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FINAL REPORT

Assessment of Fall Agriculture Irrigation Water Conservation Potential in the Scott Valley

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ABSTRACT

Irrigation of alfalfa and pasture requires large quantities of water and is sometimes considered a contributor to low flows in the Scott River. A 3-year study was conducted to evaluate the potential for agriculture water conservation in Scott Valley. The effect of irrigation termination date on forage production was evaluated to determine how late in the season irrigation is needed. The soil moisture status of several irrigated pasture and alfalfa fields was monitored weekly for the duration of the growing season using resistance blocks and a neutron probe. This permitted an evaluation of the adequacy of current irrigation practices.

The different irrigation cut-off treatments had a profound effect on soil moisture levels. However, only the early irrigation cut-off treatments, July to mid August, caused an appreciable reduction in alfalfa yield. There was no need to irrigate after the final alfalfa cutting for the soil type studied. The date of the final irrigation of the season had no effect on alfalfa yield the following season. Late-season (October) pasture yield was affected by irrigation termination date. There was little to no difference in yield between the latest two irrigation cut-off dates. Pasture species were more sensitive to moisture stress than was alfalfa. The earliest irrigation cut-off date, August 3rd, killed some grass plants and reduced yield the following year.

The monitoring study indicated that soil moisture content fluctuated considerably during the growing season. Periods of low soil moisture were generally associated with harvests, a time period when fields cannot be irrigated. The soil moisture content was typically lowest in mid to late summer between irrigations and, in the case of alfalfa, in fall after the final harvest of the season was made.

It is not possible to characterize all fields as being 'over' or 'under' irrigated. The soil moisture content of fields varied considerably between growers, which reflects differences in irrigation practices and soil types. Some fields received water in excess of crop needs, while others were under-irrigated (especially in mid-summer). High soil moisture contents were not always associated with irrigation practices. Some sites were inherently more wet than others due to a high water table.

In general, irrigated pastures were maintained at a higher soil moisture content than were alfalfa fields. Three explanations for the higher sustained soil moisture content in pastures are: 1) pasture is often grown on sites with poor drainage that are not suited to alfalfa production; 2) many pastures are grazed rather than harvested so irrigation can occur nearly uninterrupted, and 3) pastures are often irrigated later in the year than are alfalfa fields.

These results indicate some potential for water conservation. Irrigation in some fields, primarily irrigated pastures, could be reduced, either by lengthening the interval between irrigations or, more appropriately, by reducing the amount of water applied per irrigation. Since the soil remained very moist at the lower depths at many of the sites evaluated, the amount of water applied per irrigation could be reduced. However, there are practical limitations as to what can easily be achieved to improve irrigation management. Limitations are related to irrigation design constraints and convenience.

The soil moisture sensors employed in this study were found to be a very effective tool to determine when irrigation is needed and to help avoid over-irrigation. Growers are encouraged to adopt the practice of monitoring soil moisture with resistance blocks to improve irrigation management. Fifteen presentations were given at meetings throughout Siskiyou County and other areas to disseminate the results of this study. Additional publications containing data developed in this study are planned to improve irrigation management.

INTRODUCTION

The population of salmon and steelhead in the Scott River, and the Klamath River system as a whole, has declined dramatically over recent decades. It is speculated that reduced fall flows in the Scott River may be one of the contributing factors associated with the decline in anadromous fish populations. Irrigated agriculture is the largest single water user in Scott Valley. According to California Department of Water Resources (CDWR), agricultural water use and irrigated acreage has remained relatively constant over the past two decades. The hydrology of the Scott Valley is such that ground water is interconnected with the Scott River and other tributaries. Therefore, groundwater pumping in many areas is believed to have a direct influence on surface water levels. Major shifts in irrigated acreage and irrigation methods are not anticipated. Hence, water conservation is considered to be the primary means of reducing the water use of irrigated agriculture.

The purpose of this project was to determine the potential for conserving water by reducing irrigation of pasture and alfalfa fields. Water conservation efforts in the fall may increase flows in the Scott River during a time that is considered critical for chinook salmon. Alfalfa and irrigated pasture are the predominate crops produced in the Scott Valley. The late-season irrigation needs of alfalfa and pasture are not well understood. Likewise, the amount of water actually applied by growers in the fall is not known. The water needs of alfalfa and pasture are considerably less in the fall than in mid summer. Therefore, adjustments are needed toward the end of the production season to reduce the amount of water applied to fields. Growers may not be adjusting their irrigation management sufficiently to account for reduced crop water needs in the fall.

The effects of planned insufficient irrigation on hay production and forage available for fall grazing need to be evaluated. Fall grazing of alfalfa and pasture is very important to Scott Valley cattle ranches, as grazing postpones the need to feed hay, a much more expensive alternative. The objective of the study was to evaluate the potential for agricultural water conservation in the fall to augment stream flows during the critical migration period of salmonids. The intent is to conserve water without appreciably reducing yield or farm income.

DESCRIPTION OF STUDY AREA

The study was conducted in producer-owned agricultural fields scattered throughout the floor of the Scott Valley. Individual fields were located in Ft. Jones, Quartz Valley, Greenview, and Etna. Five irrigated pastures and five irrigated alfalfa fields were selected for the first year of the study. The number of fields was increased to eight of each type in the second year to include more grower cooperators and to broaden the assessment of current irrigation practices. The irrigation cut-off component of the study was conducted in an alfalfa field and an irrigated pasture in the center of the Scott Valley. An additional irrigation cut-off experiment was initiated in another pasture with another livestock producer the second year of the study.

METHODS AND MATERIALS

There were two components to this project, a research component and a monitoring component. The purpose of the research component was to evaluate the effect of irrigation cut-off date on hay production and the amount of forage available for fall grazing. Earlier cut-off would lead to water conservation at a time of year deemed critical for anadromous fish populations, but may have a detrimental effect on yield and farm income. The monitoring component involved assessing soil moisture levels during the growing season to evaluate current irrigation practices and determine if water could be conserved.

Irrigation Cut-off Study: Field trials were established in both alfalfa and pasture fields in the Scott Valley. The date of the last irrigation of the season was staggered from late July into October (table 1). Four different irrigation termination dates were evaluated to determine their effect on yield of the last cutting, the amount of after-math (plant material left after cutting) available for grazing, and any residual effect from deficit fall irrigation on yield the following year.

Irrigation cut-off treatments were accomplished by plugging three consecutive sprinkler nozzles in randomly assigned plots. There were three replicates per treatment. The treatments were imposed for two consecutive years. Yield was determined the year the treatment was imposed and the following year. The soil moisture status associated with each of the irrigation termination dates was evaluated using the same methods described in the soil moisture monitoring section below.

Table 1. Dates of final irrigation of the season for irrigation cut-off studies.

	Date of Final Irrigation	
	Alfalfa	**Pasture**
1995	July 21	August 3
	August 14	August 22
	August 30	September 20
	September 26	October 5
1996	August 3, 1996	
	August 13, 1996	
	August 30, 1996	
	October 3, 1996	

In the fall of the second year of the irrigation cut-off studies, cattle were accidentally allowed to enter the experimental area of the pasture and consumed the forage.

Therefore, it was not possible to obtain two years of data from the pasture site. Fortunately, an additional irrigation cut-off trial had already been started at an additional site. This producer generally irrigates later into the fall. The intent of the additional study was to focus more on the importance of late-season irrigation. There were only two irrigation cut-off dates in this study. The dates for the last irrigation were September 4, 1996 and September 20, 1996. Yield was measured prior to the final grazing of the season.

Monitoring Study: The moisture status of 10 fields (five pastures and five alfalfa fields) were monitored in 1996. The total number of fields was increased to 16 (eight pastures and eight alfalfa fields) in 1997. The number of fields was greater than the number originally proposed to collect data from more fields and to increase participation in the project. Fields and growers were selected to be representative of conditions (i.e., soil type, irrigation system, and management) encountered in the Scott Valley.

The original proposal was to monitor soil moisture during fall because it is believed that irrigation at that time would be most likely to affect flows during the critical salmonid migration period. However, since previous irrigation practices influence the soil moisture status in fall, it was decided to expand the monitoring process to include the entire irrigation season. This also allowed for a more complete evaluation of the adequacy of current irrigation practices. Soil moisture levels were evaluated weekly from spring through October until substantial fall rainfall had occurred.

Soil moisture was assessed using resistance blocks. The resistance blocks were installed at 1-foot increments down to 4 feet in the pastures and to 5 feet in the alfalfa fields. In July of the second season, it was decided to install an additional moisture sensor at a 6-inch depth in the pastures. Pasture species, cool-season grasses and clovers, have a significantly shallower rooting depth than does alfalfa so the 6-inch sensor was needed to more accurately assess soil moisture conditions in the root zone of the crop. Gypsum blocks manufactured by Soil Moisture, Inc. were used in 1996. In 1997 a different type of moisture sensor (Watermark™ sensor) was installed because the new type was found to more accurately reflect the actual soil moisture content than the gypsum blocks originally installed. Two sets of sensors were installed at some locations to evaluate the consistency of the Watermark sensors.

A neutron probe access tube was installed at each site approximately 3 feet from the resistance blocks. A neutron probe is a more accurate and sophisticated instrument for estimating soil moisture content than are resistance blocks. However, a neutron probe is impractical for grower use because of the cost and licensing requirements. Neutron probe readings were correlated with resistance block readings to evaluate the usefulness of the resistance blocks for irrigation scheduling purposes.

Using the soil-moisture information, an assessment can be made as to whether fields are over-irrigated under current irrigation practices, and if water conservation is feasible.

RESULTS AND DISCUSSION

Irrigation Cut-off Study:

As expected the different irrigation cut-off treatments had a profound effect on soil moisture levels (figures 1 through 8). Four distinct soil moisture regimes resulted, which correlated with the cut-off dates. The soil became extremely dry with the earliest cut-off date, July 21 for alfalfa and August 3 for irrigated pasture (figures 1 and 5). Soil in plots with the last irrigation cut-off date remained moist for the entire season (figures 4 and 8). The two other irrigation cut-off dates resulted in intermediate soil moisture levels.

The soil moisture blocks showed a noticeable decline in soil moisture soon after each cut-off date. The decline started with the uppermost sensor (installed at 1 ft.) and then progressed deeper as the season progressed. This is logical, as root density is greatest at shallower depths. There was a noticeable difference in the water extraction pattern for alfalfa and pasture. Alfalfa with its deep taproot was better able to extract moisture deep in the soil profile than were pasture species, perennial grasses and clovers. The pasture species did not extract water from deeper depths until the upper depths became excessively dry. This suggests that adequate soil moisture in the upper 1 to 2 feet is important for irrigated pasture but the deep soil moisture status is not of major concern.

The earliest irrigation cut-off resulted in a significant reduction in 3rd cutting alfalfa yield (tables 2 and 3). The reduction was much greater in 1995 than 1996 because of the earlier irrigation cut-off date (July 21 compared with August 3). There was no difference in 3rd cutting yield for the last two irrigation cut-off treatments. These two treatments were essentially the same until after the 3rd cutting because the last irrigation did not occur until after the final cutting. The date of the last irrigation affected the amount of forage aftermath available for grazing. The amount of forage available for grazing ranged from 0.24 to 0.57 tons per acre for the two years. Irrigation cut-off date also affected forage quality; the earliest two cut-off dates had significantly lower forage quality (data not included). There was no difference in yield or quality between the last two irrigation cut-off treatments, indicating irrigation after the final cutting was unnecessary.

The irrigation treatments had no carry-over effect on alfalfa yield the season after the cut-off treatments were imposed. The alfalfa fully recovered. This has been observed in previous studies. Alfalfa goes into a drought induced dormancy and is able to recover the following year when soil-moisture returns to adequate levels.

Table 2. The effect of various irrigation cut-off dates on alfalfa yield for 3rd cutting, forage aftermath, and residual effect on yield of 1st and 2nd cutting the following year.

Date of Last Irrigation	Yield (tons/A)			
	3rd Cut 9/7/95	**After-math** 11/3/95	**1st Cut** 6/14/96	**2nd Cut** 7/22/96
July 21, 1995	0.72	0.24	2.62	2.12
August 14, 1995	0.95	0.23	2.44	2.16
August 30, 1995	1.28	0.30	2.58	2.18
September 26, 1995	1.28	0.33	2.56	2.16
LSD 0.05	0.26	0.06	ns	ns

Table 3. The effect of various irrigation cut-off dates on alfalfa yield for 3rd cutting, forage aftermath, and residual effect on yield the following year.

Date of Last Irrigation	Yield (tons/A)				
	3rd Cut 9/9/96	**After-math** 11/11/96	**1st Cut** 6/7/97	**2nd Cut** 7/25/97	**3rd Cut** 9/13/97
August 3, 1996	1.61	0.27	2.35	2.43	1.74
August 13, 1996	1.76	0.42	2.63	2.63	1.99
August 30, 1996	1.87	0.55	2.62	2.68	1.93
October 3, 1996	1.90	0.57	2.38	2.59	1.81
LSD 0.05	0.16	0.08	ns	ns	ns

The results for the irrigated pasture were somewhat different (table 4). There was no statistically significant effect on the yield of the final cutting of the season for the pasture (3 of the irrigation cut-off treatments were essentially the same at the time of the cutting because their last irrigation occurred after the cutting). The earliest irrigation cut-off date for the pasture was later than it was for the alfalfa. Although not statistically significant, the earliest cut-off tended to yield less. The irrigation cut-off dates did have a significant effect on forage aftermath. There was progressively more yield with the later irrigation cut-off dates. The earliest irrigation cut-off dates affected pasture yield the following year. Shallow rooted-grasses are less able to withstand the effects of drought than is alfalfa. Some grass plants died from the earliest irrigation cut-off treatment and the yield of these plots did not fully recover the following year. There was no difference in yield the following year between the later two irrigation cut-off treatments.

Table 4. The effect of various irrigation cut-off dates on pasture yield for 3rd cutting, forage aftermath, and residual effect on yield of 1st cutting the following year.

Date of Last Irrigation	Yield (tons/A)		
	3rd Cut 9/7/95	After-math 10/20/95	1st Cut 6/11/96
August 3, 1995	1.83	0.20	2.68
August 22, 1995	1.96	0.30	3.07
September 20, 1995	1.93	0.36	3.26
October 5, 1995	1.93	0.44	3.16
LSD 0.05	ns	0.09	0.34

In an additional study, there was no difference in the late-fall yield of pasture associated with two different late season irrigation cut-off dates. Soil in this field had remained moist for the entire season and there was no difference in yield attributable to the date of the final irrigation.

Table 5. The effect of 2 late-season irrigation cut-off dates on late-fall pasture yield.

Date of Last Irrigation	Yield (tons/A) 10/7/96
September 5, 1996	0.24
September 20, 1996	0.25
LSD 0.05	ns

These results reflect what occurs on a loamy soil. The effects of irrigation cut-off date are likely to be greater on sandy or gravelly soil with a much lower water-holding capacity. Soil moisture status prior to the irrigation cut-off treatments will also affect the results. Irrigation cut-off dates could have a greater effect had soil moisture levels been lower when the cut-off treatments were imposed.

Monitoring Study:

Accuracy of Soil Moisture Sensors. A neutron probe was used to validate the soil moisture readings obtained with the less expensive soil moisture sensors used in the monitoring study. The Watermark sensor readings correlated well with the neutron moisture meter readings (see correlation coefficients in Table 6). Sites where the readings did not correlate as well were locations where there were dramatic changes in soil texture with depth. Neutron probe readings would not be expected to correlate perfectly with the Watermark sensors because they estimate soil moisture over a different zone of the soil. A neutron probe estimates soil moisture content over a volleyball-sized area. The Watermark sensors estimate soil moisture in a small area surrounding the actual sensor.

Table 6. Correlation coefficients between Watermark readings and neutron moisture meter soil moisture content in alfalfa fields. *(Grower C excluded because water in neutron probe access tube made readings impossible. Grower H excluded because gravelly soil did not permit installation of access tube).*

Depth (feet)	Sites					
	Grower A	Grower B	Grower D	Grower E	Grower F	Grower G
1	-0.82	-0.86	-0.77	-0.86	-0.86	-0.70
2	-0.89	-0.89	-0.90	-0.79	-0.89	-0.88
3	-0.93	-0.78	-0.88	-0.86	-0.93	-0.91
4	-0.70	-0.87	-0.81	-0.83	-0.89	-0.87
5	-0.62	-0.87	-0.56	-0.88	-0.93	-0.83

Not only did the sensors correlate well with neutron probe readings; the sensors were very consistent. When two sets of sensors were installed at the same site the soil moisture readings were extremely close. These results demonstrate that soil moisture sensors are sufficiently accurate for irrigation scheduling purposes in alfalfa and pasture.

Interpreting the Soil Moisture Monitoring Results. Soil moisture should be maintained between certain levels to maximize yield and avoid wasting water. When soil moisture is too low plant growth is affected, and yields and profits decrease. Conversely, very high soil moisture contents for extended periods indicate irrigation is excessive; water may be wasted and crop yield can suffer from too much water.

In 1996 gypsum block sensors manufactured by Soil Moisture Inc. were used to assess the soil moisture status. These sensors read from 0 to nearly 100. The higher the reading the wetter the soil. When the soil is saturated the blocks usually read 94 to 96. These sensors do not respond until the soil dries appreciably. When the soil dries sufficiently the moisture block readings drop rapidly. Typically, a reading of 70 to 85 means irrigation is necessary. Therefore, with these resistance blocks the higher the reading the higher the soil moisture content and conversely, the lower the readings the lower the soil moisture content.

The Watermark soil moisture sensor, installed for the 1996 season, is more sensitive to changes in soil moisture in soils with a higher moisture content. This sensor estimates soil moisture tension in centibars. The soil moisture tension refers to how strongly water is held onto the soil particles. Low soil moisture tensions indicate moist soil and high soil moisture tensions indicate dry soil. Therefore, when interpreting the graphs generated with data from the Watermark sensors remember the relationship is the inverse of that with the Soil Moisture Inc. gypsum blocks. When the soil profile is full (air spaces mostly filled with water) the Watermark reading (in centibars) is low, typically less than 5 to 10. As the soil dries the readings gradually increase. For most Scott Valley soils irrigation should occur when the centibar reading approaches 60 to 90. Following irrigation the readings should again drop to single digits. Readings that do not drop significantly following irrigation indicate that irrigation water was insufficient to reach that depth and refill the soil profile. Cases where the soil moisture tension readings never approach 60 to 90 indicate the field may be irrigated too often or with too much water per irrigation.

Results of Soil Moisture Monitoring. Soil moisture content fluctuated considerably over the season in most fields (Figures 9-34). Gaps in the lines on the graphs represent days when the field was being irrigated at the time the readings were to be taken. There was far more fluctuation in soil moisture at the shallow depths (0.5 to 2 feet) than at the deeper depths (3-5 feet). This is logical in that the shallow depth is the zone of greatest root activity. Not surprisingly, soil moisture levels were high in early spring before crop transpiration depleted the soil moisture supplied by winter and spring rains. Soil moisture remained relatively high throughout spring in most fields; crop evapotranspiration is low and sporadic spring rains occur so irrigations usually keep pace with crop water needs. In June the soil moisture tensions start to increase significantly in most fields. The figures show a spike in soil moisture tension (dry soil) in early June for most alfalfa fields. This spike corresponds to the time when fields are cut. Growers are unable to irrigate while the hay is drying. A spike in the sensor readings (low soil moisture levels) also occurred at each subsequent cutting.

The soil moisture contents encountered in this study varied considerably from grower to grower. As shown in the figures the soil remained relatively moist at some sites (figures 18, 22, 23, 24, 26, 28, 29, 30, and 31) and there was little fluctuation in soil moisture content. Other fields experienced considerable variation in soil moisture content (figures 9, 10, 11, 13, 14, 15, 16, 17, 21, 23, and 25).

Nearly all of the graphs for the alfalfa fields (figures 9-21) showed wide variations in soil moisture content. The graphs clearly indicate the dates when the alfalfa was cut and when irrigation followed (abrupt changes in direction of the line; upward for the 1996 readings with the Soil Moisture Inc. gypsum blocks and downward for the 1997 readings with the Watermark sensors).

Figure 12 shows the soil moisture content of a center-pivot irrigated alfalfa field. Center pivots are designed to deliver relatively small amounts of water on a frequent basis. This field remained moist until third cutting when irrigation ceased and the soil dried considerably. The soil in this field is variable and the location of the sensors was not representative of the field. The location was changed when the new Watermark sensors were installed in 1997. Figure 17 indicates this portion of the field was significantly under-irrigated (note excessively high soil moisture tension readings). The alfalfa in this part of the field showed visible symptoms of moisture stress.

Figures 10, 14, and 21 indicated dry conditions at times during the season. Ironically, dry soil was often preceded by periods of thunderstorm activity when the alfalfa was harvested. The rain prolonged the hay curing and delayed the irrigation that occurs after cutting. By the time the field is re-irrigated, excessive soil moisture depletions have occurred. The rain during the thunderstorm was insufficient to satisfy crop water needs. More water is needed to replenish the soil moisture and some growers are unable to catch up.

It appears from the graphs that irrigation water could have been conserved (less water applied or an irrigation delayed) in figures 19 and 20 in the spring, figure 16 in the fall, and figure 18 for much of the season. Orchardgrass was seeded in mid summer in the alfalfa field represented by figure 18. This field was irrigated more than usual to promote establishment of the orchardgrass seedlings (compare fluctuations in soil moisture content for grower E in 1996 and 1997, figures 13 and 18).

Most pastures remained relatively moist for the entire season. In contrast, the pasture in figure 25 showed wide variations in soil moisture content and had visible signs of moisture stress. The field was cut for hay rather than grazed and the swather (harvester that cuts the field) broke while the pasture was being cut in the summer. This postponed irrigation and the grower was unable to 'catch up' and rewet the soil profile (note dry soil readings for depths 2, 3 and 4 feet for the remainder of the season). The greatest fluctuations in moisture content occurred in fields that were hayed in the summer rather than grazed (figures 25, 27, and 34). The pasture represented by figure 33 received water far in excess of crop needs in spring, especially for the period of early May to mid June, but was severely under-irrigated in late summer and fall. Note that even though soil moisture tensions were extremely high at the 0.5- and 1-foot level, the 2-, 3-, and 4-foot levels remained relatively moist. This again demonstrates the shallow rooting and water extraction pattern of pasture species.

Figures 22, 23, 24, 26, 28, 29, and 31 represent pastures that remained moist and there is significant potential for water conservation. There was concern that the site of the sensors for Grower E may not be representative of the field so an additional site was selected in 1997. The results were very similar for both sites and were in agreement with the 1996 results.

In general, the soil moisture content of irrigated pastures remained consistently higher than that of alfalfa fields. In addition, soil moisture in alfalfa fields was significantly lower in the fall than it was in pastures. There are several plausible explanations for the differences in soil moisture observed in alfalfa fields and pasture. First, irrigated pasture is often produced on more marginal soil, often sites that have a high water table. The well-drained deep soils are usually reserved for alfalfa. Alfalfa will not tolerate saturated conditions for prolonged periods as well as the cool-season grasses typically used in pastures. Therefore, the high soil moisture readings in some of the pastures is not solely related to irrigation practices but may be accounted for at least in part by the high water table. Government agency estimates of applied irrigation water may be in error. In most cases applied water is calculated by using seasonal evapotranspiration data for a given crop and then dividing that figure by an assumed irrigation efficiency for flood or sprinkler irrigation. However, this method does not account for the water used by crops that is supplied by a high water table and not applied irrigation water.

Alfalfa in the Scott Valley is typically cut three times per year. Growers usually cease irrigating after the final cutting of the season and the alfalfa soon goes dormant until growth resumes in spring. Pasture production practices are different. Pastures are typically grazed rather than cut for hay in the fall. Livestock producers must feed costly hay once pasture growth ceases due to cold weather. Growers wish to prolong pasture growth as long as possible to delay feeding hay. Therefore, pastures are usually irrigated later into the fall than is alfalfa. Occasionally, growers have mistaken frost symptoms for moisture stress and irrigated when it was unnecessary. The water needs of pasture decline significantly in fall due to lower temperatures and shorter day length.

Lastly, alfalfa is typically cut three to sometimes four times per season. Most of the pastures (especially those showing little fluctuation in soil moisture levels) were only cut once in the spring or not at all. The irrigated pastures were grazed for most of the year. Growers cannot irrigate for a while prior to cutting to allow the field to dry out enough for haying equipment to enter and to dry out the soil surface to promote hay curing. In addition, grower obviously cannot irrigate while the hay is curing. Therefore, there is typically an 8 to 20 day period when fields are not irrigated. When fields are grazed rather than hayed there is not this long period when fields cannot be irrigated and the irrigation schedule can continue nearly uninterrupted.

A logical question regarding these results is whether fields are over-irrigated with current irrigation practices? There is no simple answer to this question. There are cases where fields are irrigated more than necessary or with too much water. There were also a few fields, especially alfalfa fields in mid to late summer that did not receive adequate irrigation. Few alfalfa fields appeared to have received water in excess of crop needs in the fall. The greatest potential water savings for alfalfa fields appear to be in spring (and only for some growers). Some growers may try to apply excess water in spring to compensate for the hot summer months when irrigation may be insufficient. However, the root zone of the crop is limited and applying water in excess of crop needs in spring may not be helpful.

Some irrigated pastures remained very moist throughout the growing season. The graphs did not show the wetting and drying cycles that typically occur. Ordinarily the soil dries in response to crop water use and then the soil moisture rises after an irrigation. The drying and wetting cycle repeats itself. Little change in soil moisture levels occurred in some pastures. This indicates that irrigation chould be reduced. The fields could be irrigated less frequently (i.e., skip an irrigation or lengthen the interval between irrigations). Or, the greatest potential for irrigation water conservation would be to apply less water per irrigation. This is especially the case in fields with a high water table. Given the shallow rooting depth of pasture species and the high moisture content deep in the soil profile, only enough water to wet the upper 1 to 2 feet is needed. In some cases, this could be a significant reduction in the amount of applied water.

While improvements seem warranted, there are some restrictions that need to be kept in mind. Some of the pastures are flood irrigated. It is difficult to control how much water is applied per irrigation with a flood system. Usually the amount of water per irrigation is somewhat fixed. The amount of water applied is a function of the head (amount of water delivered) and the set time (the length of time required for the water to reach the tail end of the field). The longer the time water is applied the more water that infiltrates. A certain amount of water and time is required for the water to reach the tail end of a field.

Changing the water applied with a flood system requires that the flow rate be changed or change the slope of the field. Both these changes can be difficult.

Typically, it is much easier to change the amount of water that is applied per irrigation with sprinklers. How long the sprinklers run determine the amount of water applied. Growers ordinarily use 12-hr sets. This way the water is turned on and off and the sprinklers moved in the morning and again in the afternoon. Set times different than 12 hours may be inconvenient. Aside from the increased labor with more frequent moves, a different set time may require moving the irrigation lines at night. Night moves are not always feasible because the time is inconvenient, it is difficult to find labor, and the task is more arduous in the dark. Depending upon how much irrigation set times should be reduced, it may be possible to move lines only during daylight hours or an alternative may be to install a time clock to automatically shut the lines off when needed.

Usefulness of Soil Moisture Monitoring. Alfalfa and pasture producers do not commonly practice soil moisture monitoring. However, this research clearly demonstrates the usefulness of this practice. Without a tool such as soil moisture sensors it is extremely difficult for growers to know the moisture status of their fields especially at the lower depths.

Soil moisture monitoring is extremely useful to fine tune irrigation practices. There are times when the moisture sensors would indicate that an irrigation can be skipped. Soil moisture sensors would also indicate to growers roughly how much water is needed. If the lower depths show ample water, less water can be applied; only a shallow irrigation is needed to rewet the upper part of the soil profile. The graphs showing the seasonal soil moisture content present a very useful and informative picture of what has occurred in the root zone of the crop over the season.

Education and Extension:
Several methods including publications, newsletters, meetings, and field days were used to disseminate the results of this project and to encourage adoption. The results of this research were presented at numerous meetings and conferences (see table 7). The results were presented to the Scott Valley Watershed CRMP on two occasions while the project was in progress. Three field days were held at which instructions were given on how to install the moisture sensors and how to use the information obtained to improve irrigation efficiency.

Table 7. Partial listing of educational events where data from this study were presented

Meeting	**Location**
CRMP meeting 1995	Ft. Jones, CA
UC Davis Alfalfa Field Day 1997	Davis, CA
Siskiyou County Grower's Seminar 1997	Yreka, CA
California Alfalfa Symposium 1997	Visalia, CA
Glenn County Field Crops Meeting 1997	Orland, CA
Scott Valley Field Day 1997	Etna, CA
CRMP meeting 1997	Etna, CA
Redding Irrigated Pasture Improvement 1998	Redding, CA
Washington State Hay Growers Conference 1998	Pasco, WA
Klamath Basin Hay Growers 1998	Klamath Falls, OR
Siskiyou County Grower's Seminar 1998	Yreka, CA
California Alfalfa Symposium 1998	Reno, NV
UC Davis Alfalfa Field Day 1998	Davis, CA
Intermountain Hay Growers' Field Day 1998	Macdoel, CA
Shasta County Alfalfa Field Day 1998	Big Valley, CA

Results were presented in newsletter articles and in the proceedings of some of the conferences mentioned above. Data from this project was used for a chapter on soil moisture monitoring in an irrigation scheduling manual aimed at maximizing irrigation efficiency. An article is planned for the refereed publication *California Agriculture*, published and distributed by the University of California. An instructional publication is also planned to teach growers about the use of soil moisture sensors and how to maximize irrigation efficiency.

The favorable results of this initial research project led to an additional project proposal that was just recently funded. The next phase of this project will focus on adoption of improved irrigation scheduling practices.

The results of these studies will continue to be disseminated using publications, farm visits, and meetings. The adoption of improved irrigation practices will be encouraged. As a result of this research, several growers throughout Siskiyou County and other areas have purchased soil moisture sensors and are using them to improve their irrigation practices.

SUMMARY AND CONCLUSIONS

Irrigation cut-off date affected the soil moisture content but only the early cut-off dates had a appreciable effect on alfalfa yield. Regardless of the irrigation cut-off date, all plots fully recovered by the following season and 1st and 2nd cutting yields were essentially the same. Irrigation after the final alfalfa cutting of the season appeared unnecessary for the soil type evaluated. Late-season irrigation (terminating irrigation in mid September versus late September or early October) had little effect on pasture yield. However, early irrigation termination (early August) resulted in the death of some pasture grasses and reduced yield. Cool-season pasture grasses was less able to withstand drought than was alfalfa.

The soil moisture status of the fields monitored suggests there is potential for water conservation. The greatest potential is in the spring when some growers may irrigate too frequently and/or with too much water. There is also significant potential to save irrigation water in some pastures. Given the limited root system of pasture species and the high water table that exists in some fields, the amount of water applied per irritation could be reduced in many cases.

Soil moisture sensors, particularly the Watermark sensors, were found to be a reliable tool to assist growers with irrigation scheduling and improve irrigation efficiency. It appears that, using a tool such as soil moisture sensors, there is potential for improved water management and water conservation on some ranches. There were times, especially in the spring, when fields were irrigated when the soil moisture levels did not indicate irrigation was needed. The sensors also showed that under irrigation occurred on other ranches, largely because the irrigation system was inadequate to meet peak crop needs in the mid-summer. The sensors could help indicate when irrigation is needed and approximately the depth of wetting required.

The quantity of water that could actually be conserved through improved irrigation management is unknown. Furthermore, it is also unknown if that amount would improve flows in the Scott River. Applied water in excess of crop needs is not lost to the system. Excess water eventually recharges groundwater and affects flows in the river. A critical question relates to the time delay for excess applied water to reach the groundwater. More detailed information regarding the hydrology of the Scott Valley is needed before this question could be adequately addressed. Recognizing the limited understanding of conservation impacts on Scott River flows, it seems prudent at this point to manage irrigation as efficiently as possible.

SUMMARY OF EXPENDITURES

Item	Cost
Salaries for Field Assistance	4638.23
Benefits	420.33
Travel and transportation	1221.43
Expendable equipment, materials and supplies	8883.20
General and Administrative Expenses (overhead)	3448.43
Total grant 1995-6	**15843.00**
Labor and equipment expenses exceeding grant	2768.62

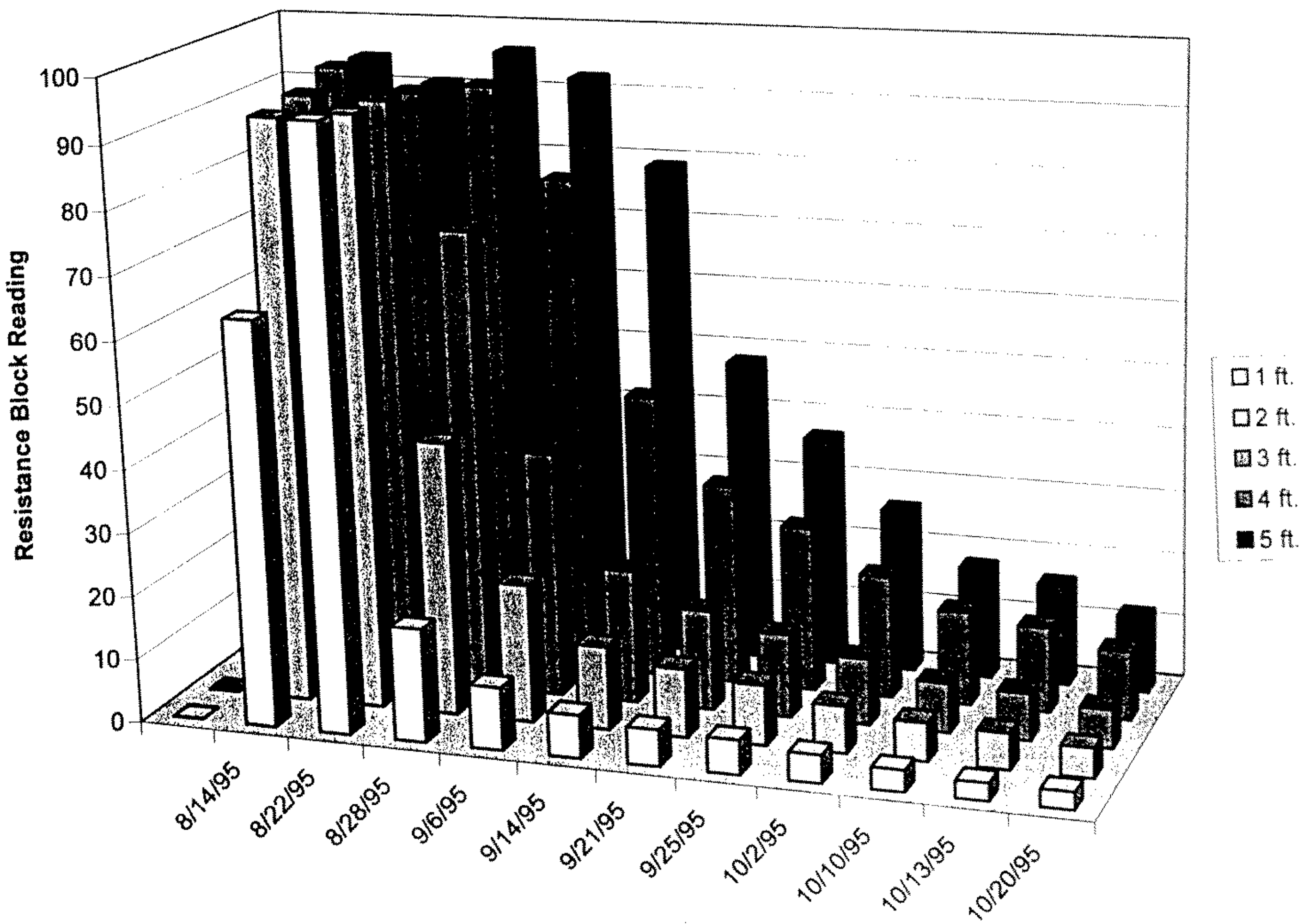

Figure 1. Soil moisture status of alfalfa field in fall with July 21, 1995 as the last irrigation. (94-96 represents saturated soil, drier soil is numerically lower)

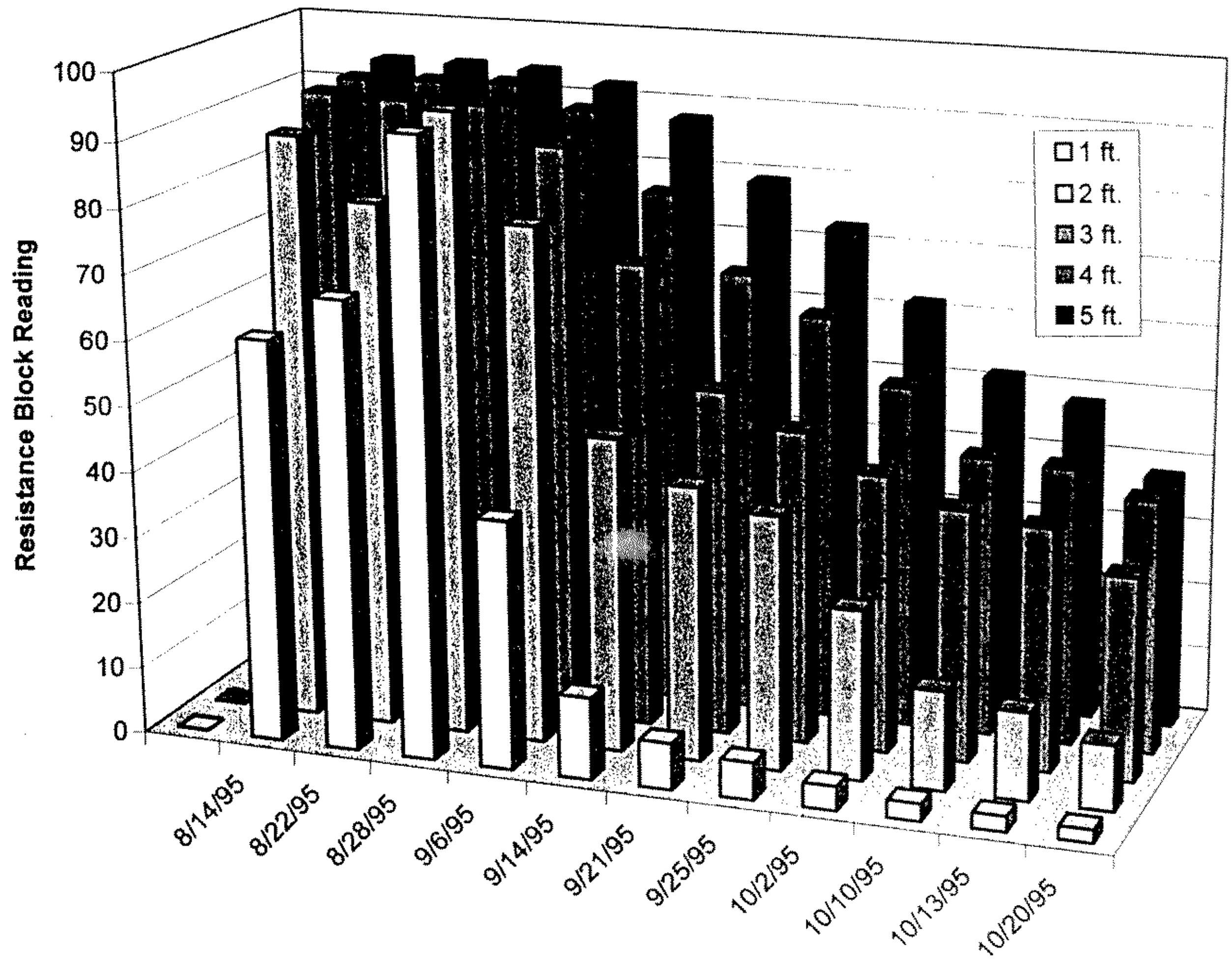

Figure 2. Soil moisture status of alfalfa field in fall with August 14, 1995 as the last irrigation. (94-96 represents saturated soil, drier soil is numerically lower)

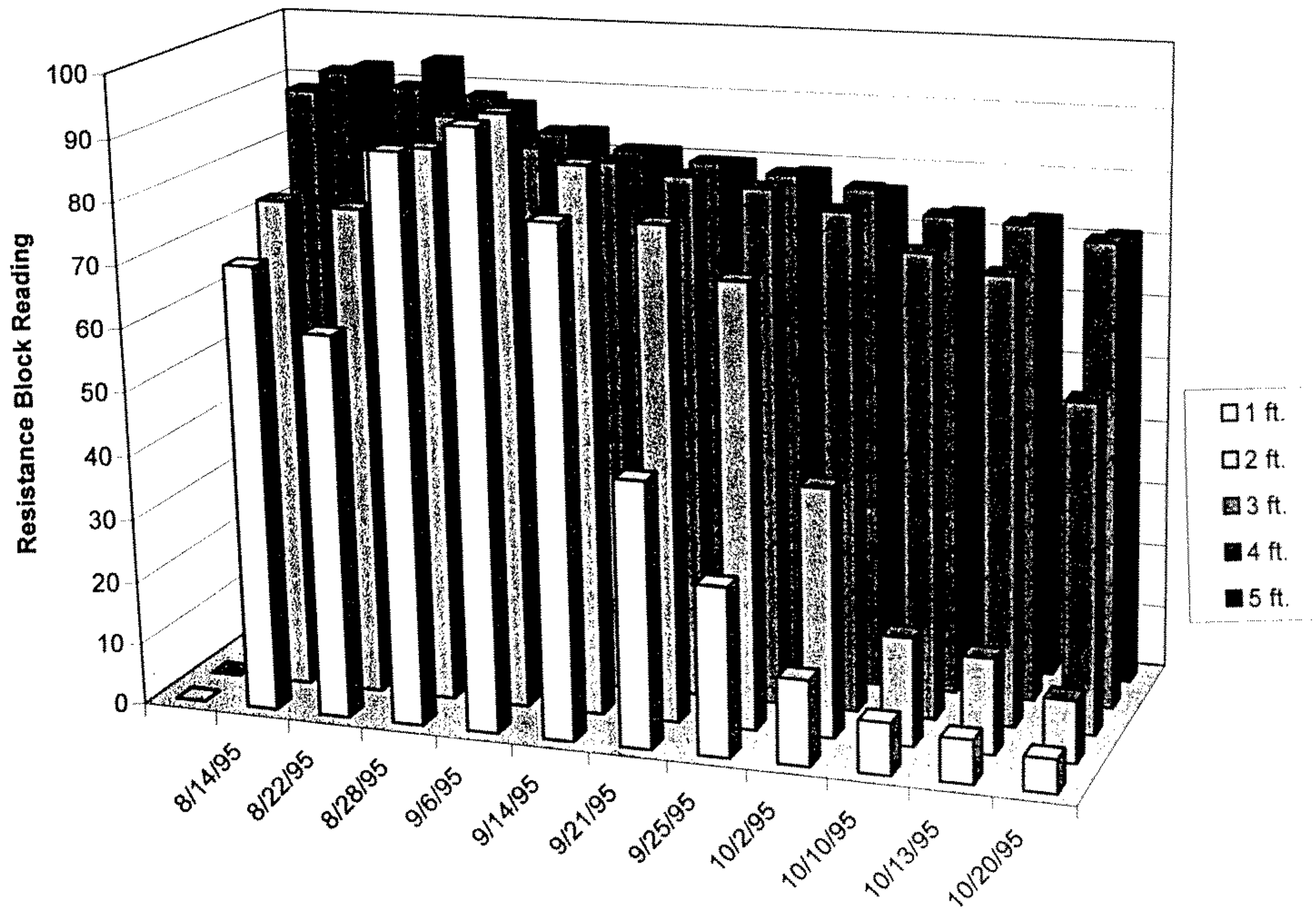

Figure 3. Soil moisture status of alfalfa field in fall with August 30, 1995 as the last irrigation. (94-96 represents saturated soil, drier soil is numerically lower)

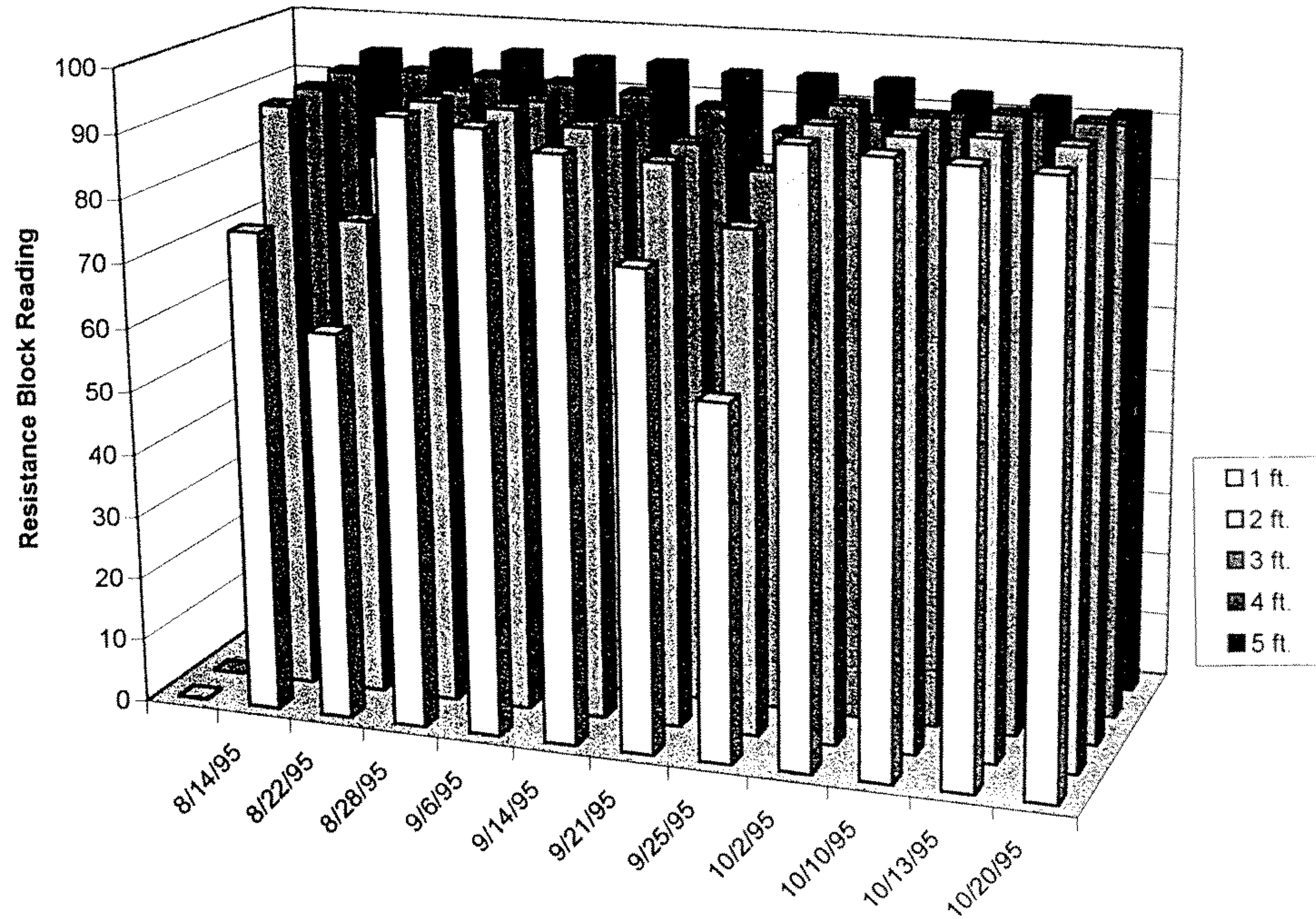

Figure 4. Soil moisture status of alfalfa field in fall with September 26, 1995 as the last irrigation. (94-96 represents saturated soil, drier soil is numerically lower)

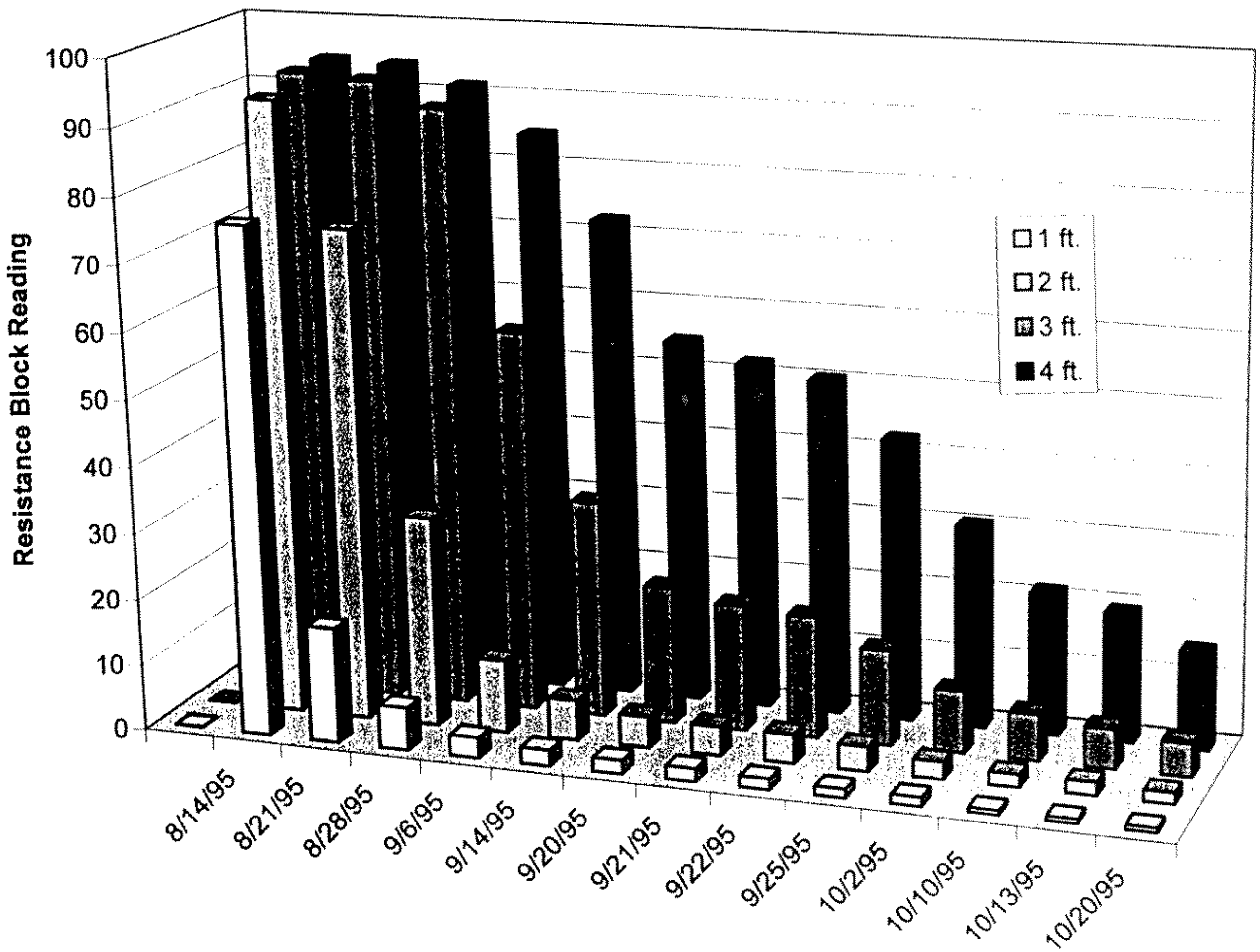

Figure 5. Soil moisture status of pasture in fall with August 3, 1995 as the last irrigation. (94-96 represents saturated soil, drier soil is numerically lower)

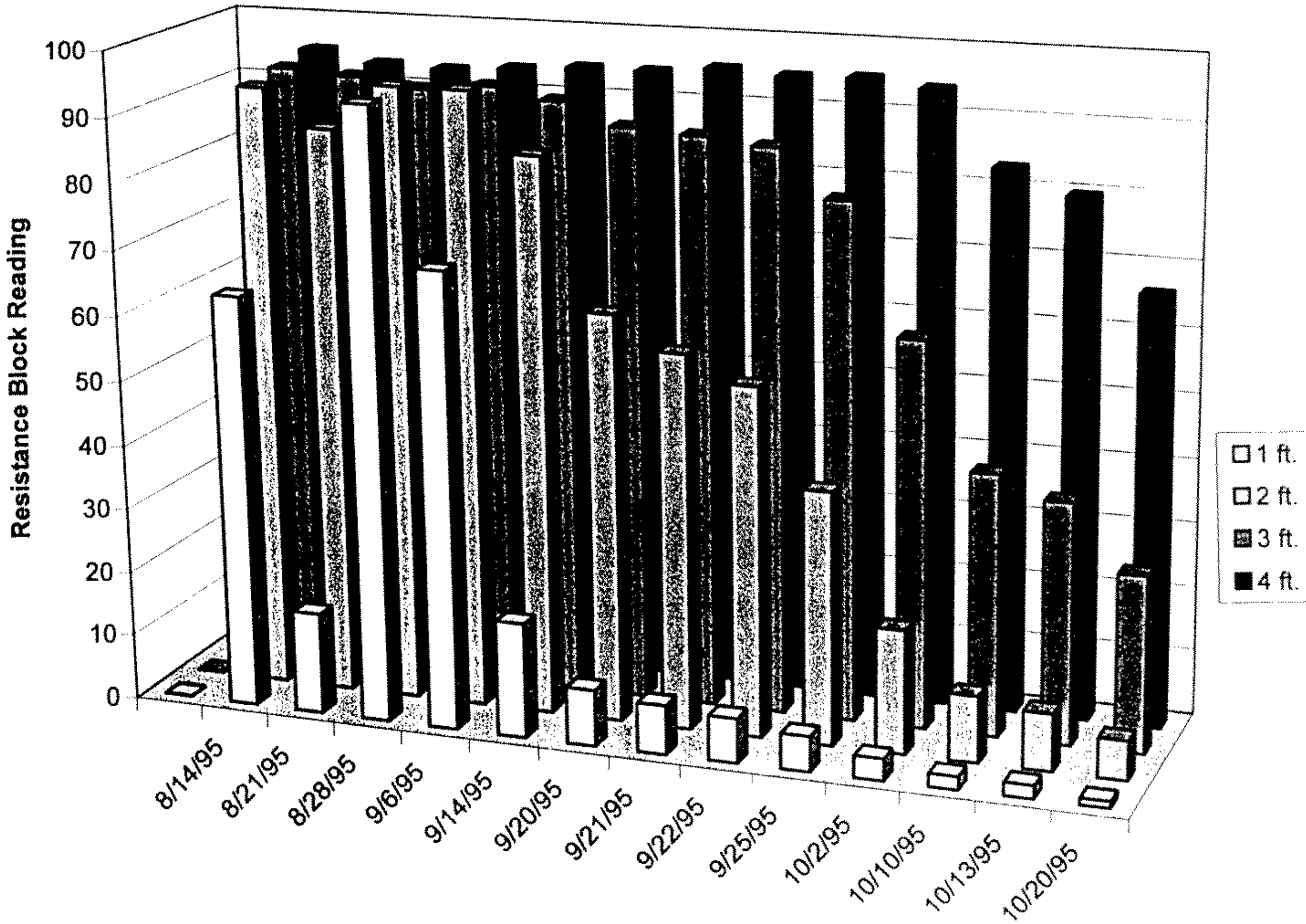

Figure 6. Soil moisture status of pasture in fall with August 13, 1995 as the last irrigation. (94-96 represents saturated soil, drier soil is numerically lower)

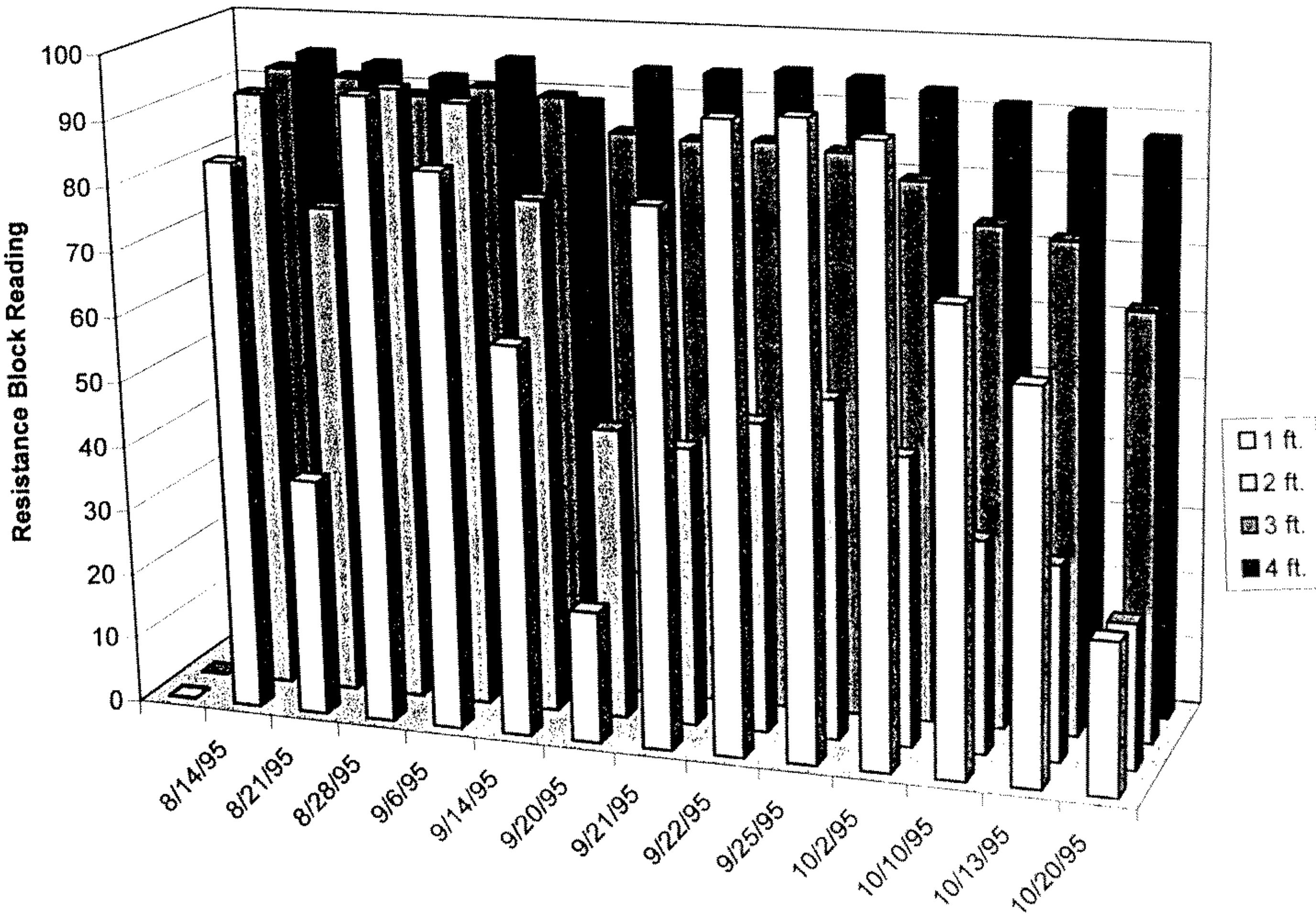

Figure 7. Soil moisture status of pasture in fall with August 30, 1995 as the last irrigation. (94-96 represents saturated soil, drier soil is numerically lower)

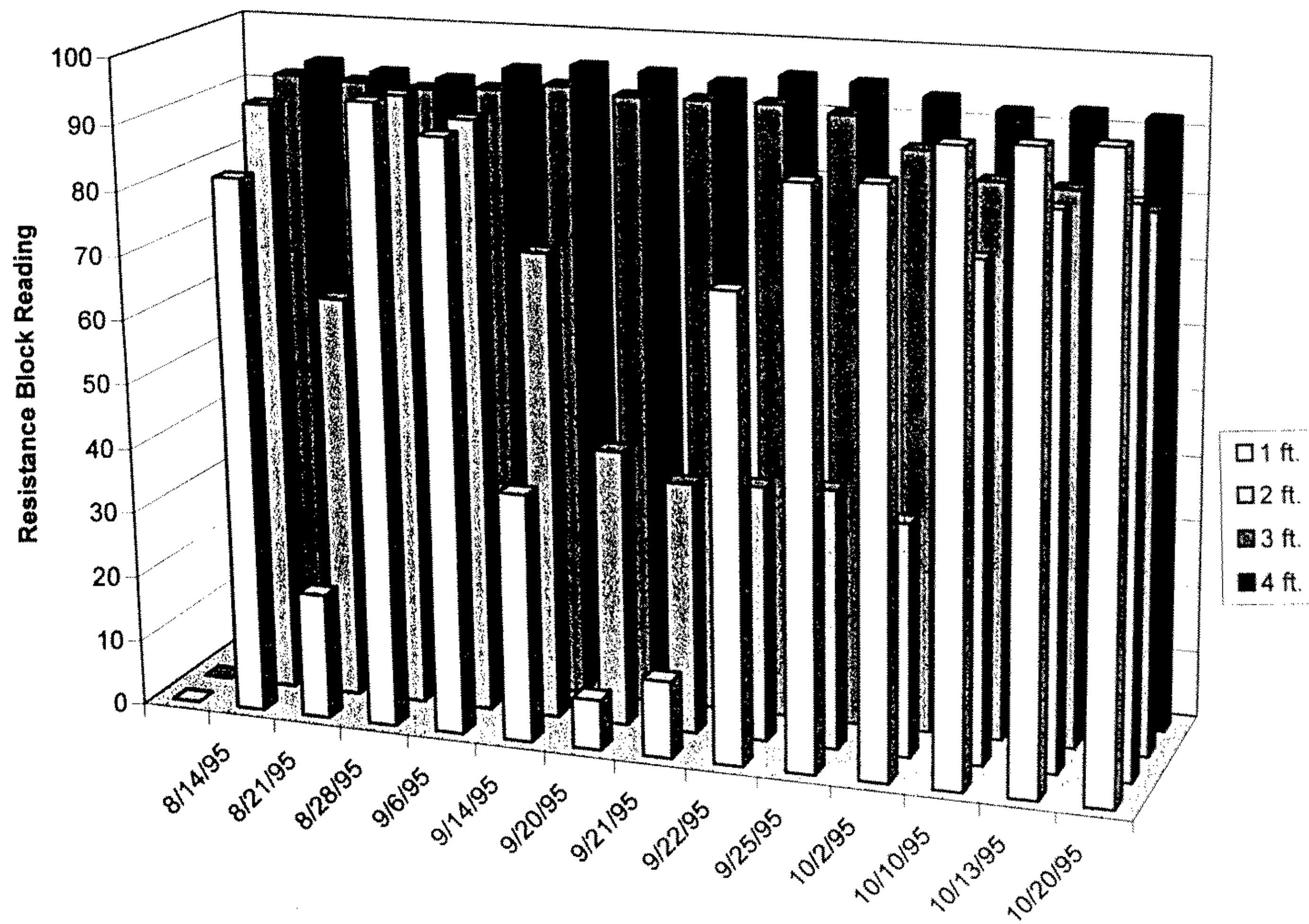

Figure 8. Soil moisture status of pasture in fall with October 3, 1995 as the last irrigation. (94-96 represents saturated soil, drier soil is numerically lower)

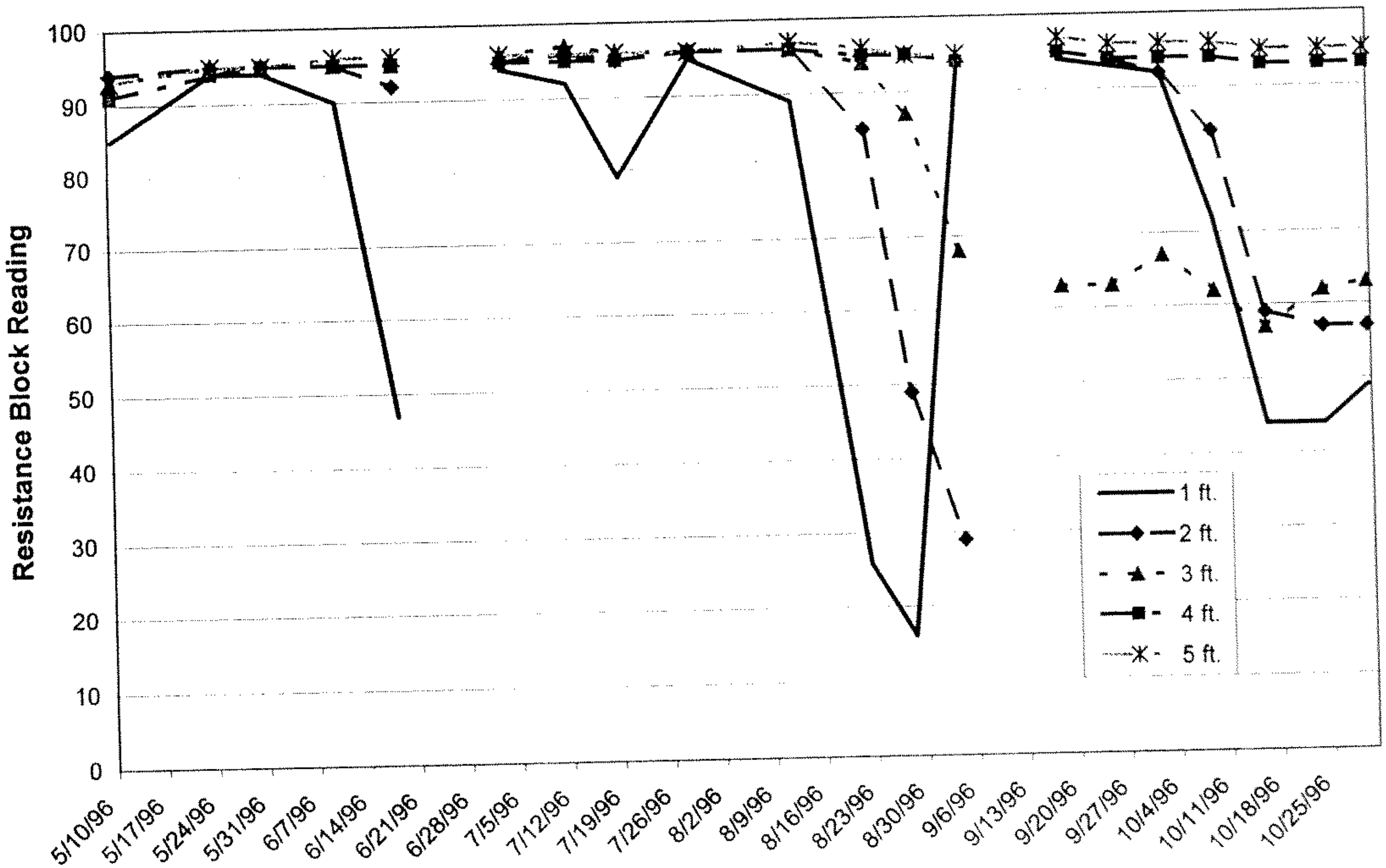

Figure 9. 1996 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower A). (94-96 represents saturated soil, drier soil is numerically lower)

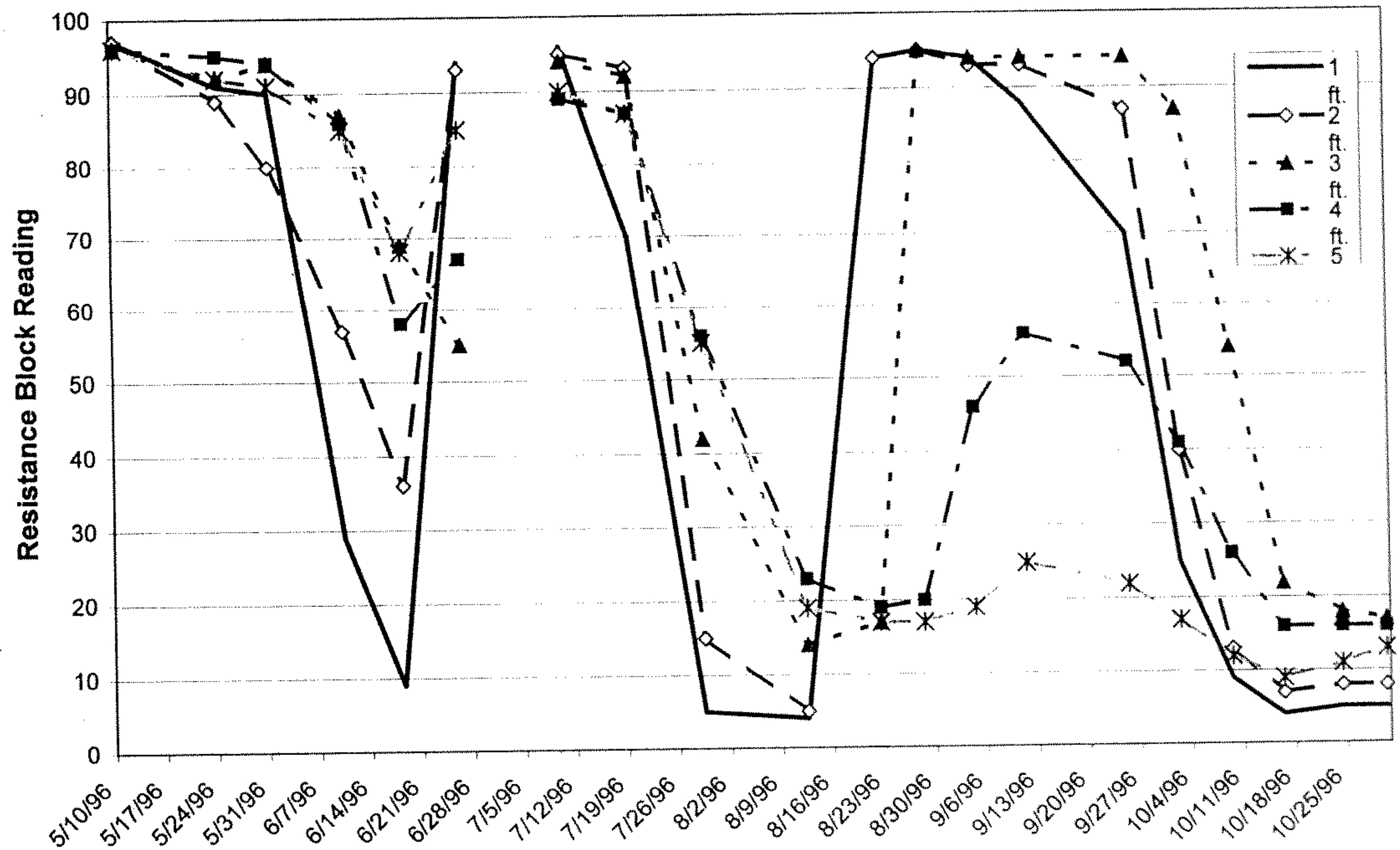

Figure 10. 1996 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower B). (94-96 represents saturated soil, drier soil is numerically lower)

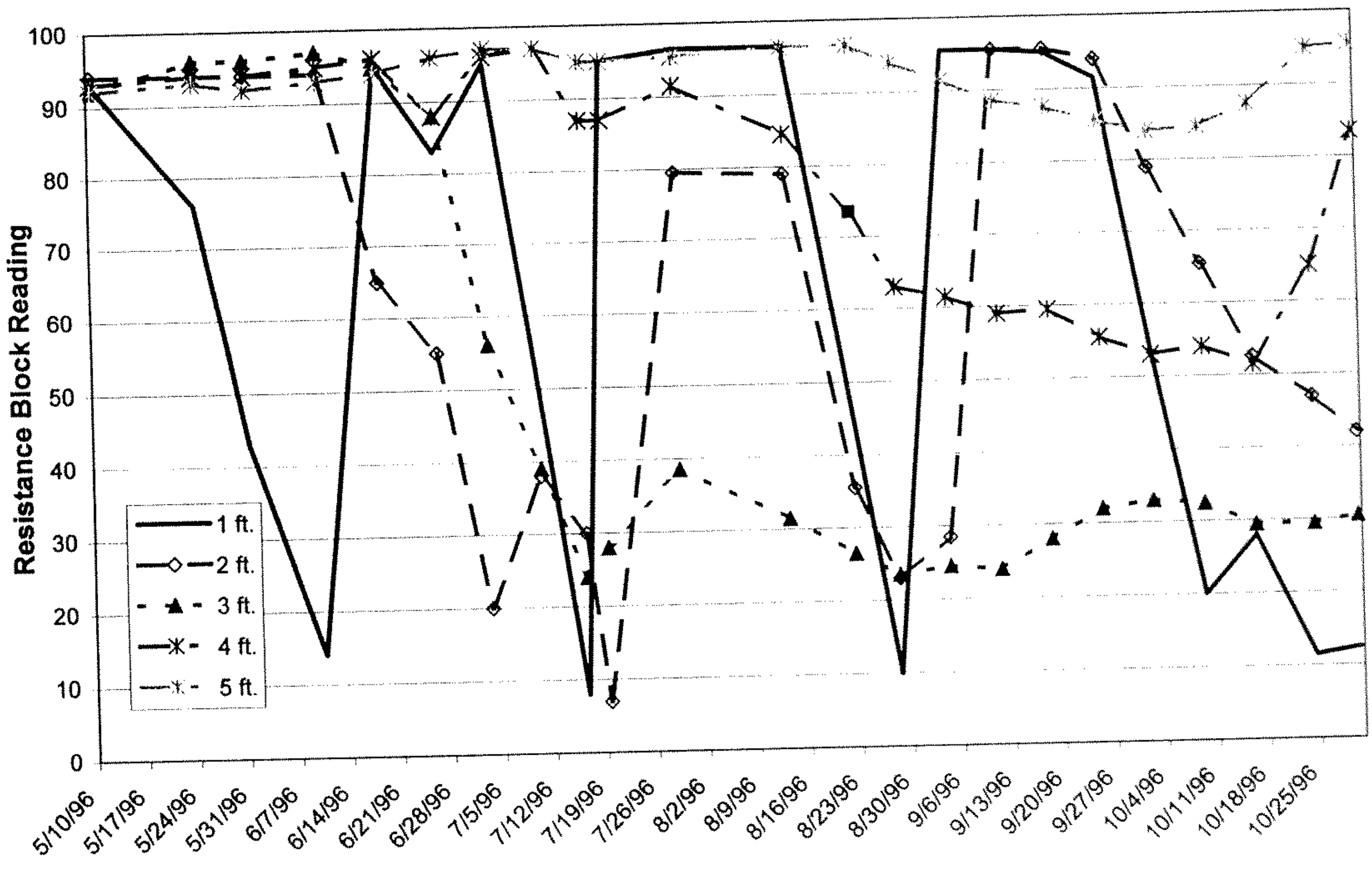

Figure 11. 1996 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower C). (94-96 represents saturated soil, drier soil is numerically lower)

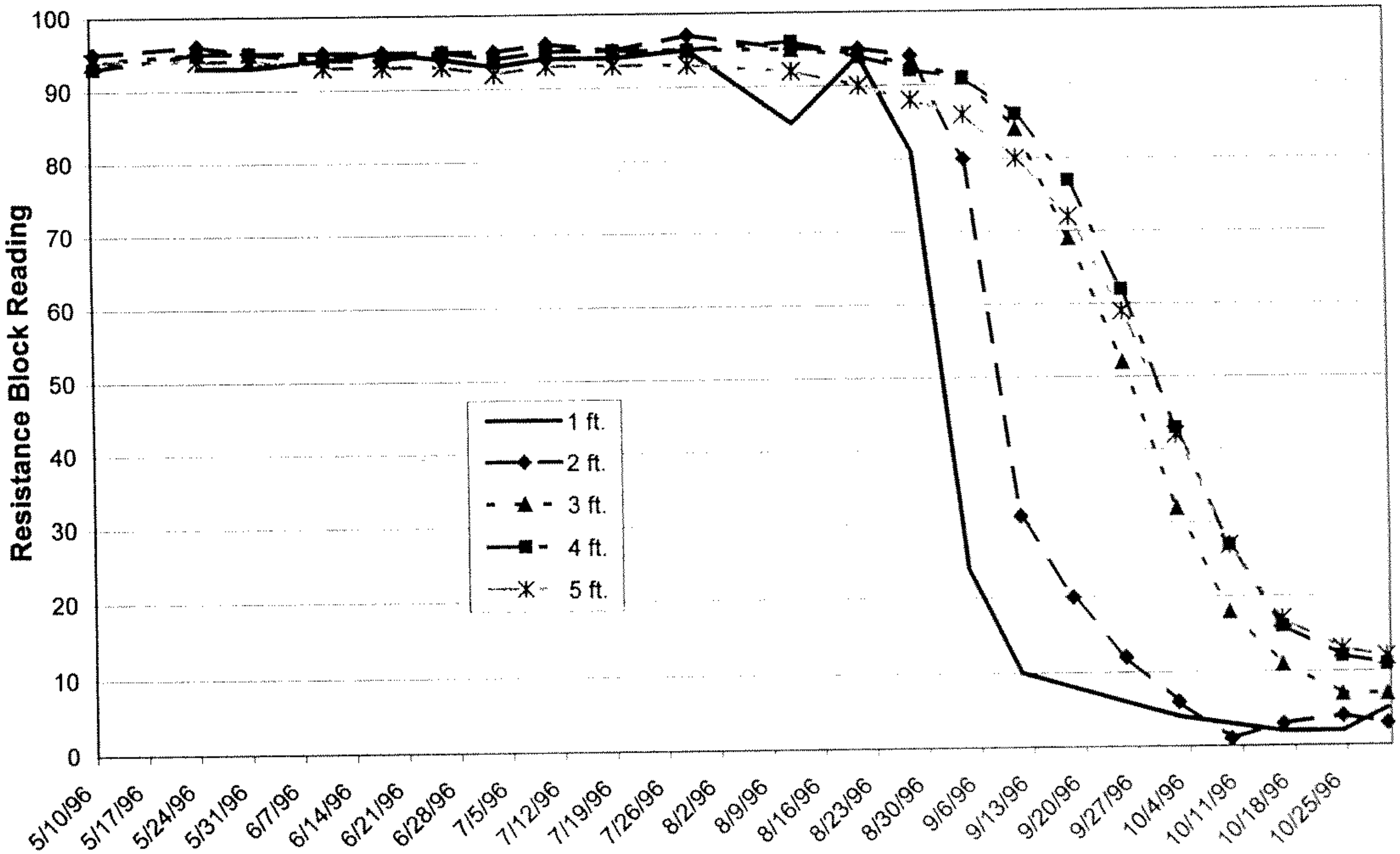

Figure 12. 1996 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower D). (94-96 represents saturated soil, drier soil is numerically lower)

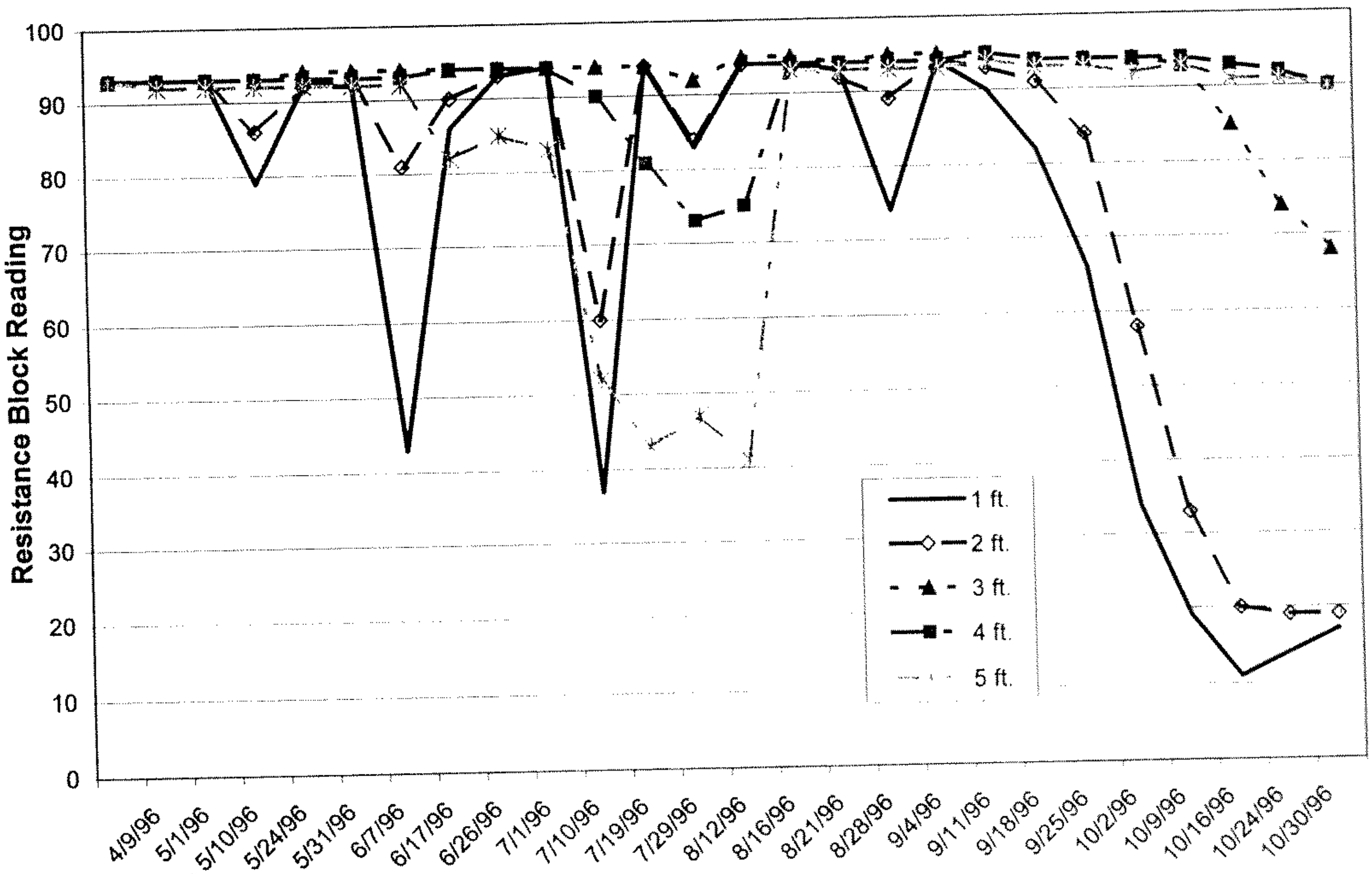

Figure 13. 1996 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower E). (94-96 represents saturated soil, drier soil is numerically lower)

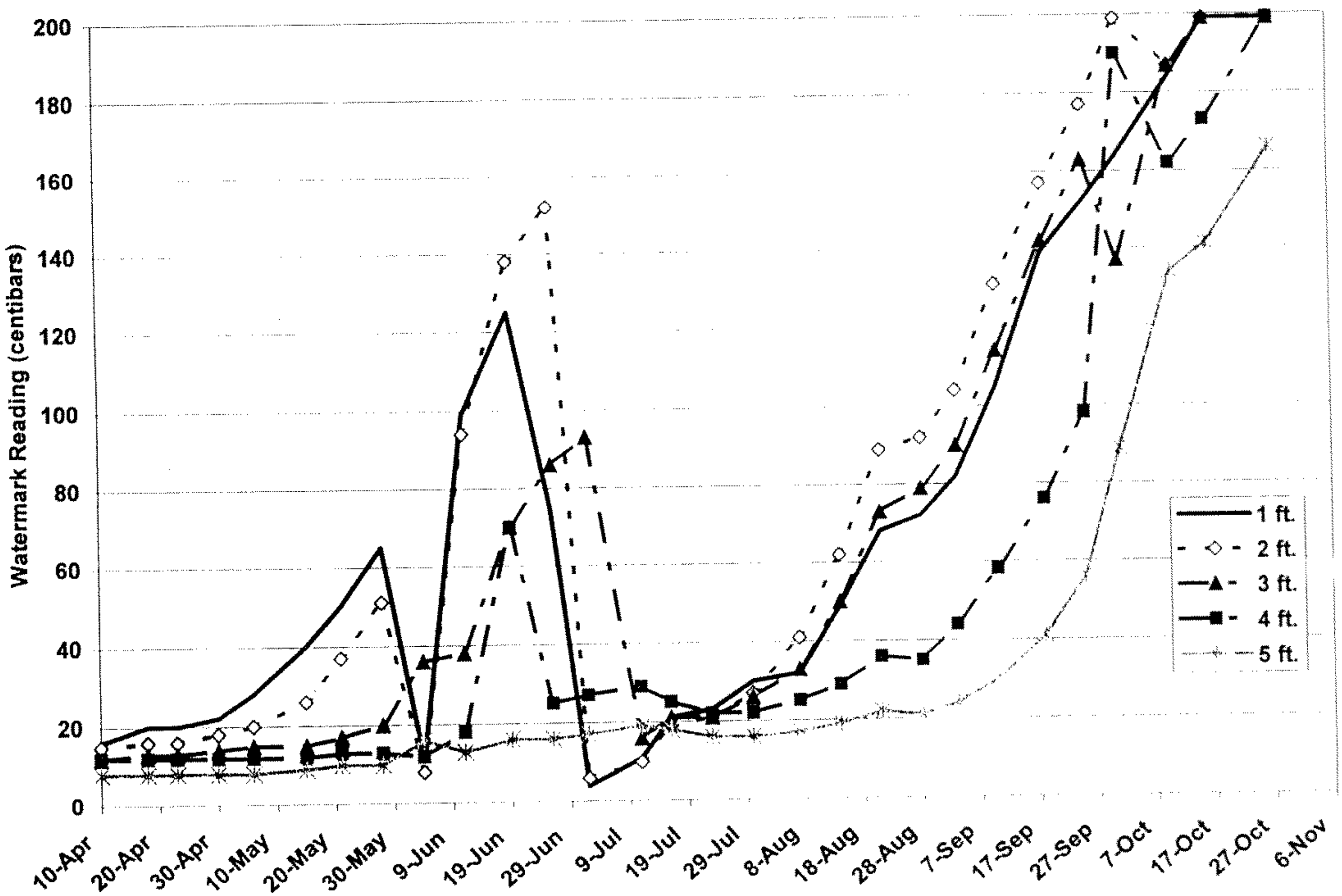

Figure 14. 1997 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower A). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

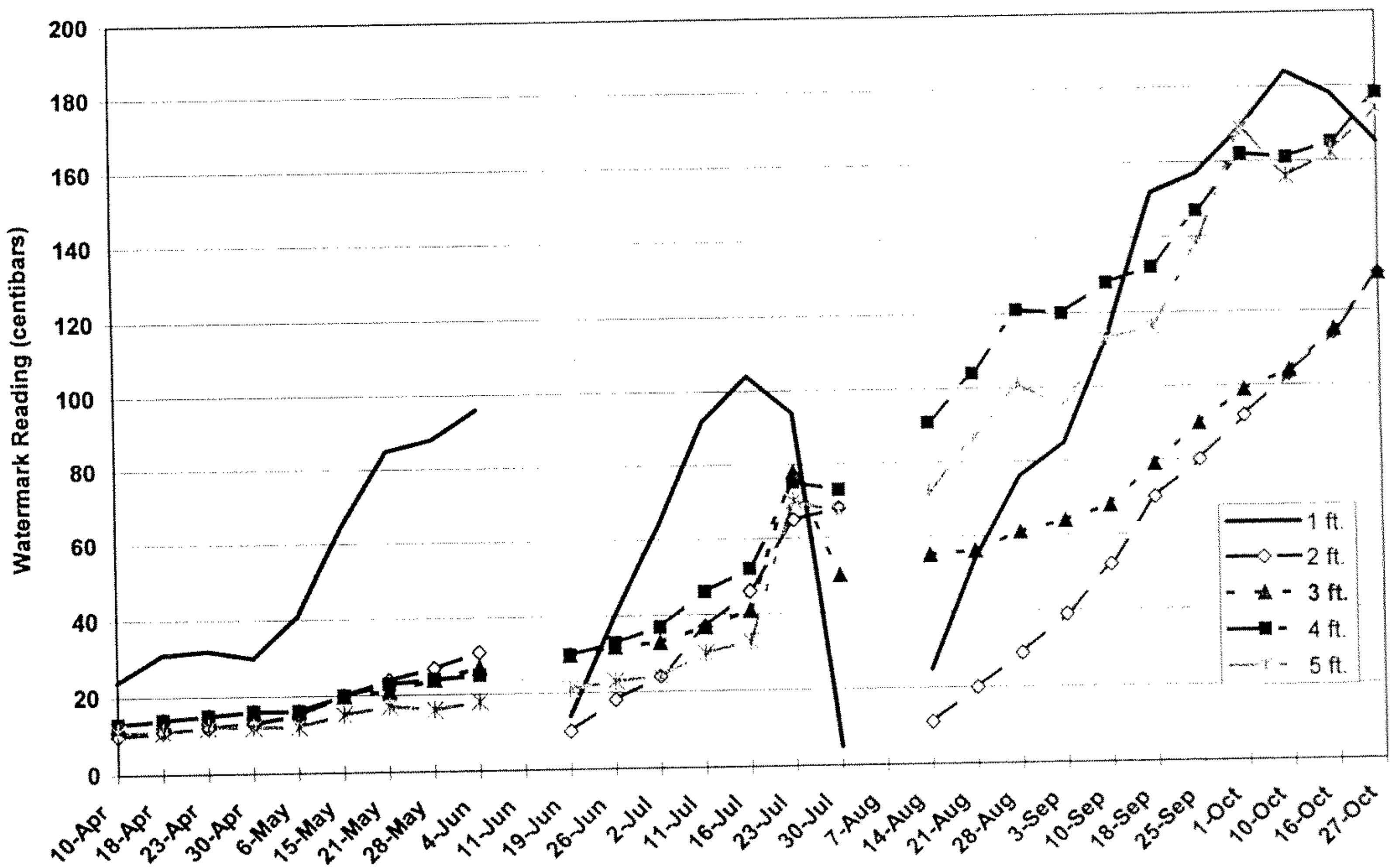

Figure 15. 1997 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower B). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

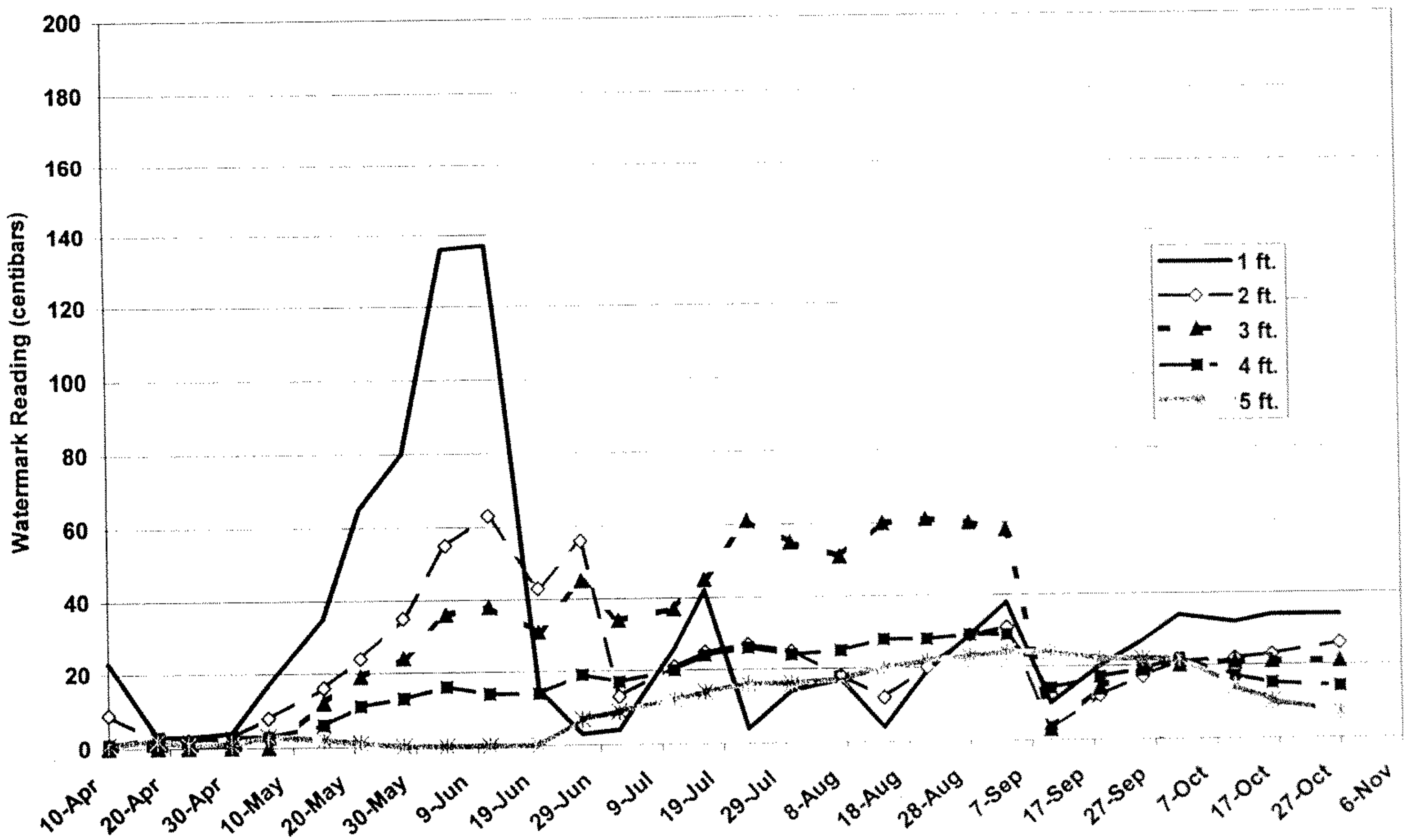

Figure 16. 1997 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower C). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

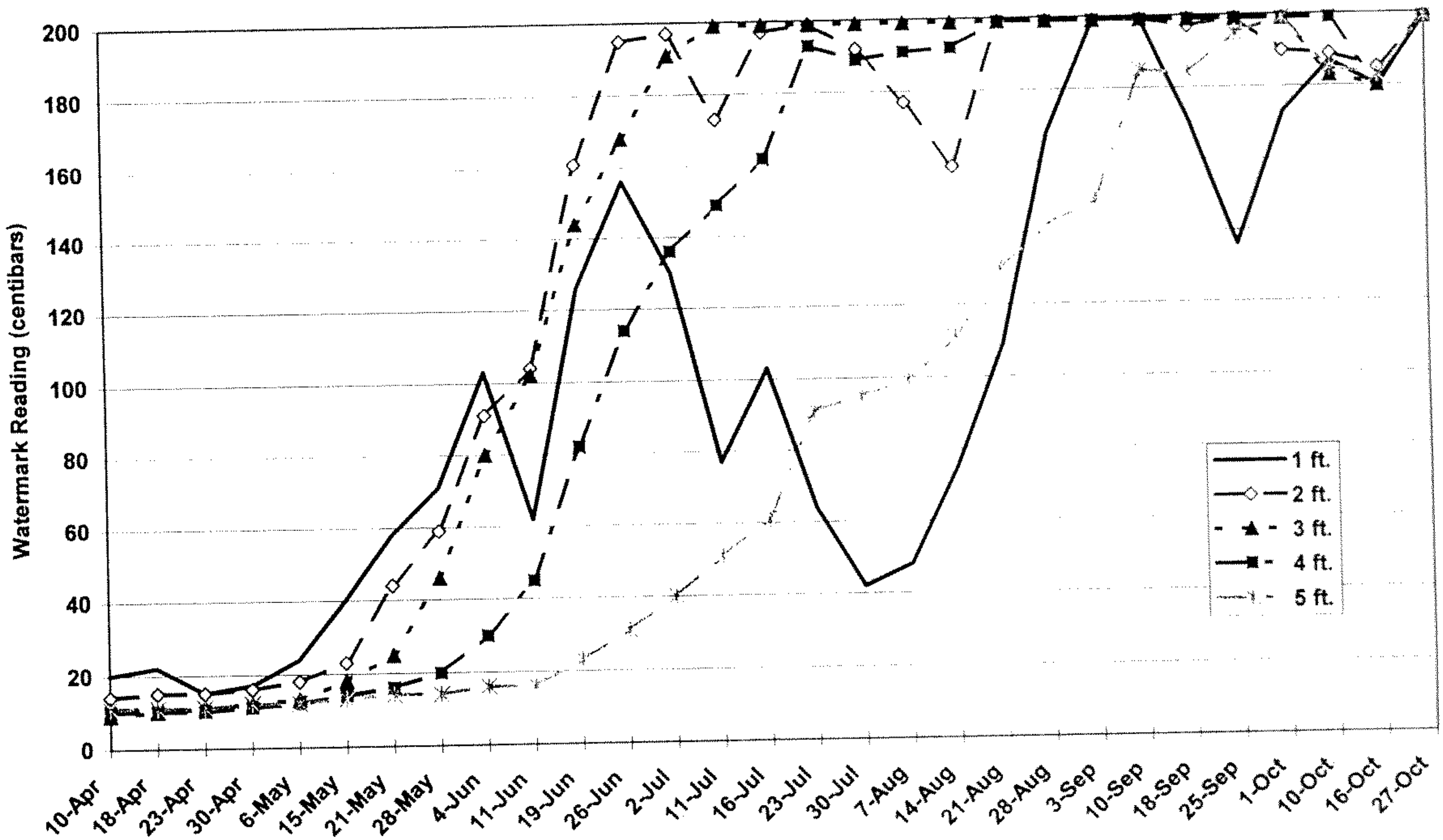

Figure 17. 1997 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower D). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

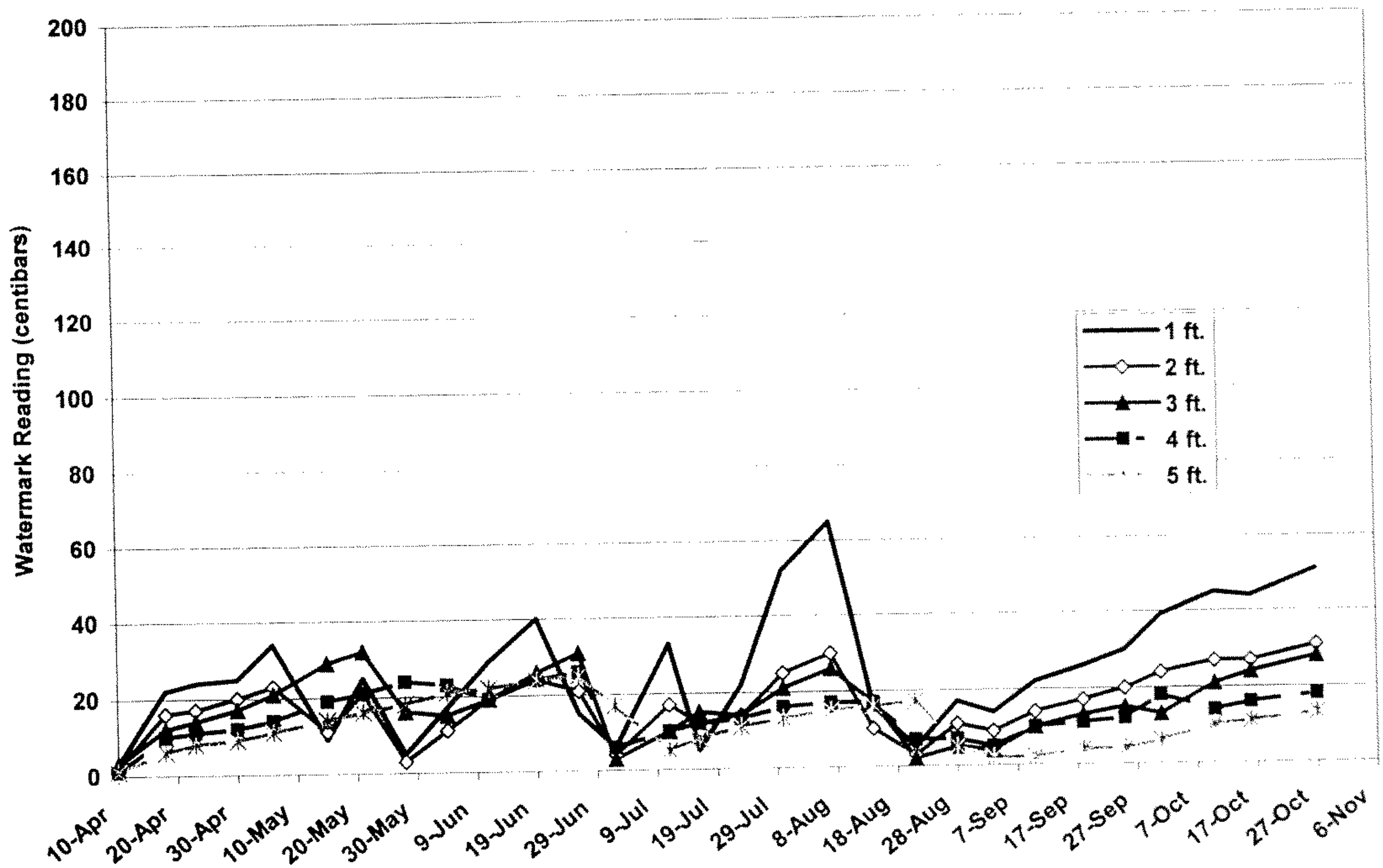

Figure 18. 1997 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower E). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

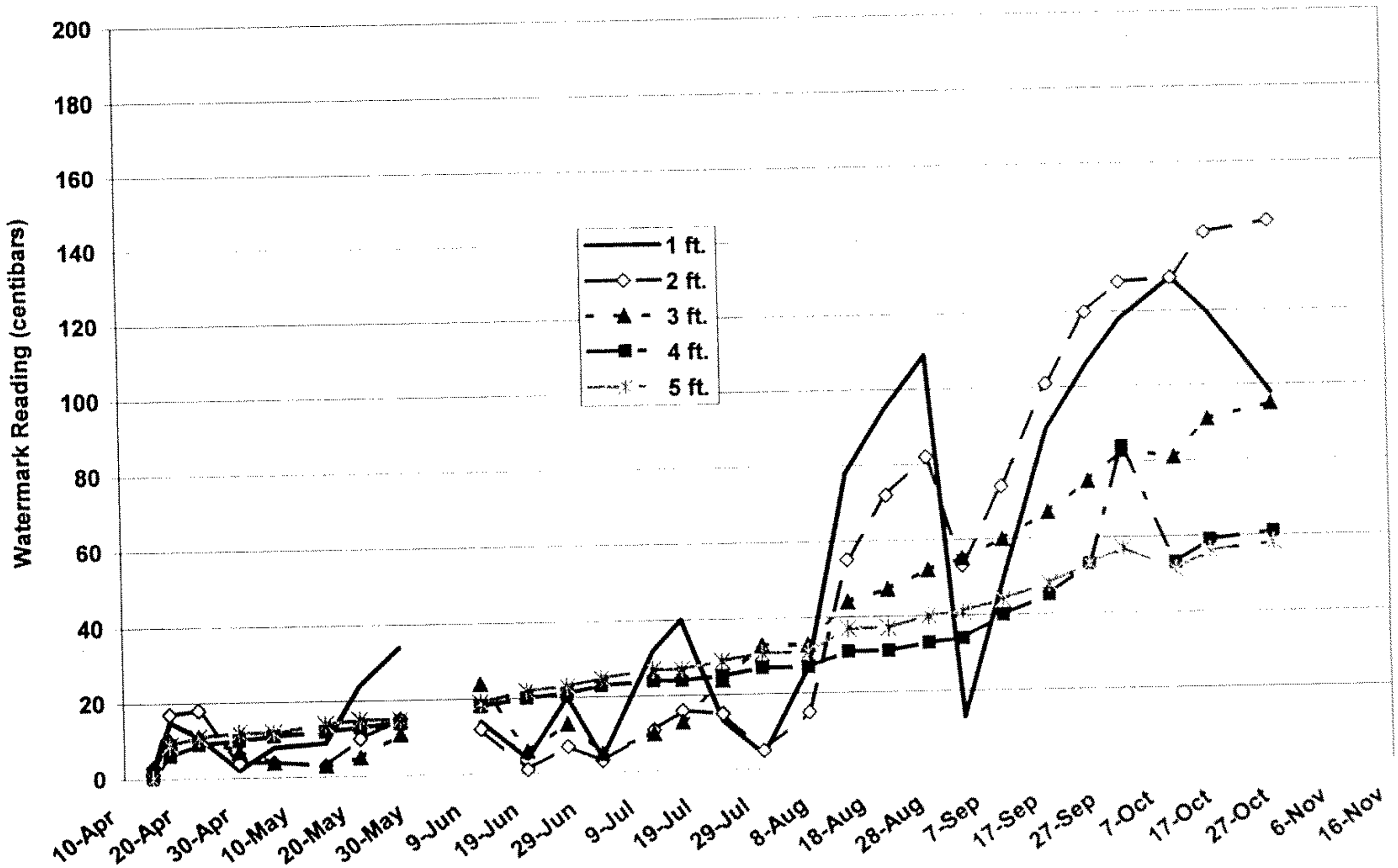

Figure 19. 1997 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower F). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

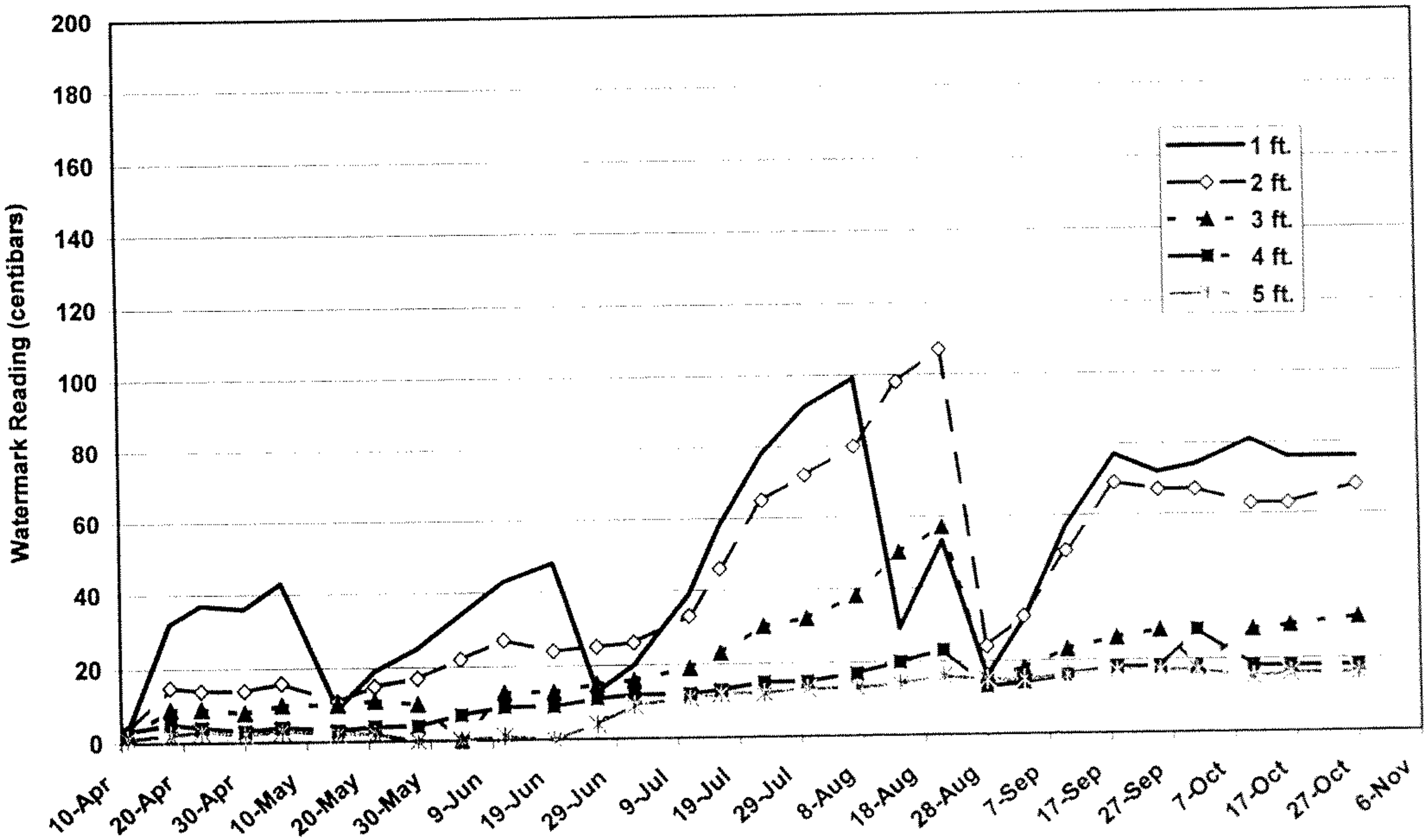

Figure 20. 1997 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower G). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

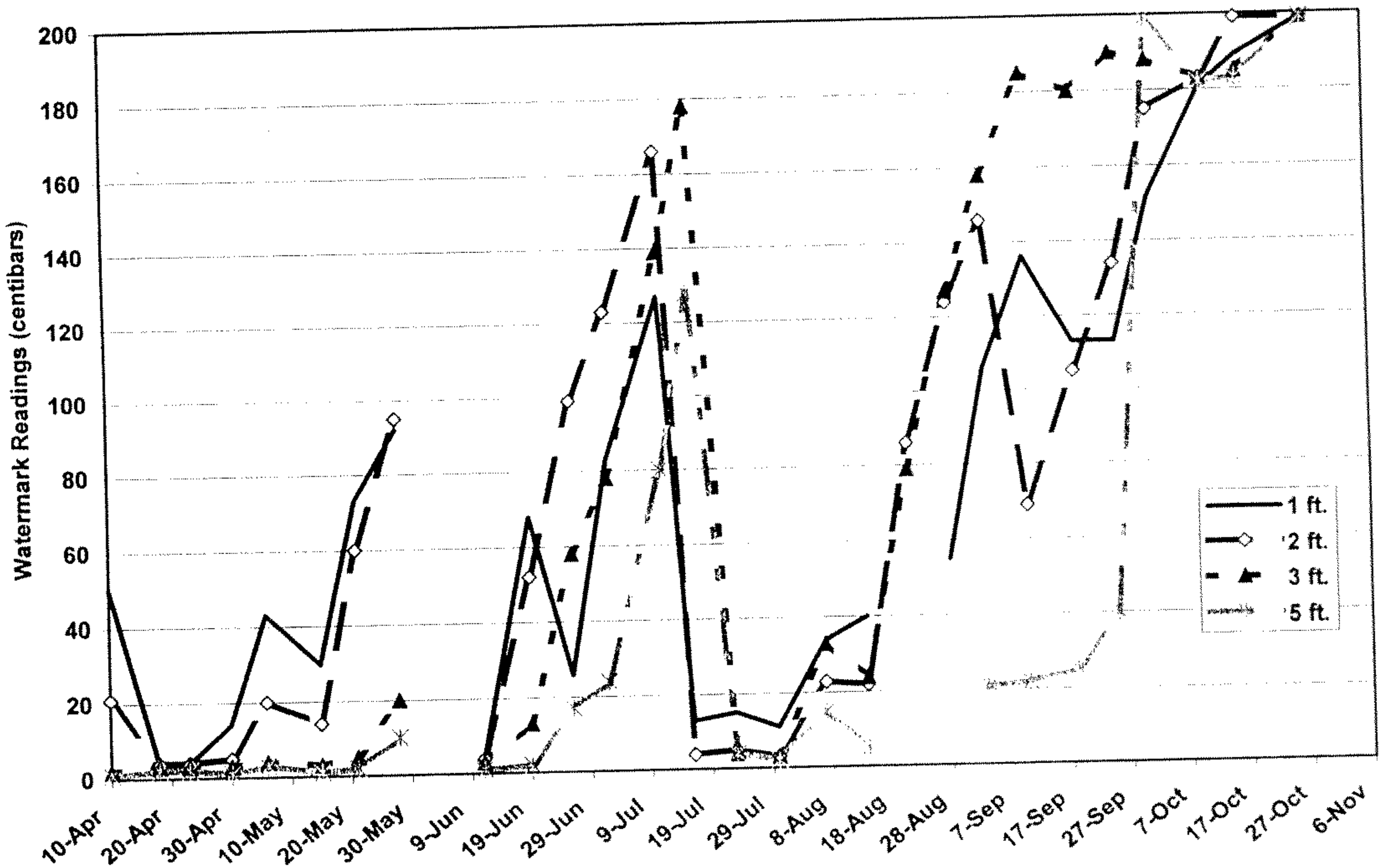

Figure 21. 1997 seasonal soil-moisture level at five depths for Scott Valley alfalfa field (Grower H). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

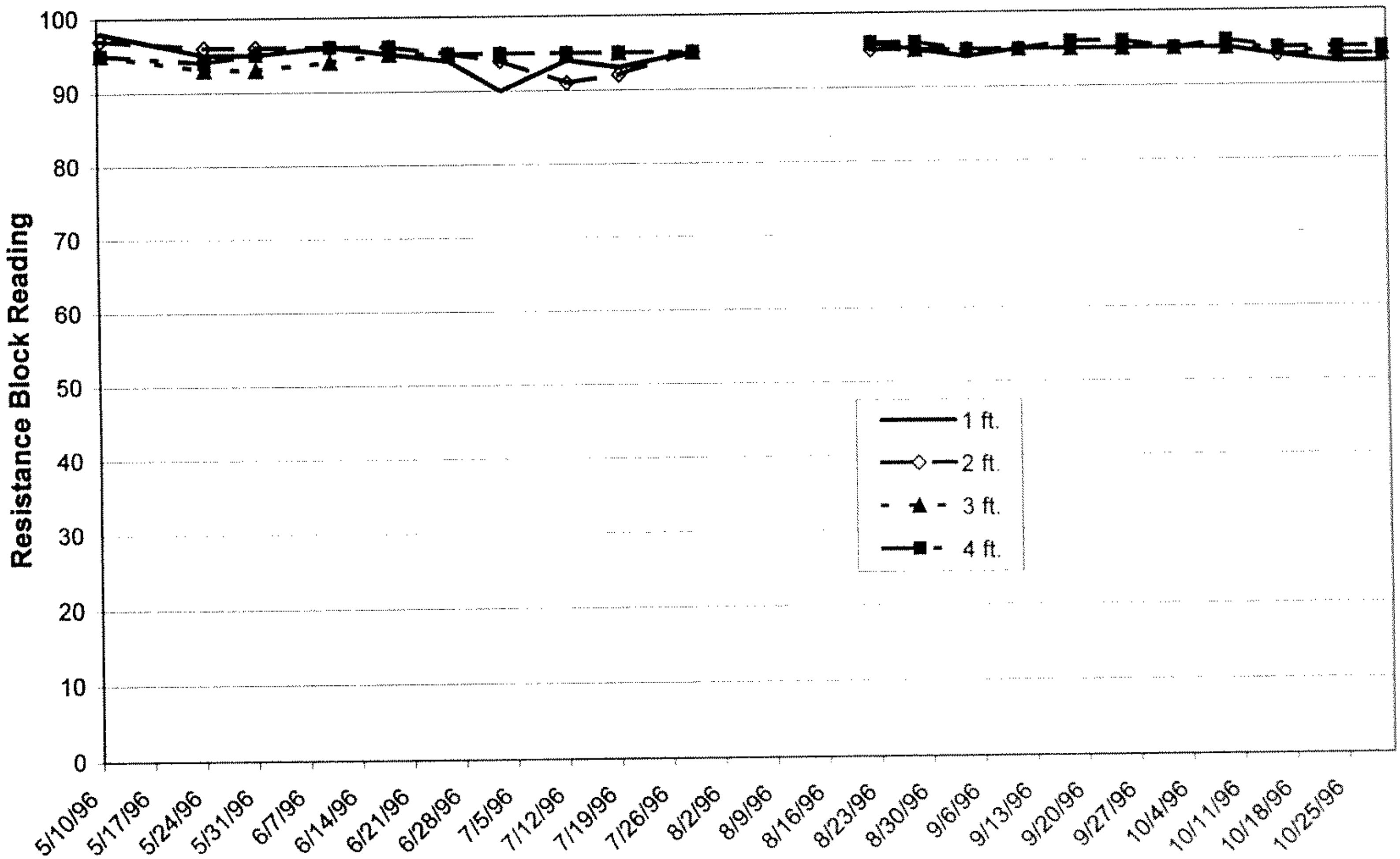

Figure 22. 1996 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower A). (94-96 represents saturated soil, drier soil is numerically lower)

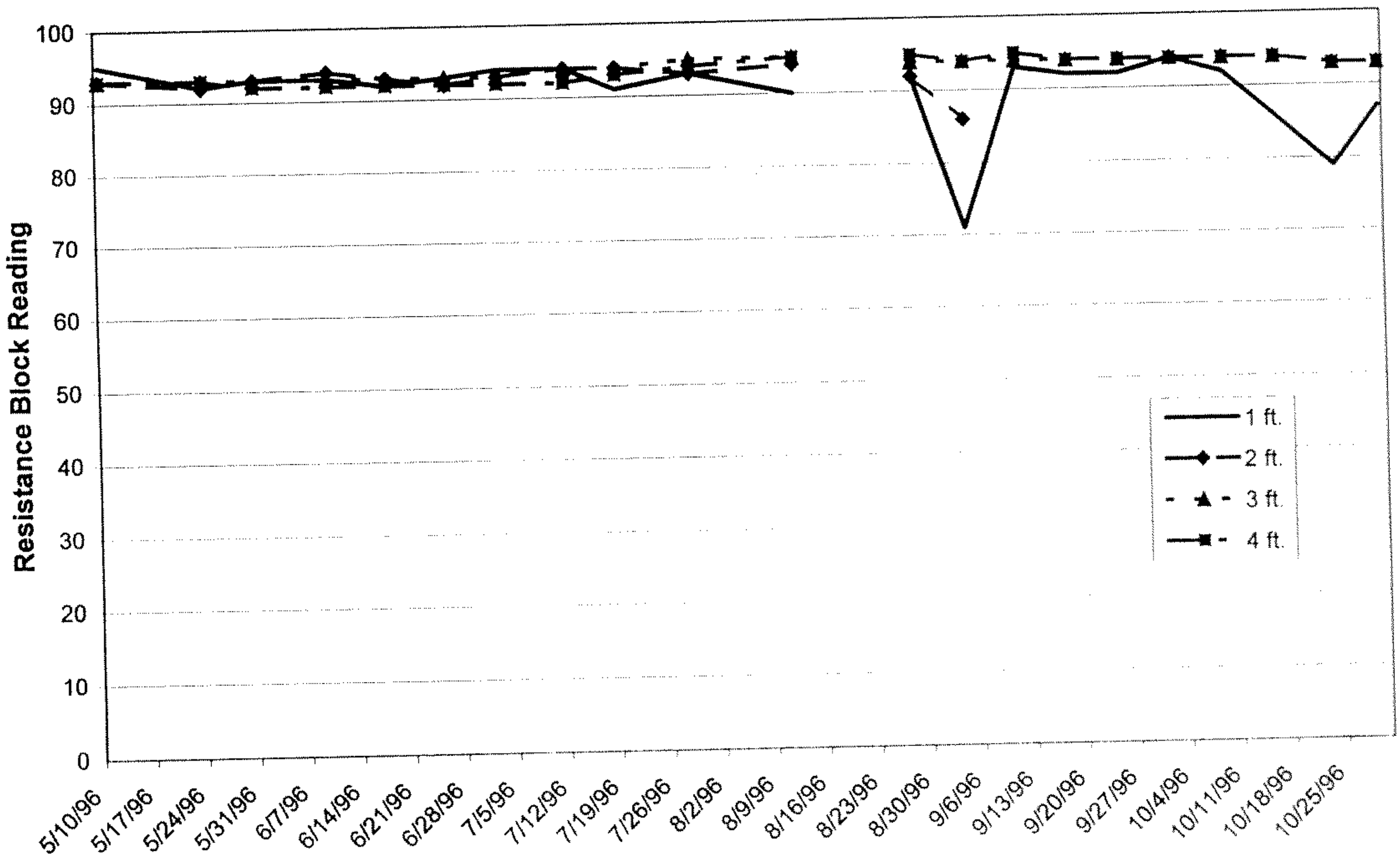

Figure 23. 1996 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower B). (94-96 represents saturated soil, drier soil is numerically lower)

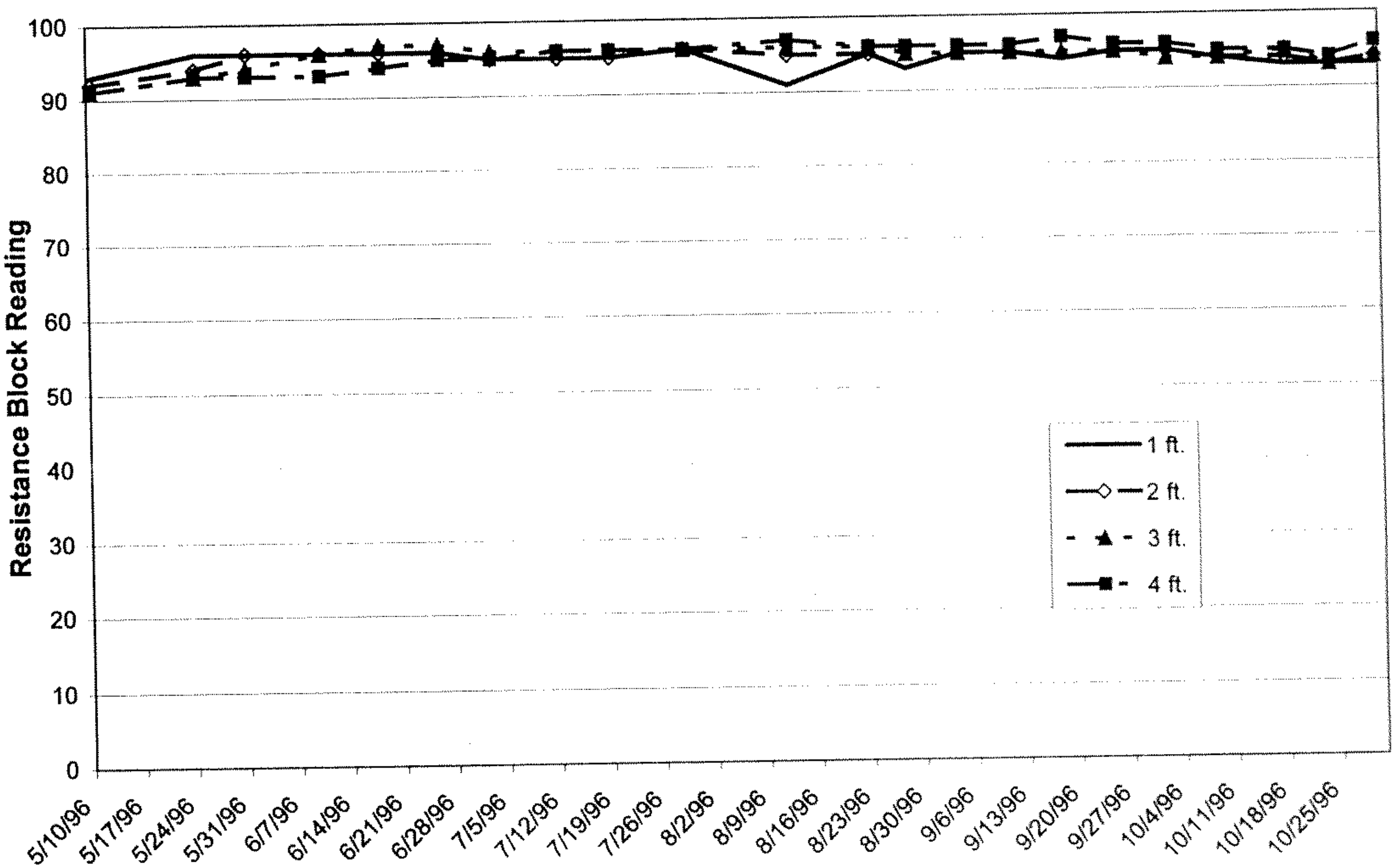

Figure 24. 1996 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower C). (94-96 represents saturated soil, drier soil is numerically lower)

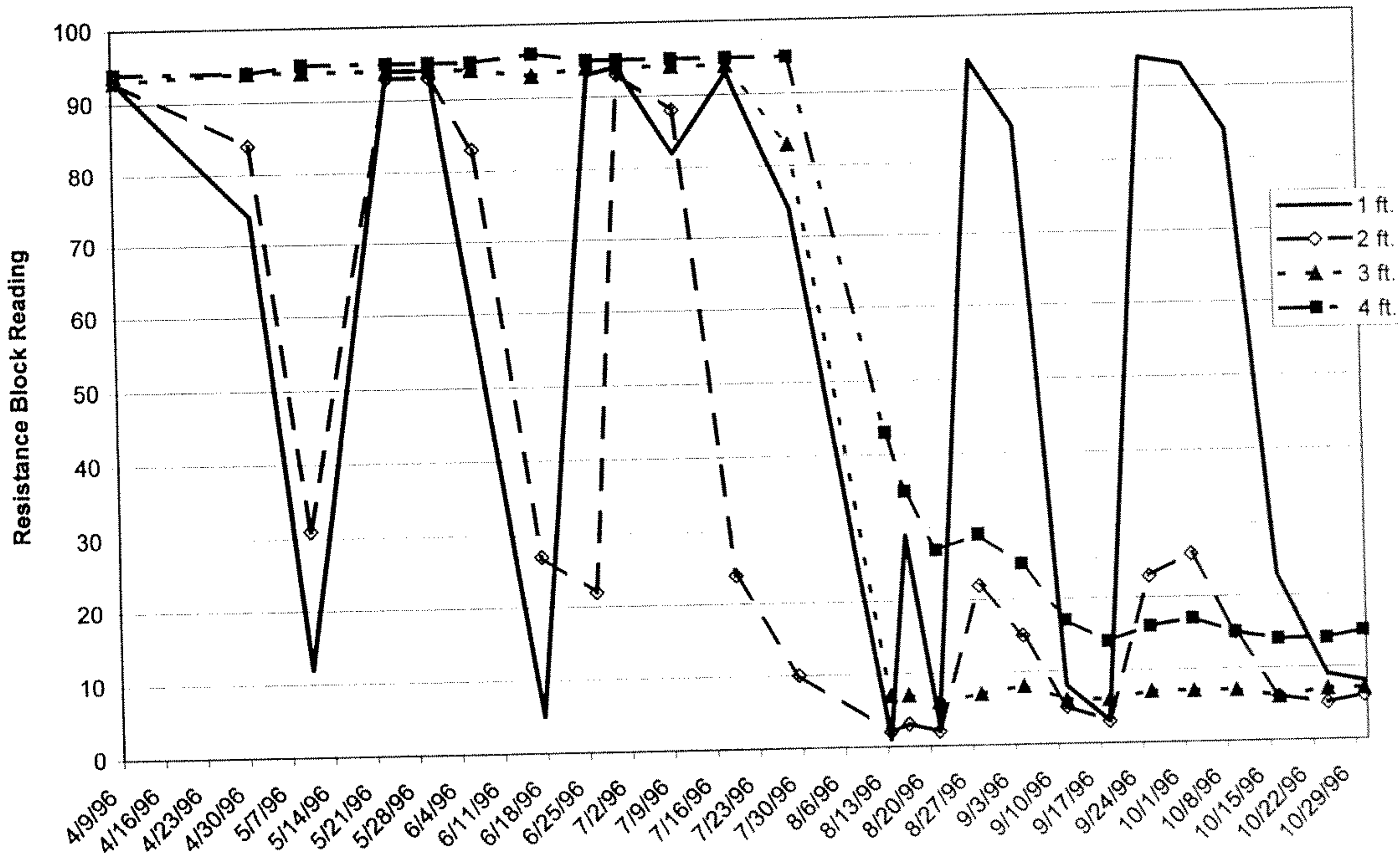

Figure 25. 1996 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower D). (94-96 represents saturated soil, drier soil is numerically lower)

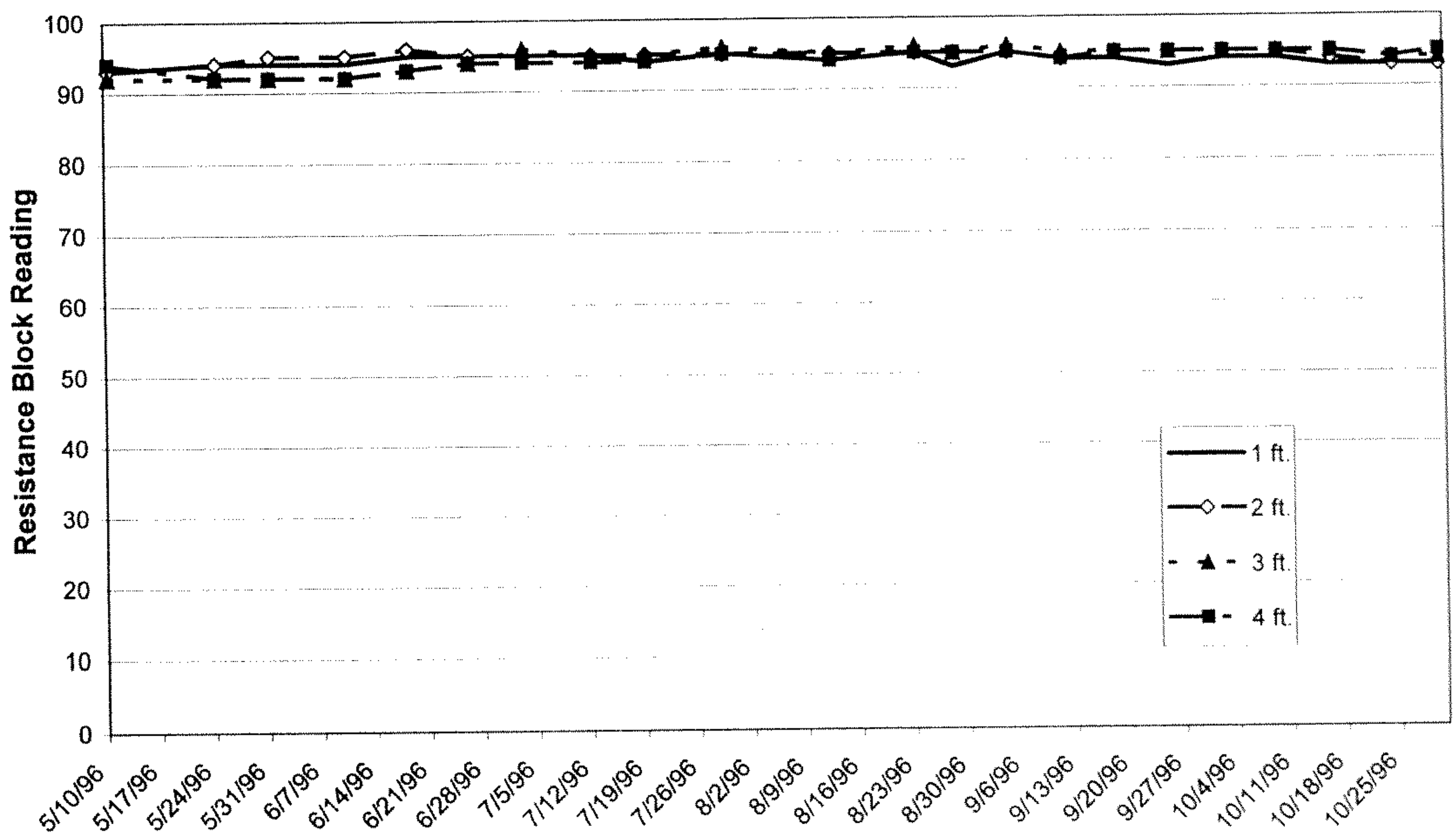

Figure 26. 1996 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower E). (94-96 represents saturated soil, drier soil is numerically lower)

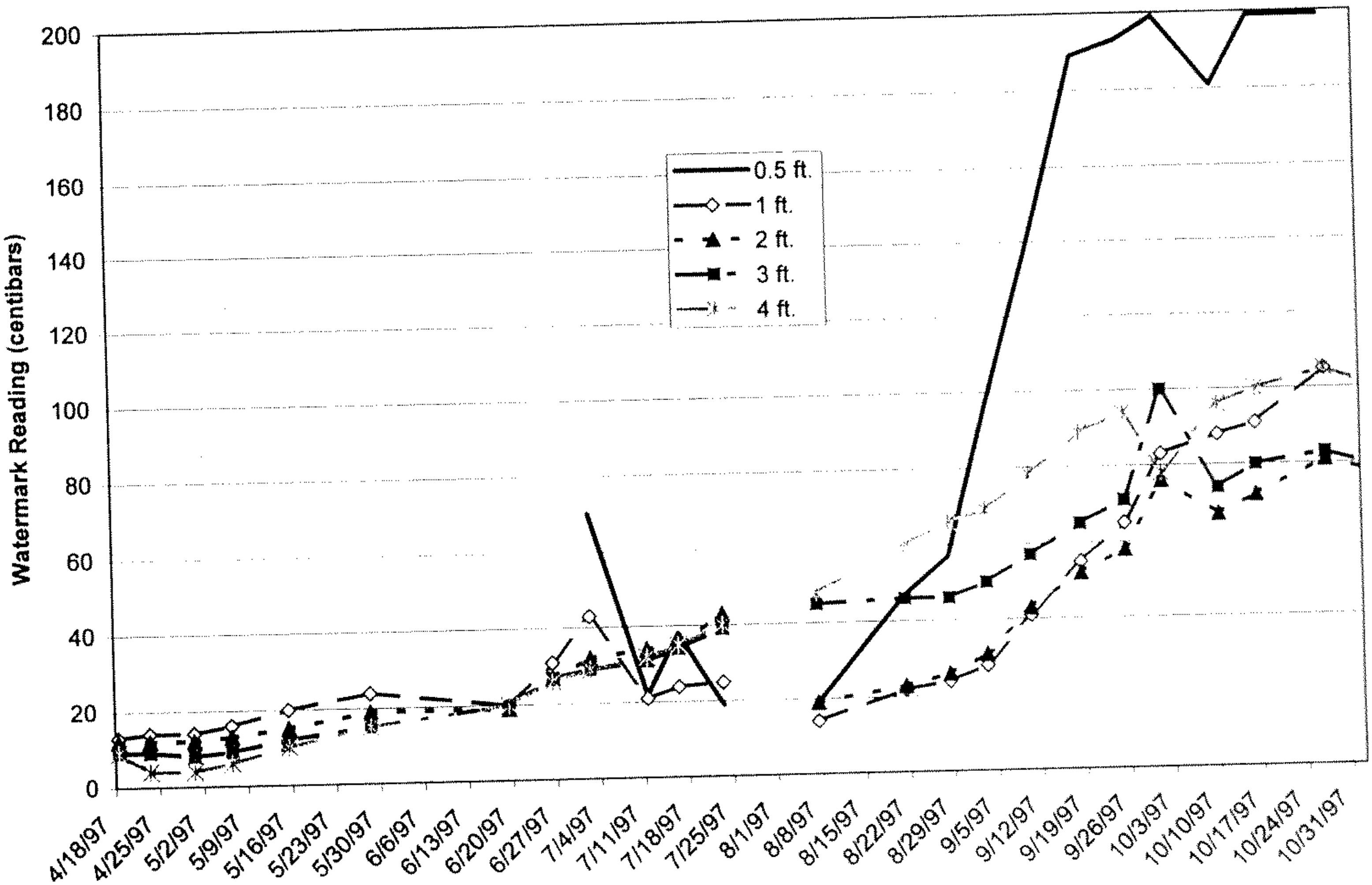

Figure 27. 1997 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower A). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

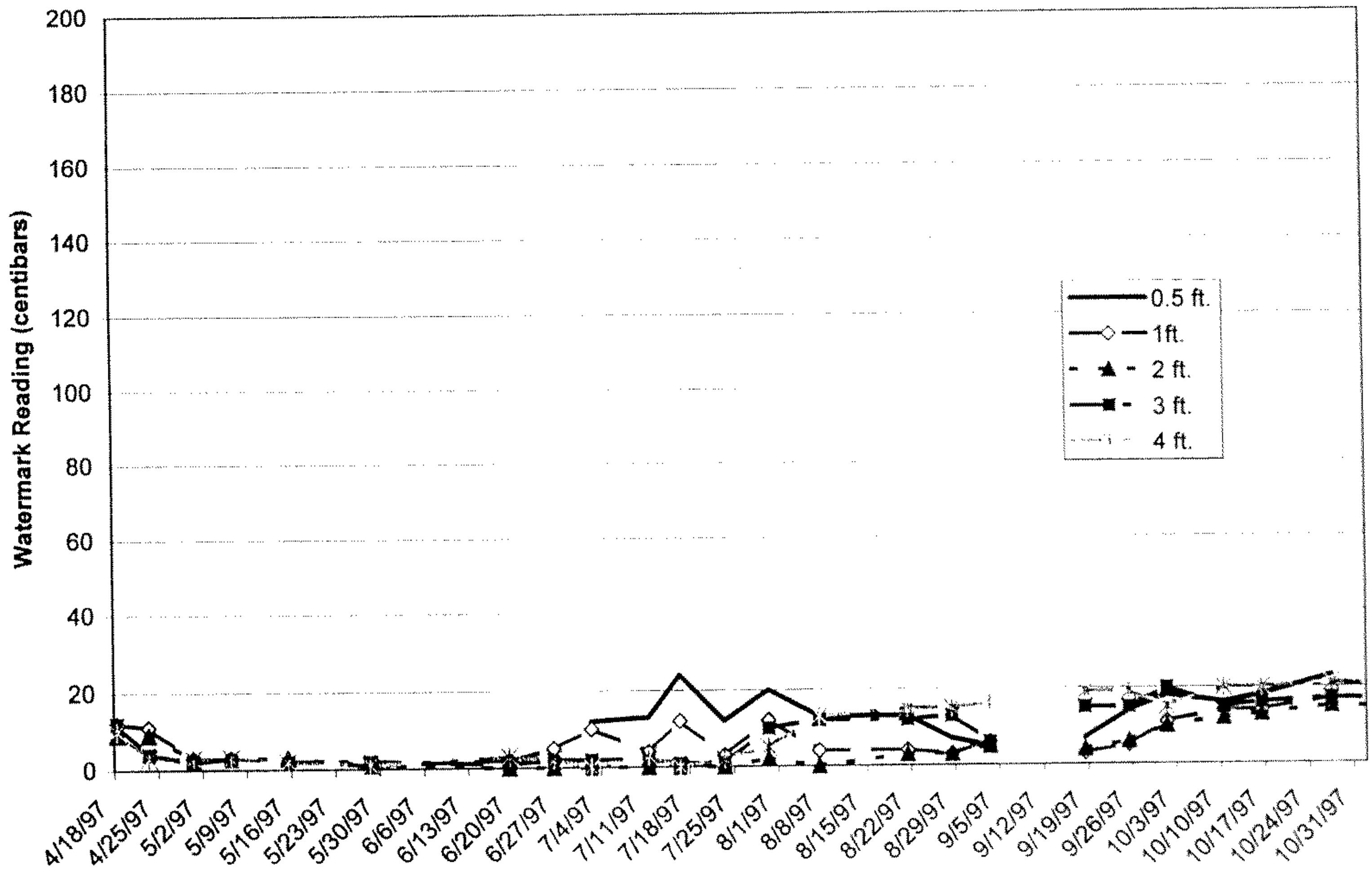

Figure 28. 1997 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower B). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

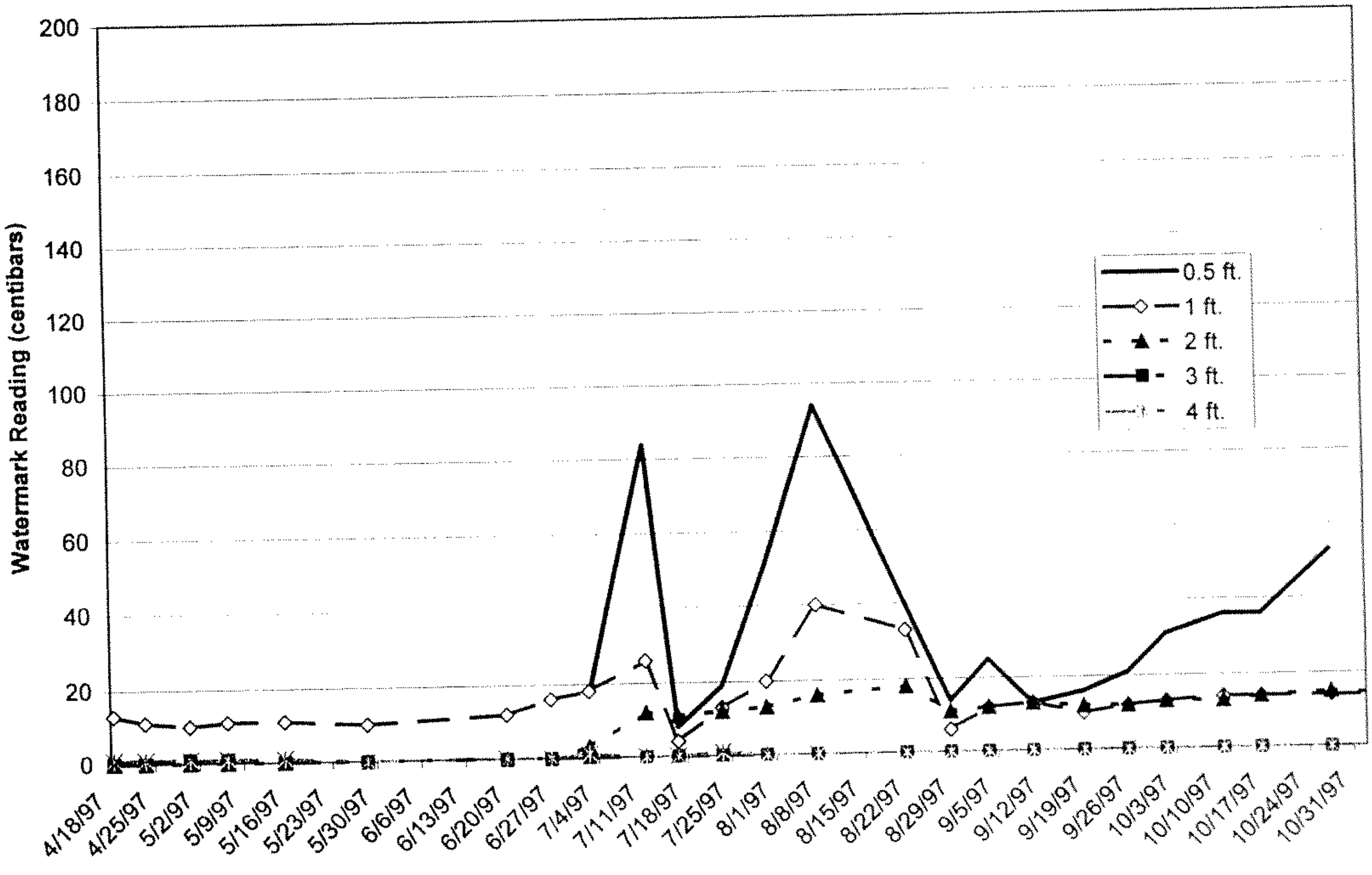

Figure 29. 1997 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower C). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

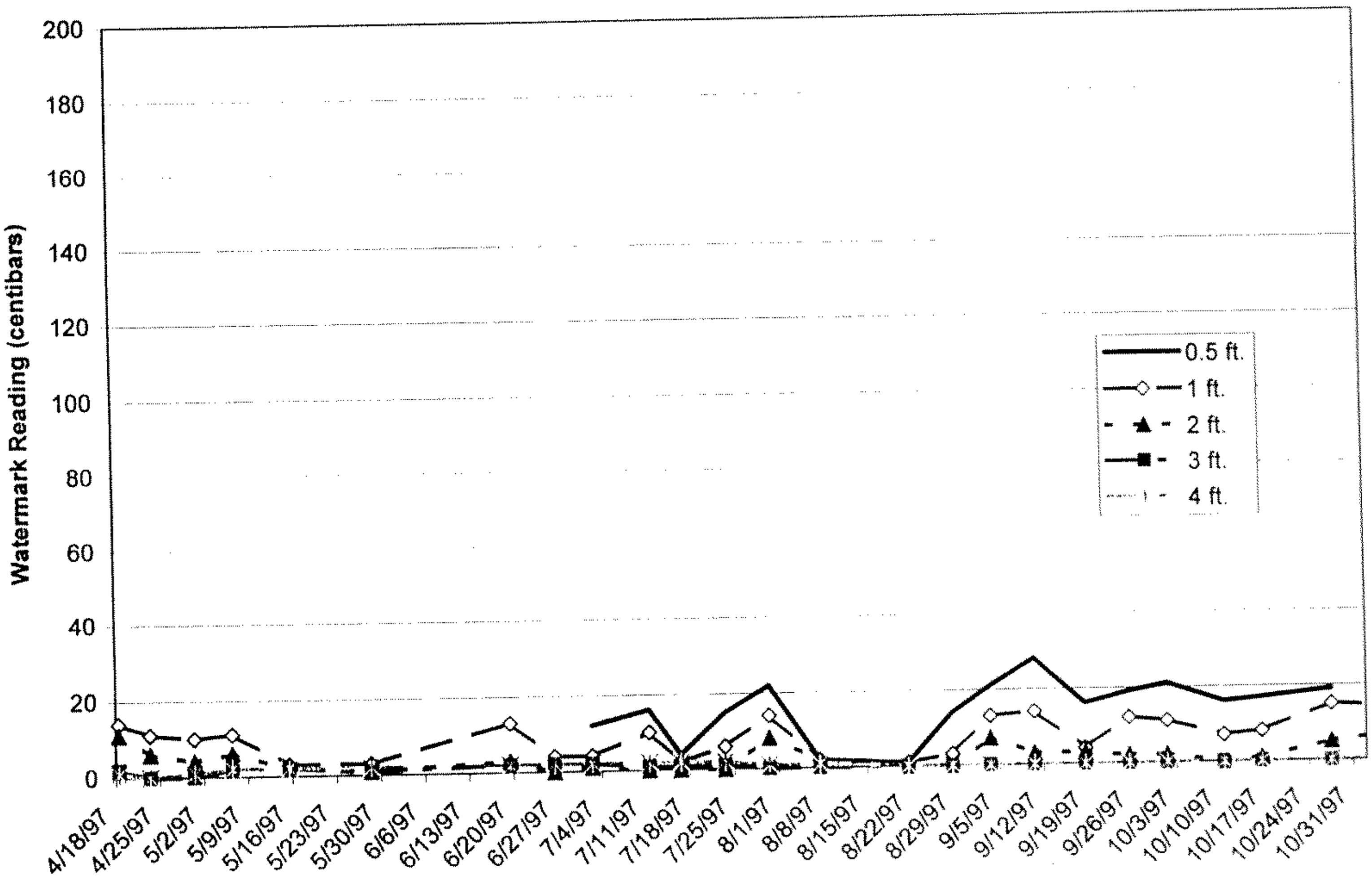

Figure 30. 1997 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower E1). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

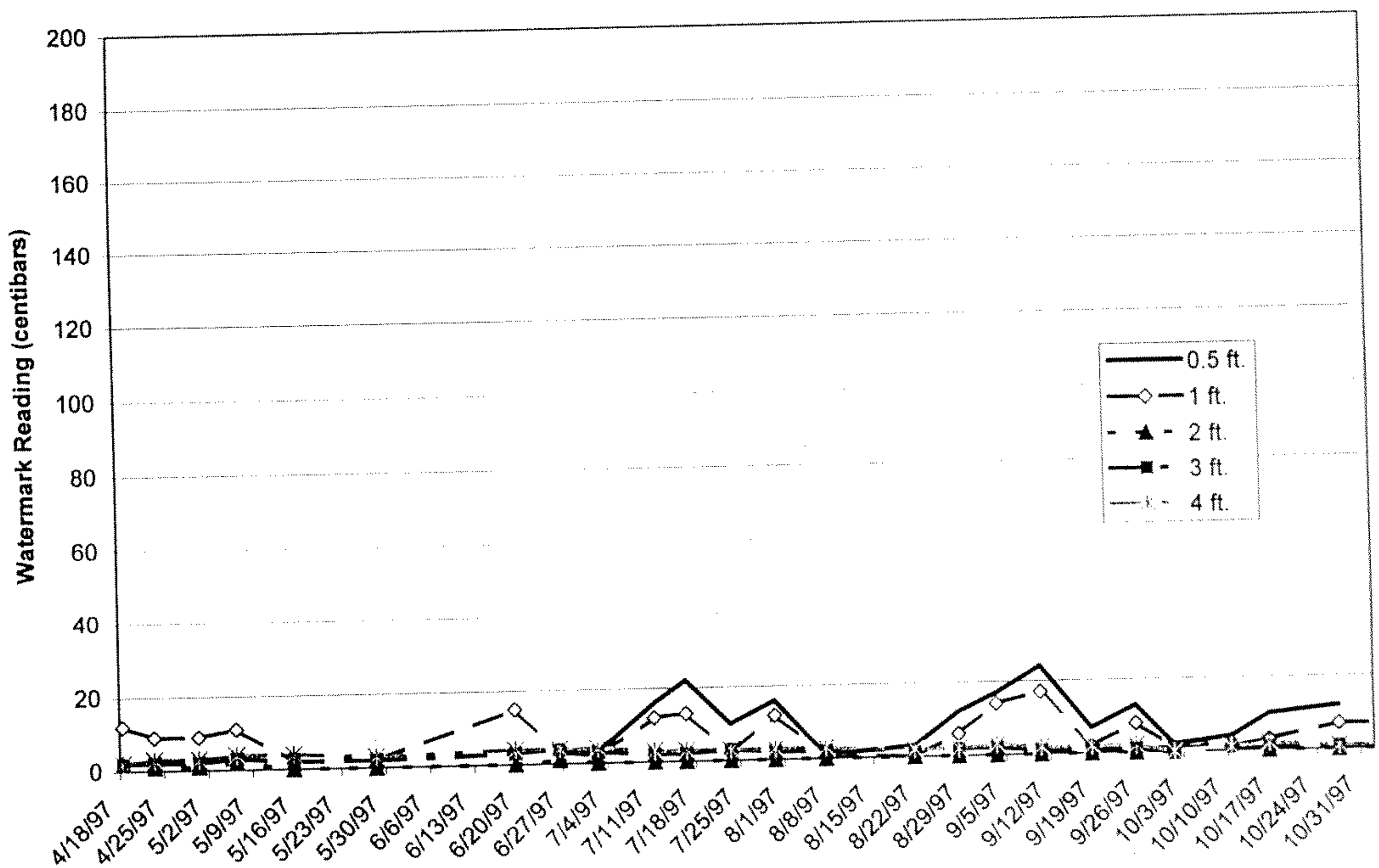

Figure 31. 1997 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower E2). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

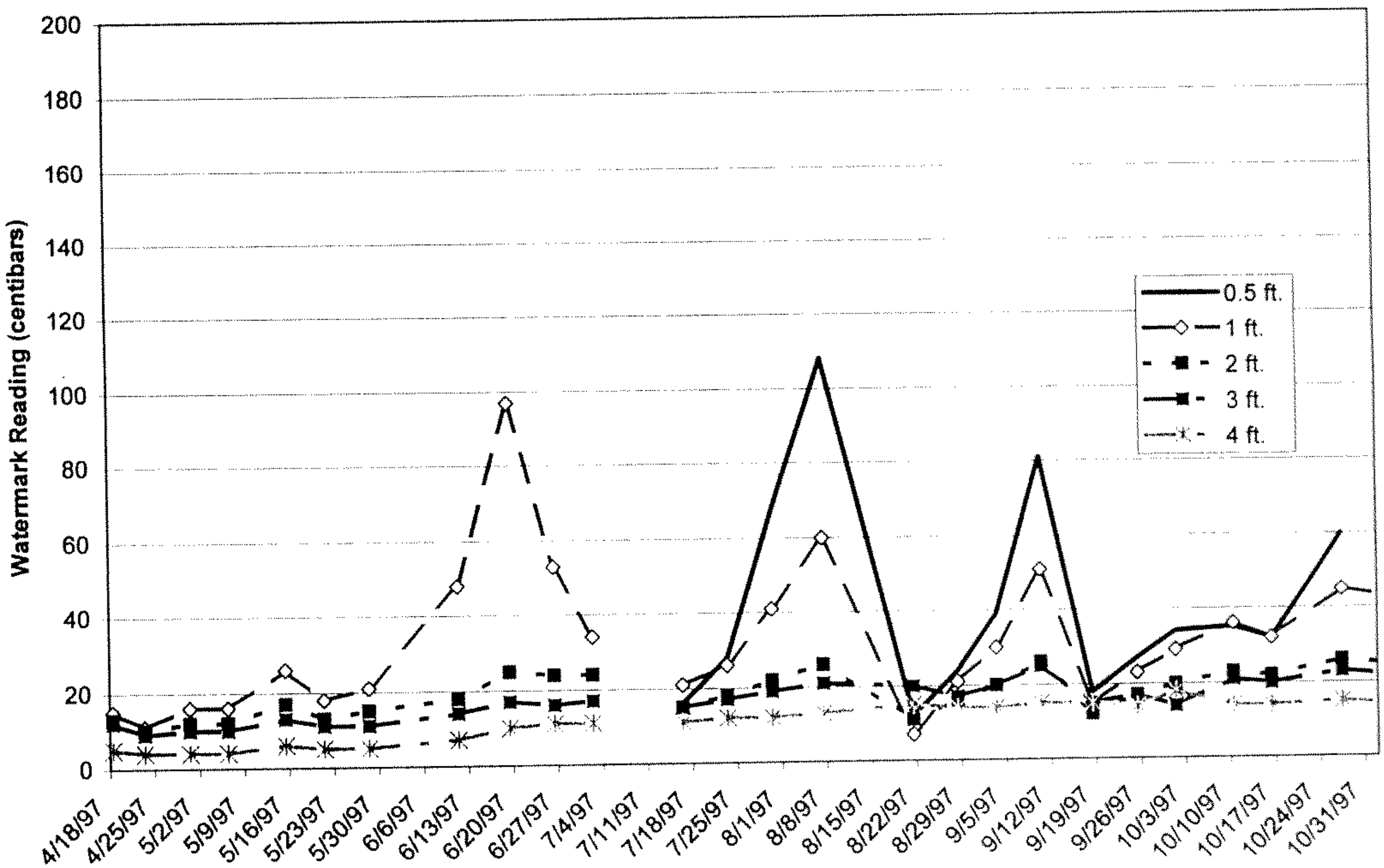

Figure 32. 1997 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower F). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

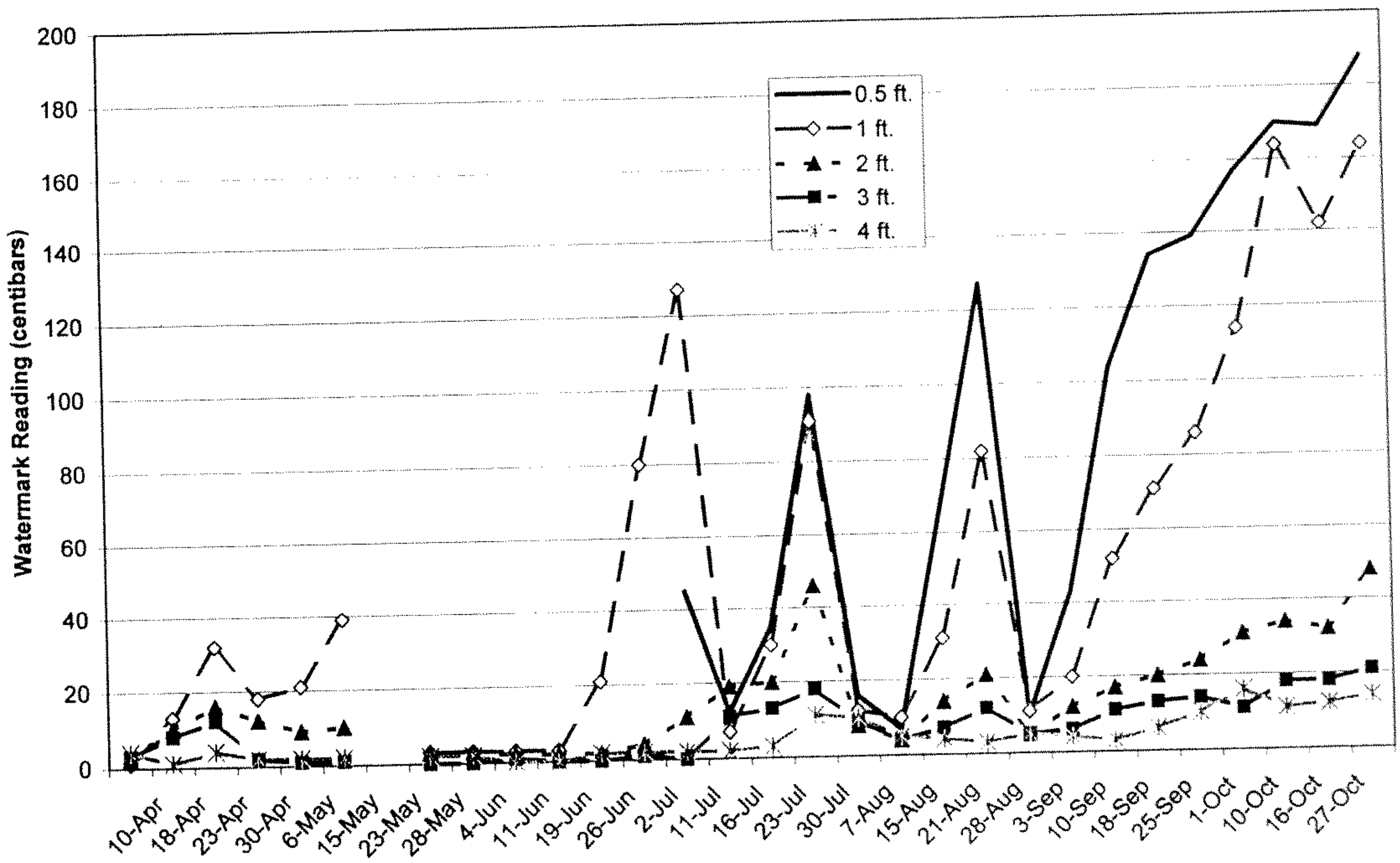

Figure 33. 1997 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower G). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.

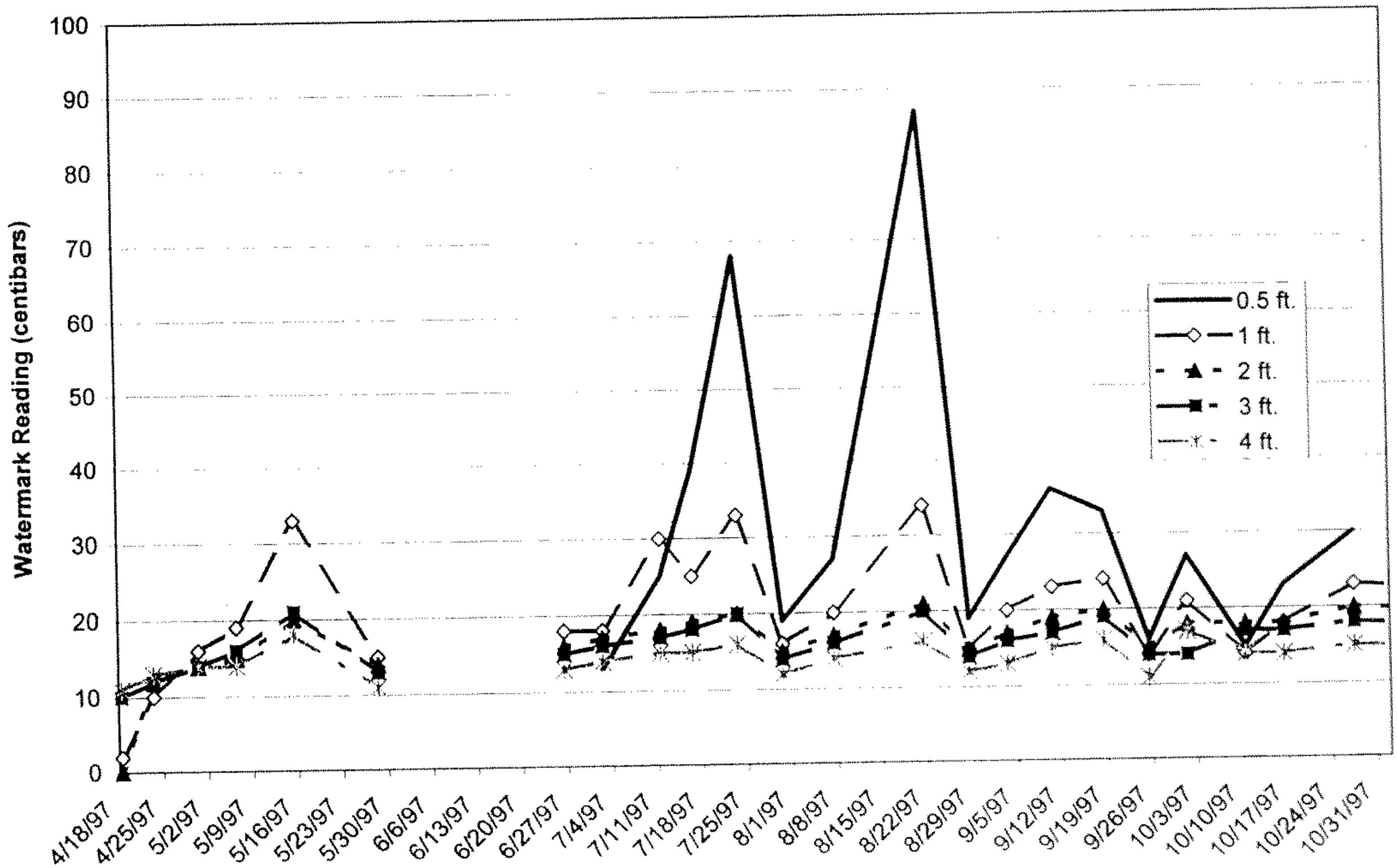

Figure 34. 1997 seasonal soil-moisture level at five depths for Scott Valley pasture (Grower H). Soil moisture expressed in centibars; the lower the value the higher the soil moisture content.