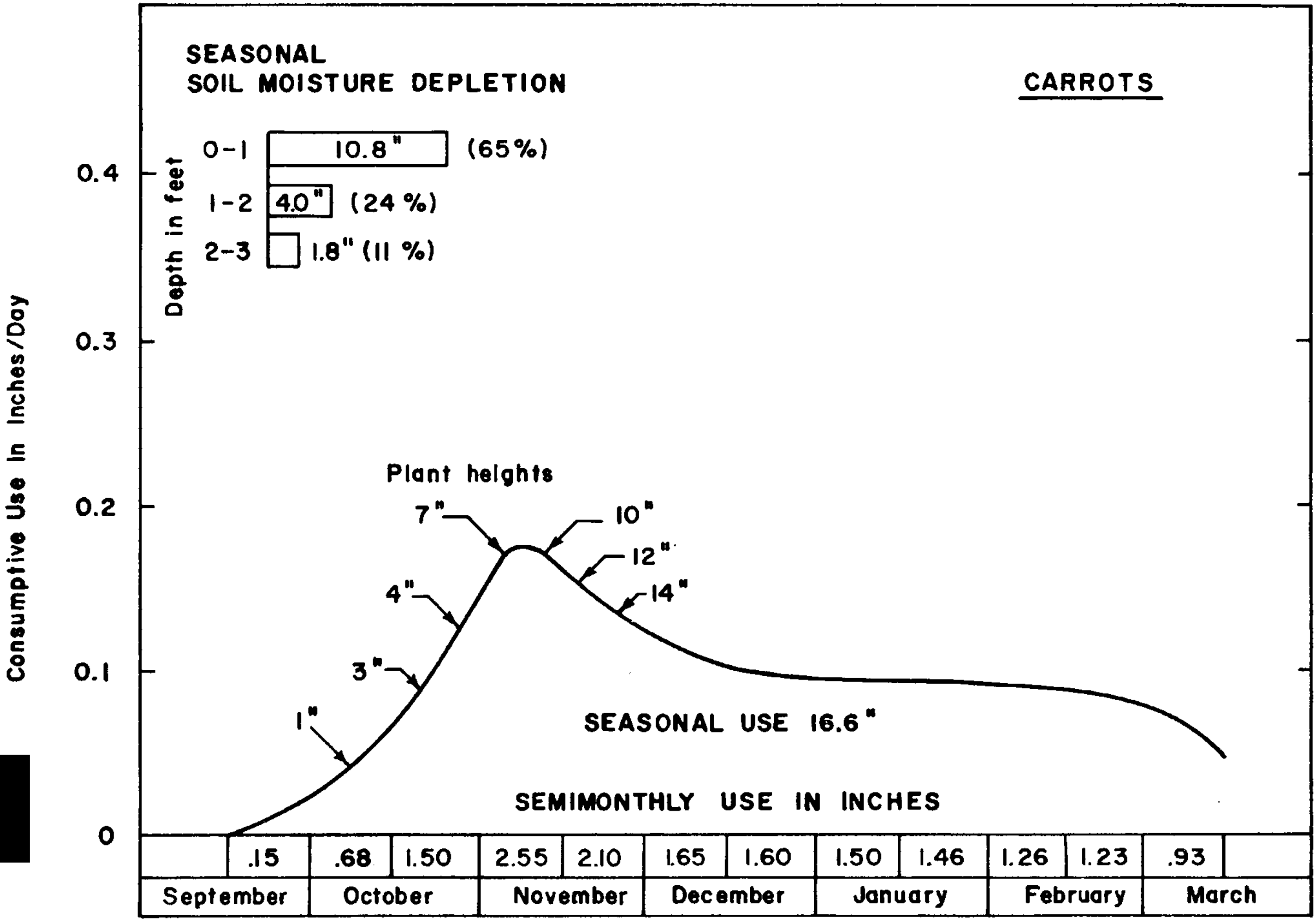

Figure 24.—Mean consumptive use for carrots at Mesa, Ariz., 1960-62.

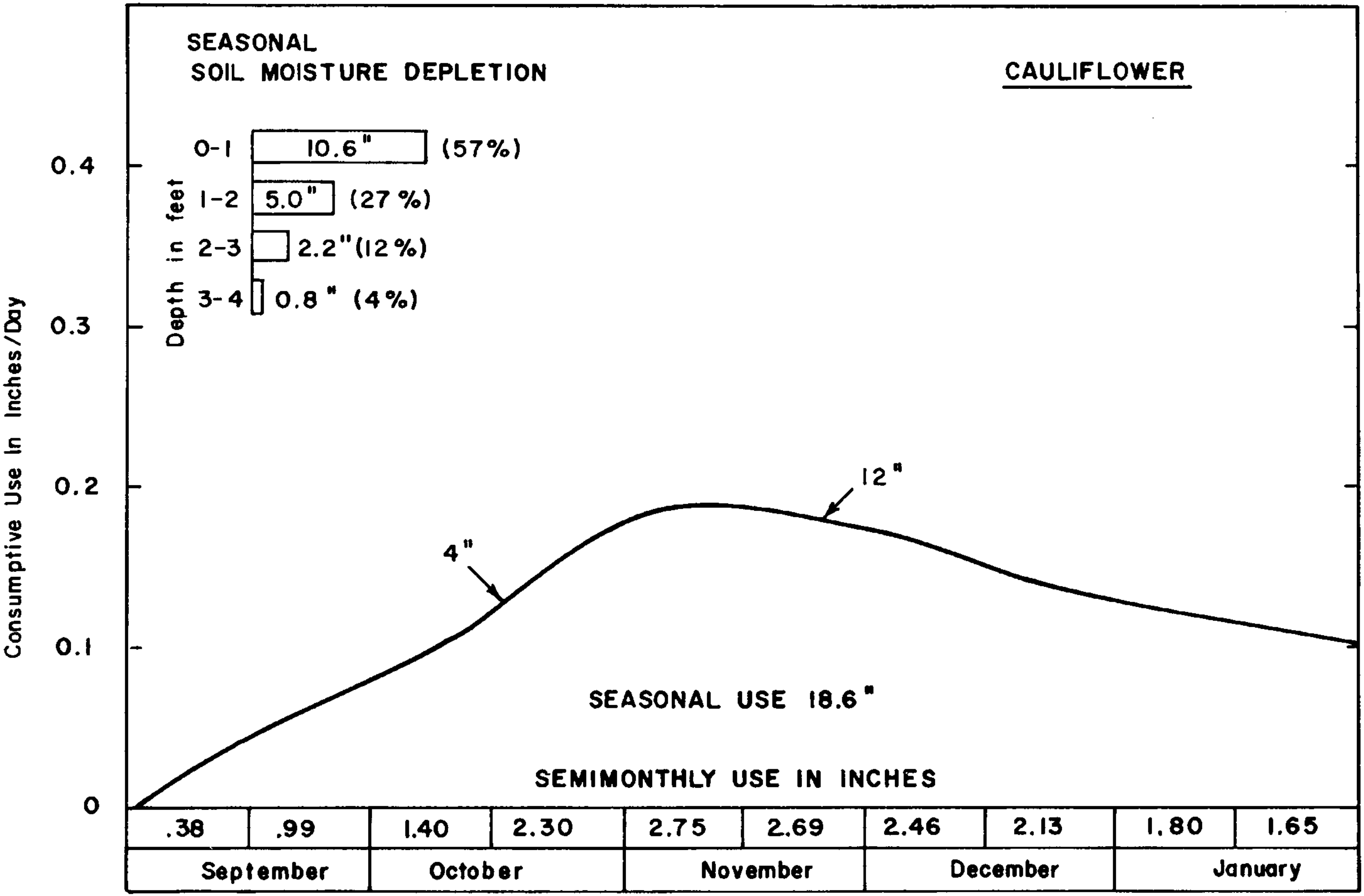

Figure 25.—Mean consumptive use for cauliflower at Mesa, Ariz., 1960-62.

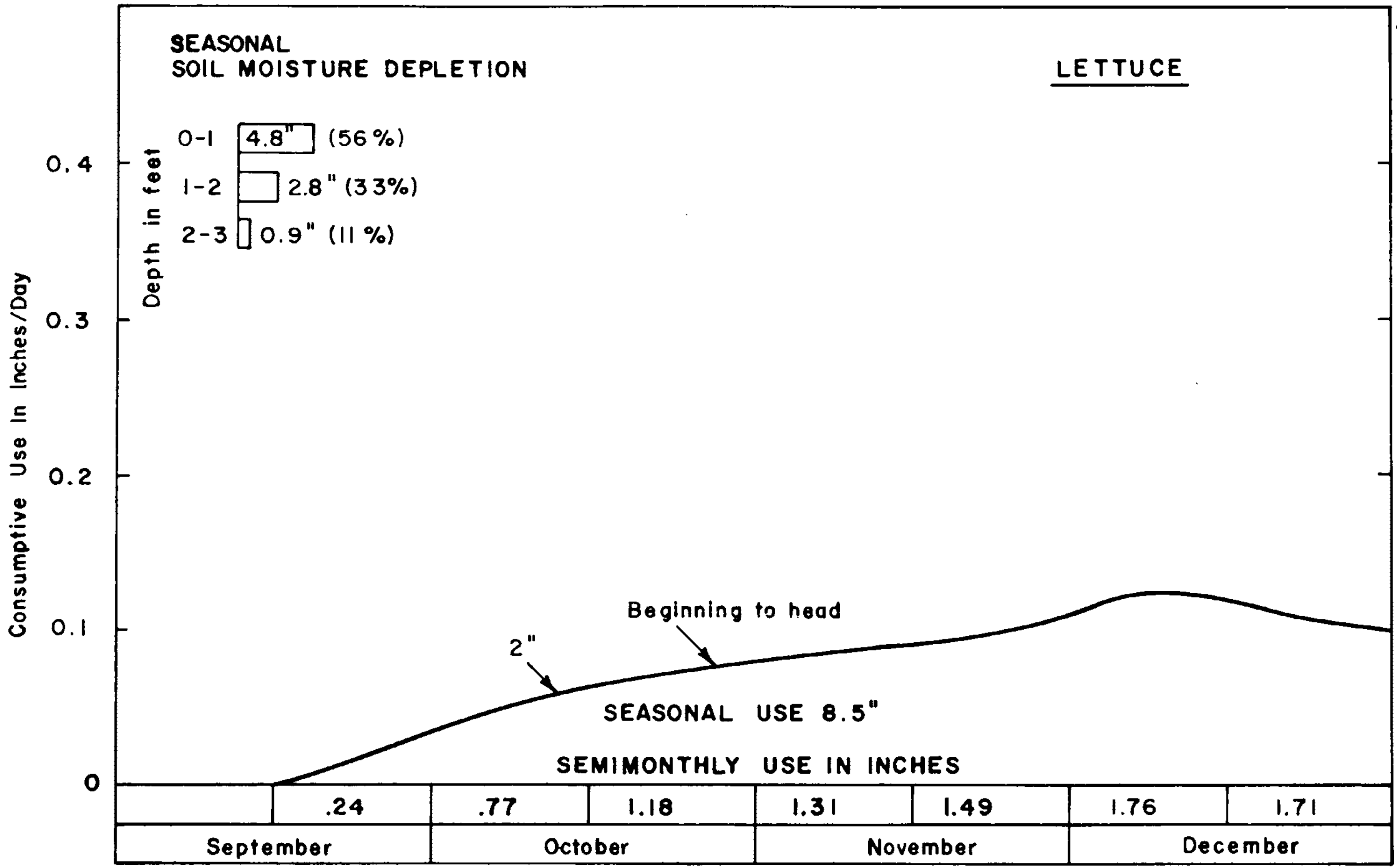

Figure 26.—Mean consumptive use for lettuce at Mesa, Ariz., 1960-62.

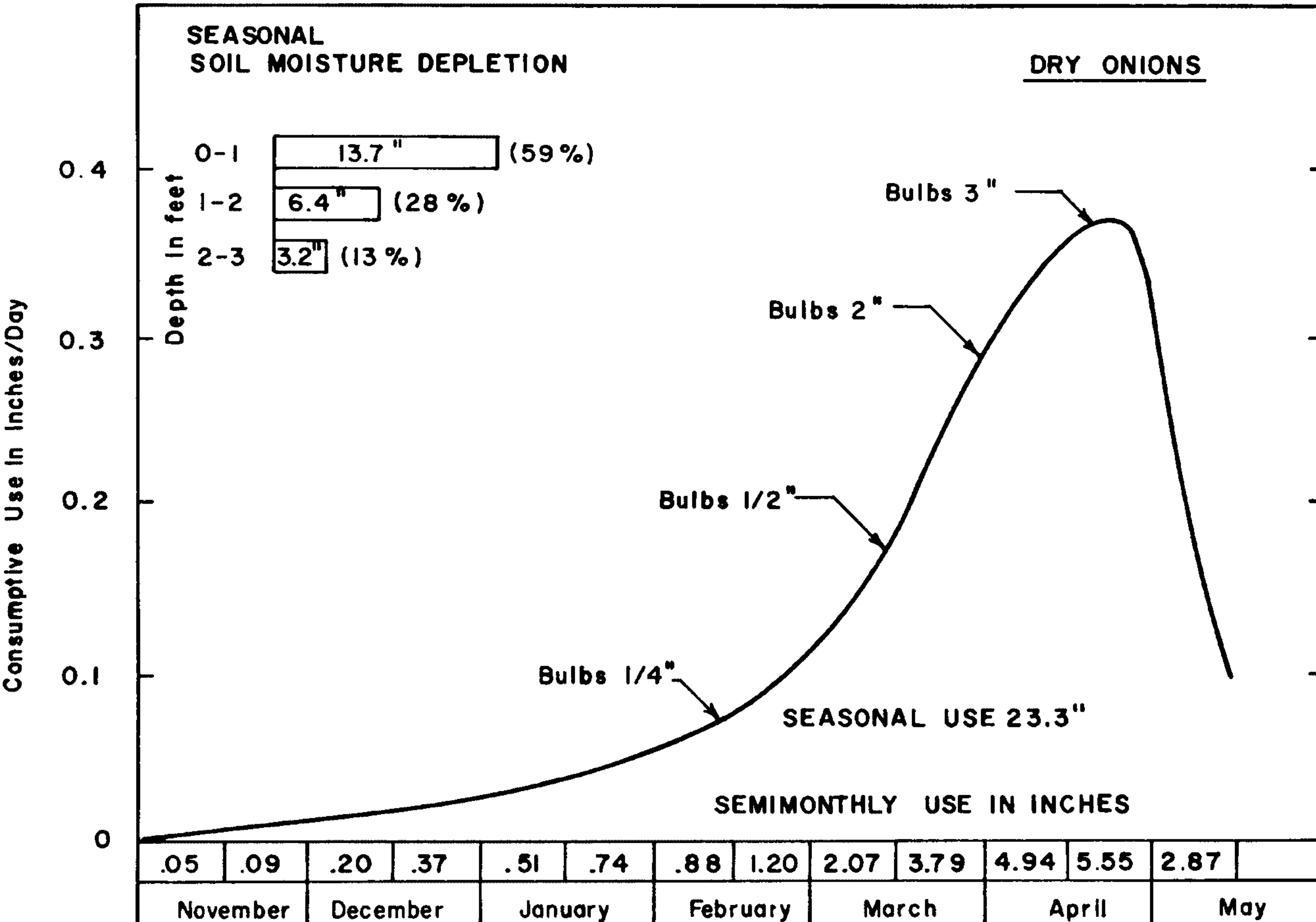

Figure 27.—Mean consumptive use for dry onions at Mesa, Ariz., 1961-62, 1964.

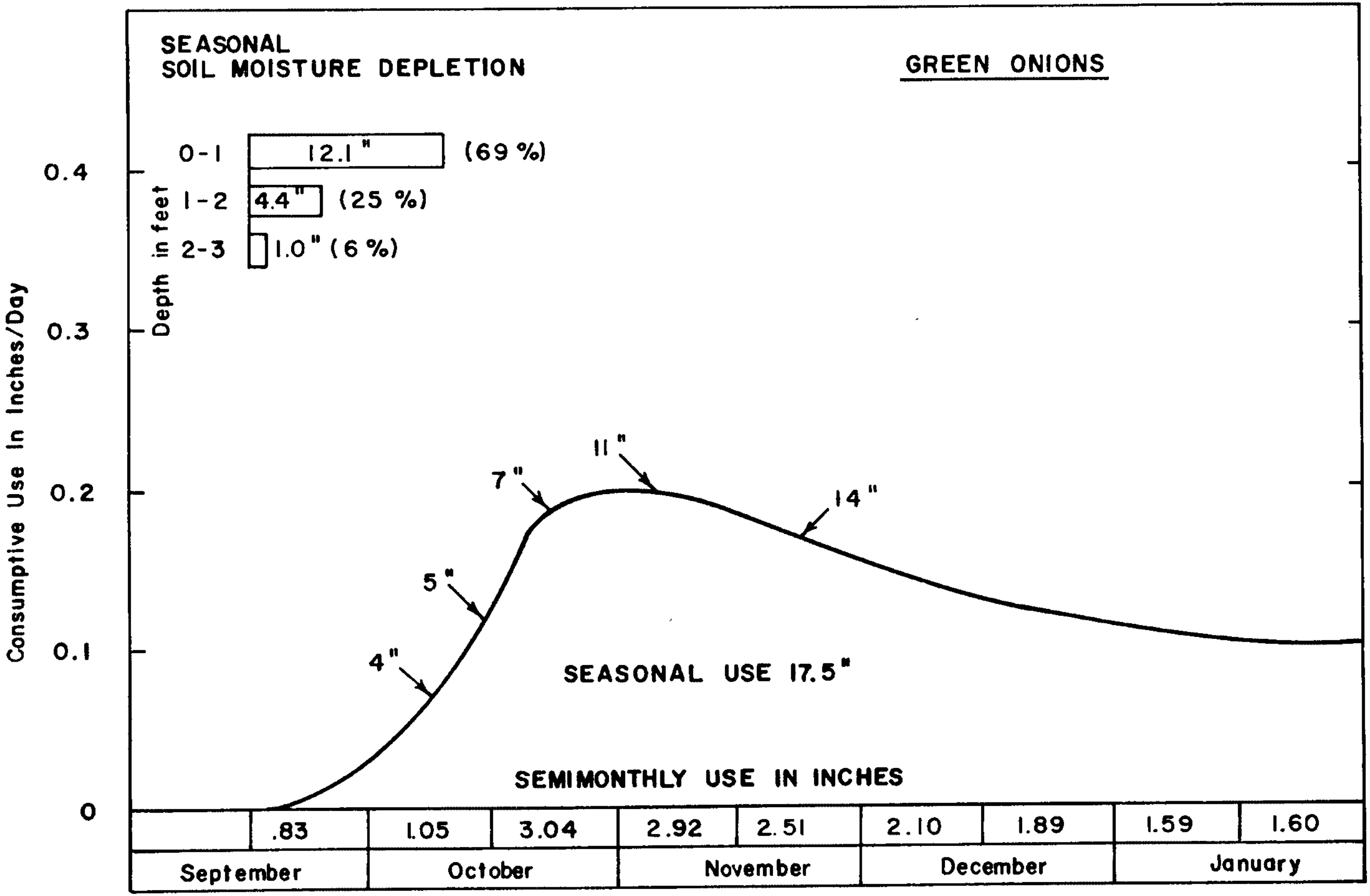

Figure 28.—Mean consumptive use for green onions at Mesa, Ariz., 1960-62.

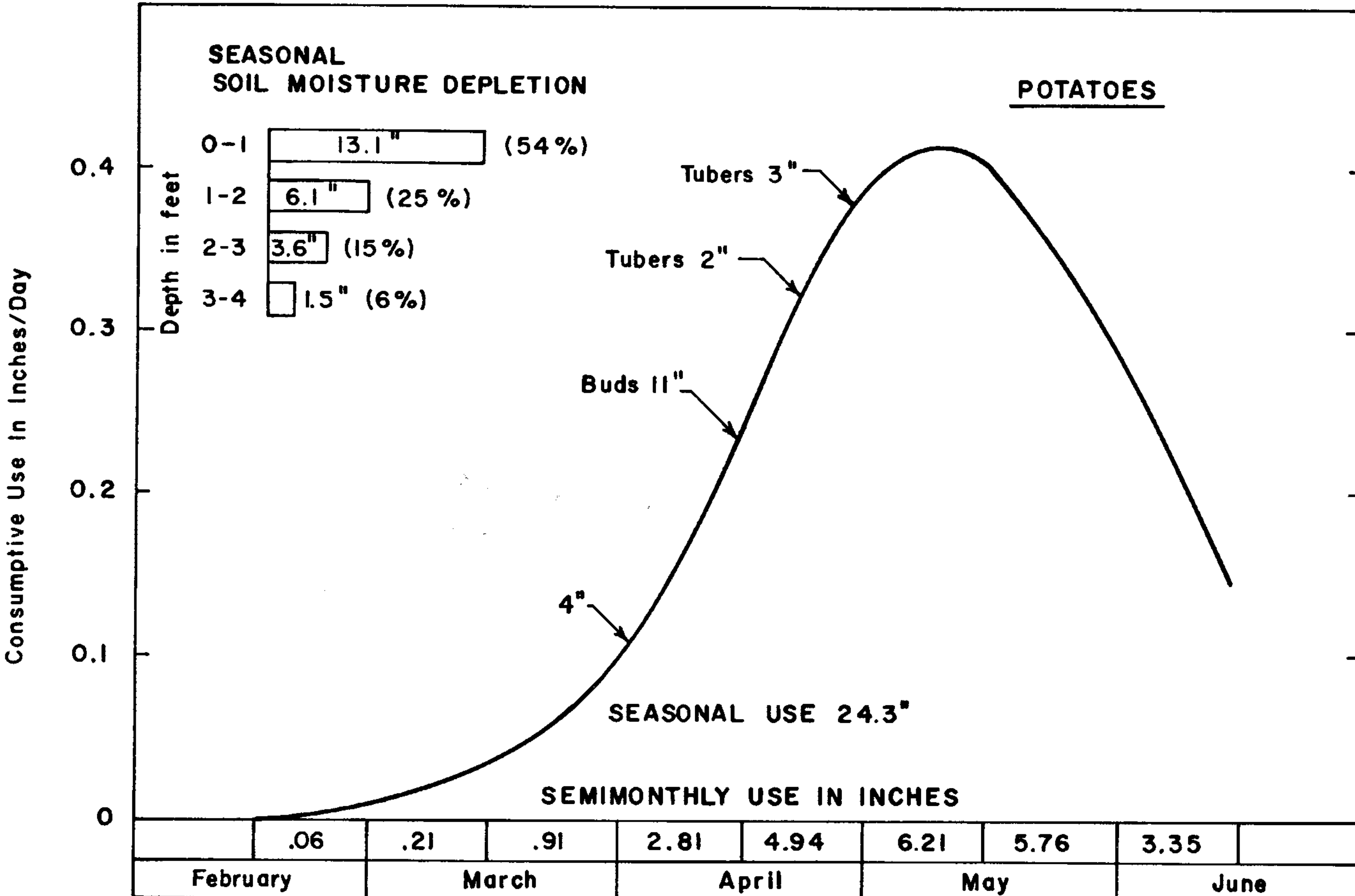

Figure 29.—Mean consumptive use for potatoes at Mesa, Ariz., 1959-63.

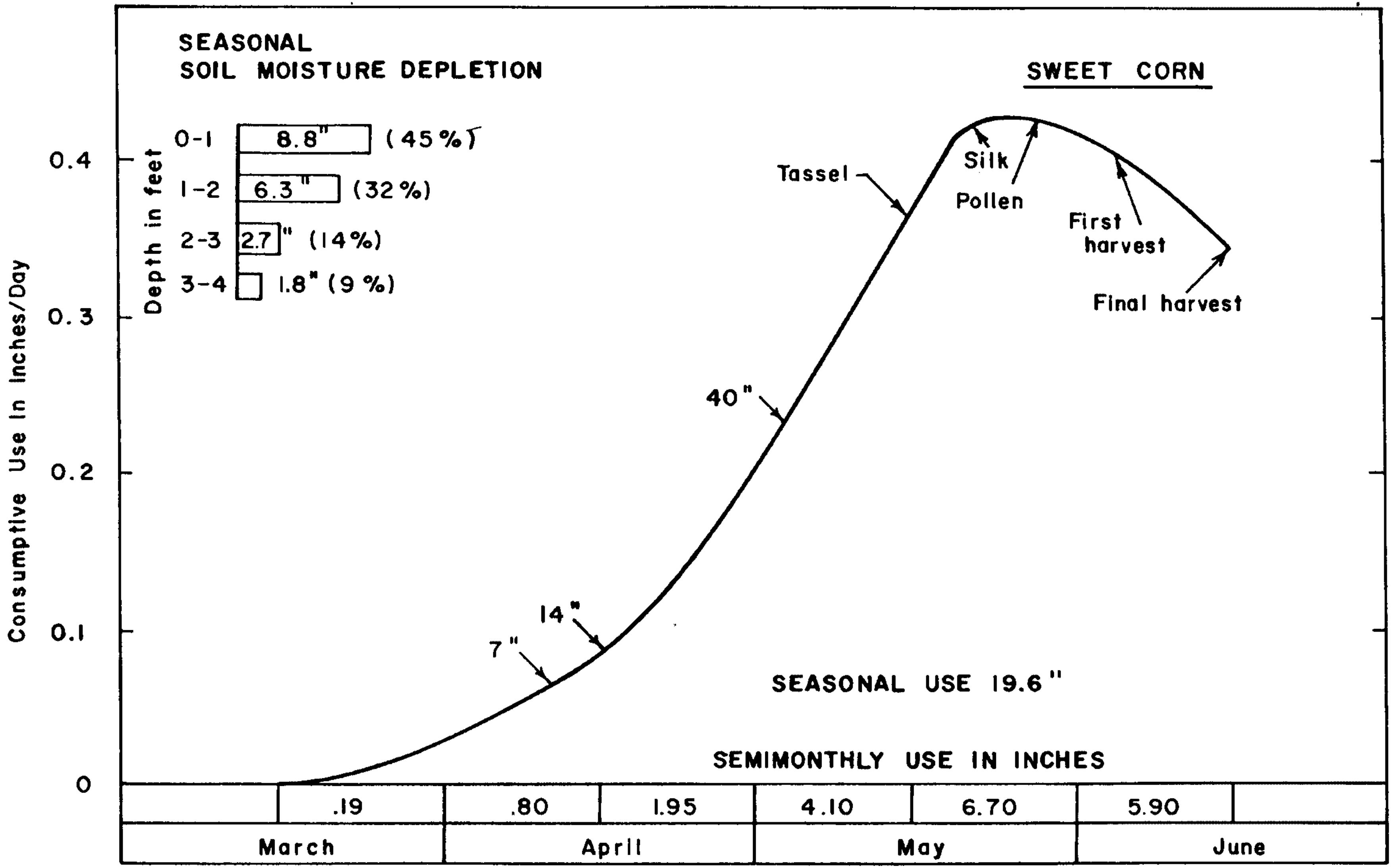

Figure 30.—Mean consumptive use for sweet corn at Mesa, Ariz., 1959, 1961-62.

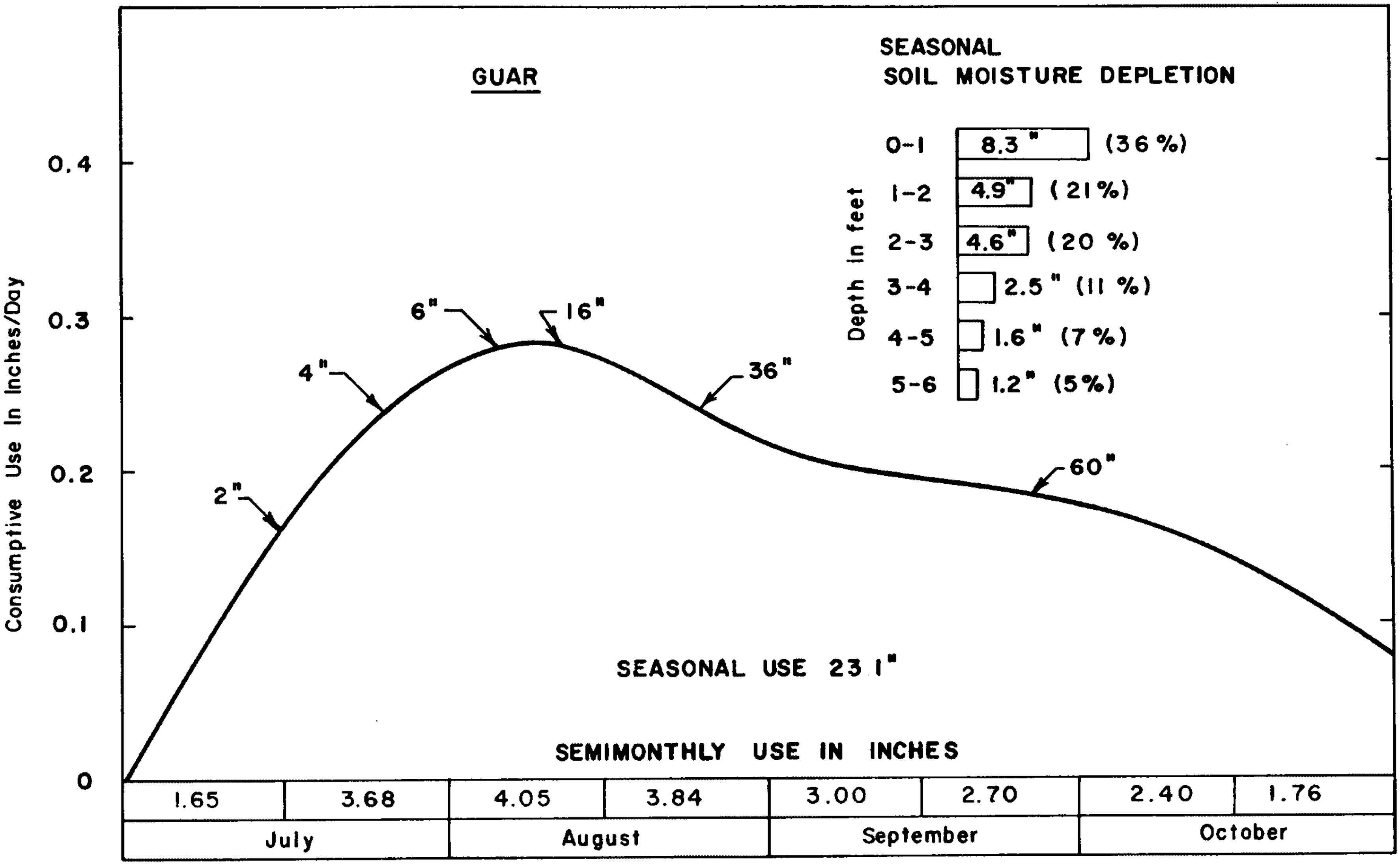

Figure 31.—Mean consumptive use for guar at Mesa, Ariz., 1946, 1959-60.

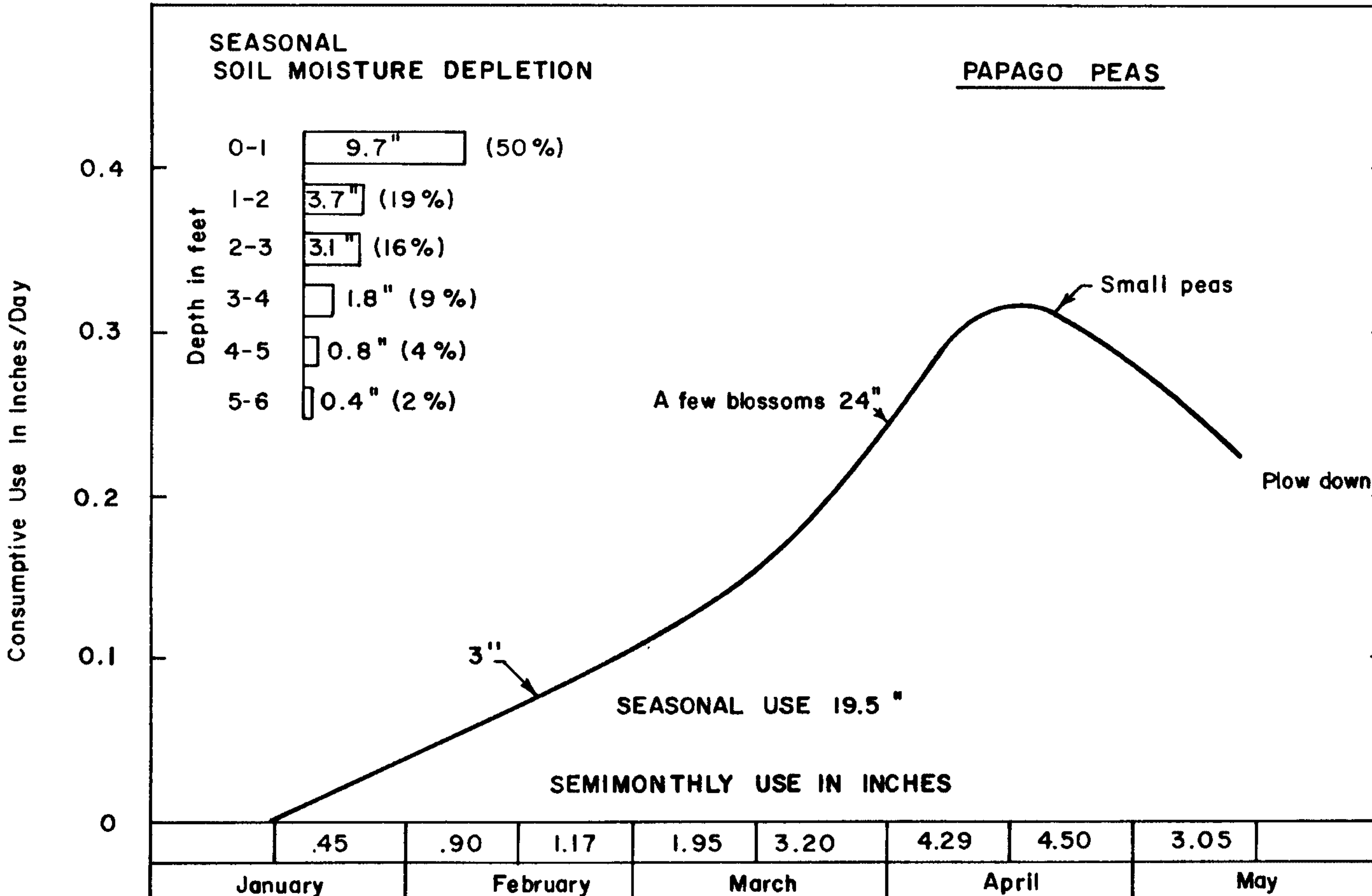

Figure 32.—Mean consumptive use for papago peas at Mesa, Ariz., 1958.

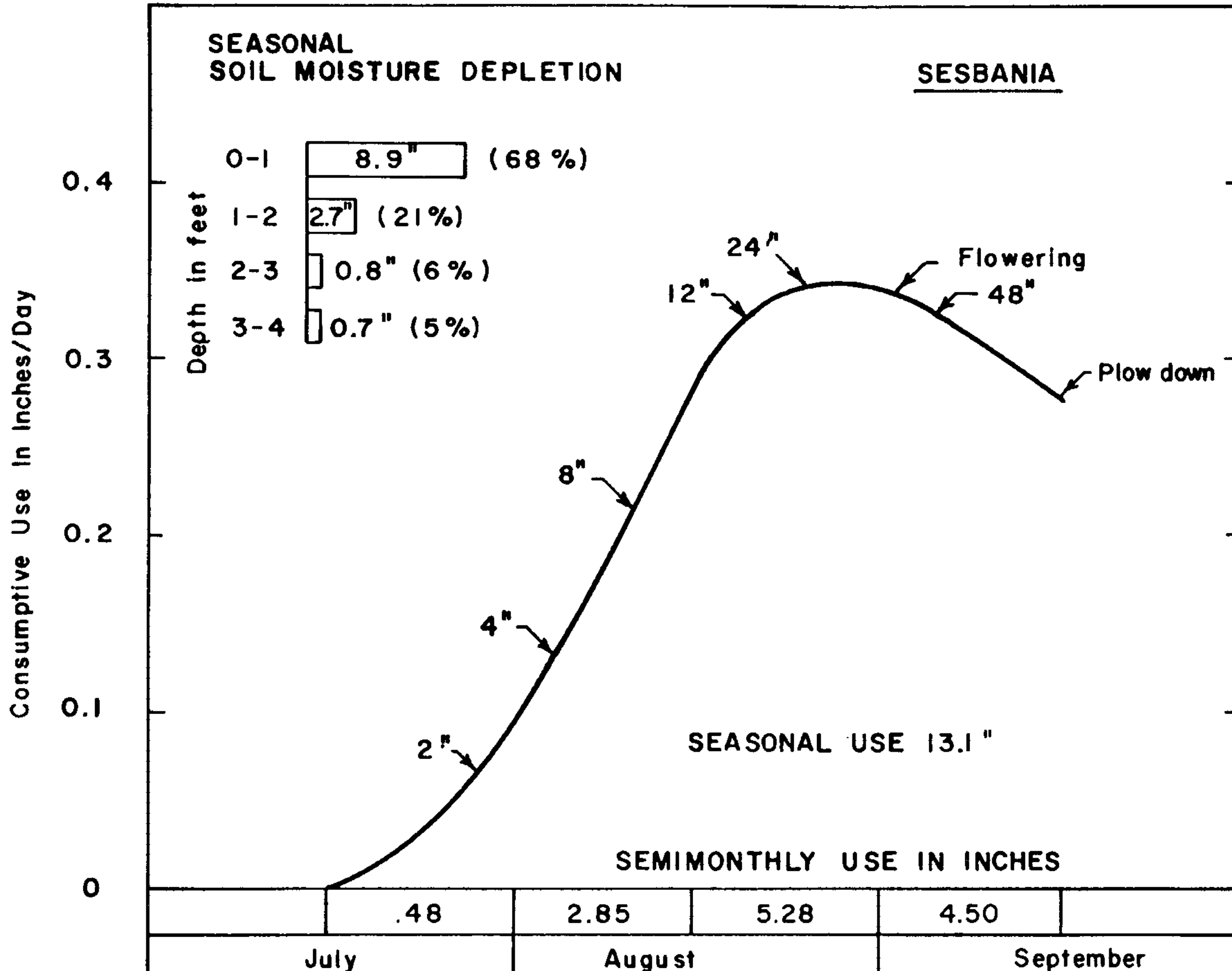

Figure 33.—Mean consumptive use for sesbania at Mesa, Ariz., 1959.

Appendix II: Blaney-Criddle Formula

An empirical formula developed by Blaney and Criddle, using climatological data and past research consumptive-use data, has been used in the United States and in many foreign countries. Originally, this formula was used for computing seasonal use, and, in recent years, it has been used when short-period research measurements were available. An important assumption in applying this formula to transfer data between areas is that crop growth and yield are not limited by inadequate water at any time during the growing season.

The Blaney-Criddle formula U = KF was first developed to determine the seasonal coefficient "K" where U is consumptive use and F is the sum of certain monthly consumptive-use factors. Disregarding many unmeasured factors, consumptive use varies with temperature, daytime hours, and available soil moisture regardless of its source. Mean temperatures can be determined from Weather Bureau records or climatic summaries (*9*). Table 1 (p. 39) presents monthly percentages of daytime hours by latitudes as used by the USDA Soil Conservation Service (*11*). Multiplying the mean monthly temperature (t) by the possible monthly percentage of daytime hours of the year (p) and dividing by 100 gives a monthly consumptive-use factor (f). The sum of the monthly "f" factors gives the seasonal "F" factor.

If the consumptive use "U" is measured at a certain location for a specific crop, the "F" factor can be determined for that year at that location and a "K" factor calculated. It is this "K" factor that is transposed to other areas, using the local area "F" factor, from which estimates of consumptive use are made, often hundreds of miles away from the original area on which the "K" factor was developed.

t = Mean monthly temperature in degrees Fahrenheit.
p = Monthly percentage of daytime hours of the year.
$f = \frac{t \times p}{100}$ = Monthly consumptive-use factor.
F = Sum of monthly consumptive-use factors for the period.
u = Short-period consumptive use, in inches.
U = Seasonal consumptive use, in inches.
k = Short-period, consumptive-use crop coefficient.
K = Empirical consumptive-use crop coefficient for irrigation season.

Table 2 (p. 40 and 41) shows the seasonal, "K," and semimonthly, "k," factors as determined for crops grown in Arizona, to be used with the Blaney-Criddle formula in estimating consumptive use of water. When the 15-day "k" factors are used, the corresponding daytime sunshine hour percentages and the mean average temperature for the 15-day period at a particular location should be used.

For example, the expected consumptive use of cotton can be estimated for the first half of July at Safford, Ariz., using the developed "k" from table 2. The "k" factor for cotton is 1.10; from table 1 for 33° north latitude, the average daytime hour percentage for July would be 9.82. The first half daytime hour percentage would be 4.75, calculated as follows: ($p = \frac{15}{31} \times 9.82 = 4.75$).
The mean temperature for the first 15 days of July is 85°F. Thus, the "f" factor for the first half of July would be 4.04, calculated as follows: ($f = \frac{85 \times 4.75}{100} = 4.04$), and the estimated consumptive use for the first 15 days of July would be 4.44 inches ($u = kf = 1.10 \times 4.04 = 4.44$).

Another example would be if the seasonal use is desired for cotton at Safford. From table 2, the seasonal "K" factor is 0.79. From temperature records and table 1, an "F" factor of 44.04 is calculated. The seasonal consumptive use would be 34.8 inches ($U = KF = 0.79 \times 44.04 = 34.8$).

Table 1 — Monthly percentage of daytime hours (p) of the year for latitudes 0 to 64° north of Equator

Lat. N.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
64°	3.81	5.27	8.00	9.92	12.50	13.63	13.26	11.08	8.56	6.63	4.32	3.02
62°	4.31	5.49	8.07	9.80	12.11	12.92	12.73	10.87	8.55	6.80	4.70	3.65
60°	4.70	5.67	8.11	9.69	11.78	12.41	12.31	10.68	8.54	6.95	5.02	4.14
58°	5.02	5.84	8.14	9.59	11.50	12.00	11.96	10.52	8.53	7.06	5.30	4.54
56°	5.31	5.98	8.17	9.48	11.26	11.68	11.67	10.36	8.52	7.18	5.52	4.87
54°	5.56	6.10	8.19	9.40	11.04	11.39	11.42	10.22	8.50	7.28	5.74	5.16
52°	5.79	6.22	8.21	9.32	10.85	11.14	11.19	10.10	8.48	7.36	5.92	5.42
50°	5.99	6.32	8.24	9.24	10.68	10.92	10.99	9.99	8.46	7.44	6.08	5.65
48°	6.17	6.41	8.26	9.17	10.52	10.72	10.81	9.89	8.45	7.51	6.24	5.85
46°	6.33	6.50	8.28	9.11	10.38	10.53	10.65	9.79	8.43	7.58	6.37	6.05
44°	6.48	6.57	8.29	9.05	10.25	10.39	10.49	9.71	8.41	7.64	6.50	6.22
42°	6.61	6.65	8.30	8.99	10.13	10.24	10.35	9.62	8.40	7.70	6.62	6.39
40°	6.75	6.72	8.32	8.93	10.01	10.09	10.22	9.55	8.39	7.75	6.73	6.54
38°	6.87	6.79	8.33	8.89	9.90	9.96	10.11	9.47	8.37	7.80	6.83	6.68
36°	6.98	6.85	8.35	8.85	9.80	9.82	9.99	9.41	8.36	7.85	6.93	6.81
34°	7.10	6.91	8.35	8.80	9.71	9.71	9.88	9.34	8.35	7.90	7.02	6.93
32°	7.20	6.97	8.36	8.75	9.62	9.60	9.77	9.28	8.34	7.95	7.11	7.05
30°	7.31	7.02	8.37	8.71	9.54	9.49	9.67	9.21	8.33	7.99	7.20	7.16
28°	7.40	7.07	8.37	8.67	9.46	9.39	9.58	9.17	8.32	8.02	7.28	7.27
26°	7.49	7.12	8.38	8.64	9.37	9.29	9.49	9.11	8.32	8.06	7.36	7.37
24°	7.58	7.16	8.39	8.60	9.30	9.19	9.40	9.06	8.31	8.10	7.44	7.47
22°	7.67	7.21	8.40	8.56	9.22	9.11	9.32	9.01	8.30	8.13	7.51	7.56
20°	7.75	7.26	8.41	8.53	9.15	9.02	9.24	8.95	8.29	8.17	7.58	7.65
18°	7.83	7.31	8.41	8.50	9.08	8.93	9.16	8.90	8.29	8.20	7.65	7.74
16°	7.91	7.35	8.42	8.47	9.01	8.85	9.08	8.85	8.28	8.23	7.72	7.83
14°	7.98	7.39	8.43	8.43	8.94	8.77	9.00	8.80	8.27	8.27	7.79	7.93
12°	8.06	7.43	8.44	8.40	8.87	8.69	8.92	8.76	8.26	8.31	7.85	8.01
10°	8.14	7.47	8.45	8.37	8.81	8.61	8.85	8.71	8.25	8.34	7.91	8.09
8°	8.21	7.51	8.45	8.34	8.74	8.53	8.78	8.66	8.25	8.37	7.98	8.18
6°	8.28	7.55	8.46	8.31	8.68	8.45	8.71	8.62	8.24	8.40	8.04	8.26
4°	8.36	7.59	8.47	8.28	8.62	8.37	8.64	8.57	8.23	8.43	8.10	8.34
2°	8.43	7.63	8.49	8.25	8.55	8.29	8.57	8.53	8.22	8.46	8.16	8.42
0°	8.50	7.67	8.49	8.22	8.49	8.22	8.50	8.49	8.21	8.49	8.22	8.50

Table 2 — Blaney-Criddle "K" factors for various crops

Crop	Seasonal "K" values	January 1-15	January 16-31	February 1-14	February 15-28	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30	October 1-15	October 16-31	November 1-15	November 16-30	December 1-15	December 16-31
Cash and oil crops:																									
Castor beans	0.84								0.07	0.21	0.35	0.58	0.98	0.95	0.93	0.86	1.08	1.44	1.56	1.23	0.82	0.48			
Cotton	.79							0.06	.11	.20	.34	.50	.79	1.10	1.30	1.43	1.36	1.23	1.00	.79	.47	.27			
Flax	.78	0.84	0.86	0.82	0.85	0.81	1.07	1.24	1.26	.79	.59	.38	.27									.68	0.81	0.87	0.90
Safflower	1.21	.08	.20	.23	.44	.59	1.01	1.63	2.21	1.98	1.00	1.70	1.43	.34											
Soybeans	.68												.24	.38	.45	.71	.93	1.13	1.07	.86	.68				
Sugarbeets	.77	.66	.66	.61	.56	.62	.93	1.14	1.21	1.23	1.18	1.14	1.03	.71	.38					.03	.18	.47	.66	.67	.68
Bermuda lawn and hay crops:																									
Alfalfa	1.20				.92	1.20	1.22	1.18	1.34	1.31	1.42	1.39	1.33	1.30	1.16	1.14	1.06	1.39	1.27	1.10	.87	.80	.80		
Bermuda lawn	.97								.66	.70	.88	1.00	1.12	1.19	1.15	1.16	1.05	.96	.82	.71					
Blue panic grass	.98							.83	1.03	1.03	1.11	1.07	1.03	1.11	1.11	1.10	1.01	.95	.89	.89	.75	.32			
Small grain and forage crops:																									
Barley	.93	.34	.46	.76	1.03	1.41	1.72	1.91	1.44	.52													.08	.25	.28
Sorghum grain (single crop)	.87													.14	.74	1.29	1.67	1.34	.86	.51	.18				
Sorghum grain (double crop)	.90							.03	.28	.71	1.37	1.61	1.60	.90	.71	.59	.96	1.66	1.18	.90	.67	.56	.44	.16	
Sorghum forage (double crop)	.94							.02	.32	.80	1.42	1.49	1.42	1.05	.74	.59	1.15	1.79	1.39	1.10	.73	.56	.44	.10	
Wheat	.89	.40	.47	.63	.98	1.47	1.80	1.80	1.47	.67	.17												.08	.23	.37
Fruits:																									
Grapefruit	.66	.45	.55	.48	.47	.47	.50	.49	.52	.55	.62	.67	.70	.76	.71	.80	.75	.79	.76	.83	.69	.72	.58	.63	.61
Grapes (early)	.64					.10	.32	.56	.79	.82	.68	.88	.75												
Grapes (late)	.70						.35	.33	.56	.78	1.06	.73	.77	.79											
Oranges	.53	.34	.44	.43	.52	.39	.43	.42	.49	.47	.47	.55	.56	.58	.57	.66	.59	.63	.65	.69	.55	.59	.58	.46	.34
Vegetables:																									
Broccoli	.77	.95	1.09	1.08														.12	.27	.62	.85	1.29	1.09	1.08	.91
Cabbage (early)	.72	.89	.80															.07	.23	.56	1.02	1.33	1.15	1.05	.94
Cabbage (late)	.82	1.07	.95	.86	.89	.65												.12	.41	.81	1.02	1.29	1.21	1.14	1.04
Cantaloup (early)	.73							.06	.19	.29	.72	1.25	1.40	.88	.37										
Cantaloup (late)	.69															.08	.40	.83	1.31	1.17	.77	.49	.27		
Carrots	.63	.89	.75	.66	.69	.40													.05	.25	.53	1.19	1.06	.94	.86
Cauliflower	.78	1.07	.85															.11	.30	.51	.82	1.29	1.36	1.41	1.14
Lettuce	.50																		.07	.27	.43	.59	.75	.98	.90
Onions (dry)	.80	.30	.38	.46	.67	.95	1.50	1.66	1.81	.85												.02	.05	.11	.20
Onions (green)	.88	.99	.85																.26	.38	1.06	1.38	1.28	1.17	1.03
Potatoes	1.01				.03	.09	.34	.93	1.65	1.78	1.53	.85													
Sweet corn	.98						.07	.26	.62	1.19	1.82	1.49													
Green manure crops:																									
Guar	.78													.38	.81	1.00	.93								
Papago peas	1.01		.21	.47	.62	.91	1.29	1.54	1.42	1.08								.83	.81	.87	.64				
Sesbania	.82														.11	.72	1.28	1.26							

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Appendix III: Conversion Factors

1 inch	= 25.4 millimeters (mm)
	= 2.54 centimeters (cm)
1 inch/day (in/d)	= 25.4 mm/d
1 foot (ft)	= 30.48 cm
	= 0.3048 meter (m)
1 acre (acre)	= 4046.856 m^2
	= 0.4047 ha
1 hectare (ha)	= 10 000 m^2
	= 2.471 acres
1 cubic foot (ft^3)	= 7.481 U.S. gal
	= 28.316 liters (L)
1 U.S. gallon (gal)	= 231 in^3
	= 3.785 L
1 acre-inch (acre-in)	= 3,630 ft^3
	= 102.79 m^3
	= 1.028 ha-cm
1 acre-foot (acre-ft)	= 43,560 ft^3
	= 1233.48 m^3
	= 0.12335 ha-m
1 cubic meter (m^3)	= 35.315 ft^3
	= 264.17 U.S. gal
1 acre-inch/hour (acre-in/hr)	= 1.01 cubic feet/second (ft^3/s)
	= 452.6 U.S. gal/minute (gal/min)
	= 102 787.1 liters/hour (L/h)