THE EFFECT OF SOIL MOISTURE ON CONSUMPTIVE WATER-USE EFFICIENCY, ROOT DEVELOPMENT, AND GROWTH COMPONENTS OF ALFALFA (MEDICAGO SATIVA L.)

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ABSTRACT

An experiment at Tucson, Arizona determined the consumptive water-use efficiency of four alfalfa (*Medicago sativa* L.) cultivars grown under three irrigation regimes. Two additional experiments investigated relative growth rates of roots and shoots and anatomical features of seedling alfalfa roots.

Significant differences in dry forage production and consumptive water-use efficiency were found between cultivars, harvests, and irrigations. More forage was produced under the medium regime (irrigated when 70% of available soil moisture was depleted to a depth of 91.4 cm) than under high and low soil moisture levels. The highest forage yield occurred during the second harvest (June 10) and the lowest during the seventh harvest (October 29). The most efficient water-use was obtained when alfalfa utilized 90% of the available soil moisture in the upper 1.21 m prior to irrigation.

Differences in the leaf/stem ratio, specific leaf weight, and leaf area index were found between harvests while no differences were found between cultivars and irrigation regimes.

Differences were found between the dry weight production of roots and shoots of seedling alfalfa grown under three moisture levels. No significant differences were found in the number of xylem elements and per cent of the root that was vascular cylinder.

INTRODUCTION

Agriculture uses more water than any other industry; however, Wadleigh (1969) states that only 2% of the water extracted from the soil by crop plants is converted into the substance of usable produce.

Seldom is the water in the soil at any time sufficient for one growing season. Additional moisture must be obtained from precipitation or irrigation. In order to make the most efficient use of water applied to crops, we must have a knowledge of the factors affecting the water-requirement of plants, such as precipitation, humidity, temperature, length of the growing season, water supply and quality, type of crop and variety, fertility, soil, water management, and cultural practices.

This study investigated: (1) the consumptive water-use efficiency and soil moisture extraction patterns of four alfalfa cultivars grown under three irrigation regimes; (2) the distribution and anatomy of alfalfa roots; and (3) the seasonal trends of leaf/stem ratio, specific leaf weight, and leaf area index of alfalfa cultivars.

LITERATURE REVIEW

Water Requirement

Dry Forage Production

Lawes (1850) demonstrated that fertilizers could lower the water requirement of plants, and since then many researchers have investigated the relationship between the water requirement of plants and components of yield. Generally, these experiments have shown that the water requirement of plants is reduced when the dry matter production is increased.

Shantz and Piemeisel (1927) investigated the water requirement of a number of plants at Akron, Colorado, and found a negative correlation between the amount of dry matter produced and the water requirement and evaporation. Therefore, the years with heavy growth and high dry matter production had the lowest evaporation and water requirement.

Seasonal differences in the water requirement of alfalfa (*Medicago sativa* L.) were reported by Scofield (1945). The dry plant material produced in the summer and fall required approximately 75% more water than that produced in the spring and early summer.

Dreibelbis and Harrold (1958) found a linear relationship between water requirement and yield in the first and second cuttings of several meadow crops. During seasons of high rainfall corn (Zea mays L.) and wheat (Triticum vulgare L.) had a high water requirement and during dry seasons the water requirement was low due to reduced evaporation. They concluded that the water requirement values varied from year to year and were greatly affected by meteorological conditions.

Variation in the water requirement has also been found between species. Briggs and Shantz (1913) found that sorghum (Sorghum vulgare L.) and millet (Panicum miliaeum L.) produced the same amount of dry matter as alfalfa on one-fourth the water. Alfalfa was also shown to have a water requirement 2.1 times greater than wheat.

Hunt (1962) observed significant differences in the yield and water requirement between species and among genotypes within species. Russian wildrye (Elymus junceus Fisch) produced less yield and had a higher water requirement than intermediate wheatgrass (Agropyron intermedium [Host] Beauv.). A high positive correlation was found between parent-progeny for yield and water requirement. Keller (1953) also noted significant differences in the water requirement among genotypically different strains of orchardgrass (Dactylis glomerata L.).

Cole (1969) determined the water requirement of seven cultivars of alfalfa and found significant differences among cultivars in the seedling and mature stages of growth.

The experiment was conducted in a greenhouse and the plants were grown in pots covered with styrofoam to reduce evaporation from the soil surface. The water requirement ranged from 502 to 587. More variation in the water requirement was noted within cultivars than between cultivars.

Davis, Fry, and Jones (1963) reported the total annual water requirement of alfalfa, assuming a 70% efficiency of the irrigation system, was 137.16 cm (4.5 ft) of water. This investigator noted that even though water may be a limiting factor, a good crop can often be produced.

Bourget and Carson (1962) studied the effects of fertility on the water requirement of oats (*Avena fatua* L.) and alfalfa and reported that on fertilized plots the water requirement was reduced. Allison, Roller, and Raney (1958) showed a marked decrease in the water requirement of several crops grown in lysimeters with adequate nutrients supplied. Dry matter produced had a greater effect on water loss than cropping sequence or fertility level and there was a linear relationship between dry matter produced and water-use.

Sprague and Graber (1938) also noted a decrease in the water requirement of alfalfa and bluegrass (*Poa pratensis* L.) when fertilized with nitrogen. The largest difference was noted in the bluegrass with a water requirement of 713 for the treated versus 1,363 for the non-treated.

McNeill and Frey (1969) studied the effects of fertility on oats and found the oats responded to increased fertility under both wet and dry regimes. Davidson (1969b) obtained similar results from Lolium perenne L. and Trifolium repens L. and concluded the efficiency of the foliage was increased when an adequate supply of nutrients were present. Montgomery (1911) concluded that the lowest water requirement was obtained when plants were grown at 60% available soil moisture with an adequate supply of nutrients.

Baker and Hunt (1961) reported a significant reduction in the water requirement of grasses by clipping the forage at 2 inches (5.1 cm) compared to 4 inches (10.2 cm). Sprague and Graber (1938) observed a decrease in the water requirement of alfalfa and bluegrass with frequent clipping. The frequent clipping kept the forage in a vigorously growing stage which provided a low water requirement when compared with plants clipped at a more mature stage of growth.

Soil Moisture Level

The influence of irrigation on the water requirement and consumptive use of crops has been investigated extensively. Stanhill (1957) in a review of the literature of soil moisture regime experiments found that 66 of the 80 papers reviewed reported that plants respond to differences in soil moisture level.

Bennett and Doss (1963) studied the effects of soil moisture regimes on cool-season, perennial forage species and found that all species increased in yield up to the point where 63% of the available soil moisture has been removed from the rooting zone. When no more than 32% of the soil moisture was allowed to be depleted the yield was reduced by a higher incidence of disease. In general water was used by all species in proportion to the amount available for evapotranspiration.

Krogman and Hobbs (1965) stated that the maximum evapotranspiration rate was associated with complete ground cover. In this experiment plots were irrigated when 25, 50, and 75% of the moisture remained in the soil. The average daily rates of evapotranspiration from the treatments were .17 (.43 cm), .19 (.48 cm), and .23 (.58 cm) inches per day respectively with no significant difference in the yield of the high and medium moisture regimes.

Erie and French (1969) studied the effect of irrigation on fall-planted safflower (Carthamas tinctorius L.) and determined that yield increased with each additional increment of water added up to seven irrigations. This resulted in the greatest yield per centimeter of water used by the plant. The level of moisture depletion before irrigation had no significant effect on any of the factors studied.

Maurer, Ormrod, and Scott (1969) obtained the highest yields from bean (Phaseolus vulgare L.) plants when the moisture level was maintained at 88% available and yields decreased as the available soil moisture decreased. The consumptive use was greatest for the high regime, but there was no significant difference in the water-use efficiency between treatments. Hanson (1967) studied the water-use efficiency of alfalfa under high, medium, and low irrigation regimes and found that treatments which provided relatively high soil moisture levels were more efficient in water use.

Joy (1970) evaluated the water-use efficiency of four alfalfa cultivars under three irrigation regimes and found that the low and medium regimes were more efficient than the high regime. The values for 1968 were 403, 493, and 698 for the low, medium, and high regimes, respectively. In 1969 the efficiency decreased and the values were 541, 598, and 894 for the low, medium, and high regimes, respectively. Scofield (1945) determined the water requirement of alfalfa. He grew the plants in cans under three regimes of near field capacity, 50% available moisture, and near permanent wilting point. Scofield observed that the rate of growth decreased as the stress conditions were increased, but the efficiency of water use was apparently the same for all groups with values ranging from 734 to 794.

Kemper, Robinson, and Golus (1961) also observed a reduced growth rate as soil moisture stress increased, but felt it was partially compensated for by a rapid rate of growth following a release of the soil moisture stress. The rapid growth rate was attributed to increased turgor pressure and an accumulation of simple sugars during previous periods of large stress. The rapid growth rate decreased by more than 50% from the maximum value within four days following the time of moisture stress release.

Bezeau and Sonmer (1964) found that 50% available moisture in the soil produced the highest yield of alfalfa over 3 years. They also found that the 50% level of available soil moisture produced the highest percentage of nutrients. In contrast, Matson (1964) found little difference in the yield of soybeans grown on the Mississippi delta whether the moisture at the center of the root zone reached 75% or 50% available soil moisture or permanent wilting point. Tests conducted in Arkansas showed yield reductions only when the soil moisture level reached 15% or less of the available capacity.

Plaut, Blum, and Arnon (1969) studied the effect of soil moisture on the yield of grain sorghum and obtained the highest yield and water-use efficiency when the soil moisture was not allowed to fall below 20% of the available capacity. Kilmer et al. (1960) obtained the largest growth response of a number of forage species when the soil moisture was maintained at an intermediate value of 4 atm. tension.

Lehman et al. (1968) suggested that the optimum range of the irrigation schedule may be narrow in soil with low permeability, but greater in the more permeable, well-drained soils. They found that frequent short irrigations produced the most economical yields, but later in the growing season a long irrigation was necessary to maintain a favorable salt balance.

Leaf Area Index, Specific Leaf Weight, and Leaf/Stem Ratio

In 1911 Montgomery reported that water loss was more closely related to leaf area than to dry weight. In corn the narrow leaf lines were more drought resistant and better able to withstand dry conditions. Smith, Mott, and Bula (1964) found under field conditions that the leaf area index was the most important factor in accounting for the variation in yield of alfalfa. Chronological age was the most important factor in determining the leaf area index. Light intensity and day length were the most important variables contributing to leaf area index determination while temperature, water deficits, and CO_2 levels had little effect on leaf area index.

Fuess and Tesar (1968) reported that the maximum leaf area index of 5.44 was reached during the late bud stage and that leaf area index showed a positive relationship to individual cuttings, but could not be used to predict seasonal production.

Al-Kawaz (1970) reported a positive correlation between the leaf/stem ratio and water-use efficiency of mature alfalfa. Cole (1969) also found a significant association between the leaflet to stem and petiole ratio and water-use efficiency of seven alfalfa cultivars tested. Leaf area was also highly correlated with the amount of water transpired.

Maurer et al. (1969) studied the effects of five soil water regimes on growth of snap beans and found the high soil moisture regime produced taller plants with a larger leaf area than did the lower regimes, but there were no significant difference between the dry matter produced per liter of water used between treatments. The water consumption was highest in the high regime which was irrigated then 22% of the available moisture had been utilized.

Wilfong, Brown, and Blaser (1967) found that the leaf area index for ladino clover (*Medicago repens* L.) and first growth alfalfa differed from that of the second and third growth alfalfa. The optimum leaf area index ranged from 2.4 to 4.9 which intercepted 95% of the incident light.

At this point apparent photosynthesis was near maximum and little effect was gained from higher leaf indices.

Pearce et al. (1969) reported that physical characteristics of leaves have been associated with differences in the photosynthetic capabilities of a plant and the specific leaf weight is one of these characters which can be affected by the environment, especially light intensity. A positive correlation of .79 was found between specific leaf weight and net photosynthesis of 13 alfalfa cultivars. The specific leaf weight varied from 1.9 to 5.3 mg per cm^2 while photosynthesis ranged from 20.7 to 50.8 mg of CO_2 per dm^2/hr. They also reported that leaves developed in dim light are thinner and have lower specific leaf weights than leaves developed in bright light.

Barnes et al. (1969) observed significant variation of specific leaf weight within and among alfalfa cultivars. The ranking of the plants did not vary with the stage of growth. Significant differences were found between cultivars and plant age and they concluded that the specific leaf weight and leaf area were independently genetically controlled. The leaf area was determined by measuring the length and width of the individual leaves and multiplying by a coefficient of .71. The correlation coefficient between the leaf area and the product of .71 multiplied by the length and width was found to be .966.

Root Development

The rooting pattern of plants has been investigated extensively. Researchers have found that root development is influenced by a number of variables such as soil type, soil moisture, fertility, cultural practices, aeration, and climatological conditions.

Tanner (1968) states, "In general, the plant part nearest the source of an essential will be least affected by its deficiency." Thus, when water becomes limiting the shoot will be affected first and to the greatest degree. Likewise, when photosynthesis is reduced by low light intensity or defoliation, root growth is retarded more than top growth. Therefore, the root to shoot ratio is a shifting equilibrium and management factors such as clipping, pruning, and cutting stimulate top growth in order to re-establish the shoot to root balance. Conversely, when the top growth is stimulated by fertilization and irrigation the root growth is also stimulated in order to maintain the shoot to root balance.

Dennis, Harrison, and Erickson (1959) found that frequent cutting of alfalfa curtailed root production and winter survival. When the alfalfa was cut frequently more of the total water absorbed was from the surface area when compared to that cut less frequently.

O'Donnell and Love (1970) reported the rooting activity of Kentucky bluegrass was higher when it was cut at 4.4 cm (1.73 in) versus 2.2 cm (.87 in) for the same period. Each 15.2 cm (5.99 in) of depth, irrespective of the height of cut, was 1.5 to 3 times as active as the increment immediately below it. It was felt that physical measurement of roots may tend to overestimate the importance of roots above 20.3 to 35.4 cm (8 to 10 in) and underestimate those below this depth. Weaver (1926) also investigated the activity of roots and found that in terms of function, the larger, thicker, and heavier roots are least significant and the delicate branches are of greatest importance. In terms of weight, 2-month-old alfalfa had a root area of 85 cm^2 (13.18 in) which consisted of a taproot weighing 21% of the total, primary branches 40% of the total, secondary branches 35% of the total, and the tertiary branches, which are the most important in water absorpiton, accounted for the remaining 3% of the total. Consequently, mechanical determination of root activity may be misleading.

Weaver (1926) concluded that crops may suffer in a period of drought if the soil surface is kept too moist early in the life of the plant. Gardner (1964) reported the smaller roots become more important as the soil becomes drier, thus for a mature root system the rate of root growth is less important than the magnitude of the root system.

Nakayama and van Bavel (1963) studied the root activity of sorghum and observed 90% of the root activity occurred in the region 91.4 cm (36 in) and 38.1 cm (15 in) laterally from the plant. Lipps and Fox (1964) found the root activity was in the surface area early in the growing season as long as soil moisture was present, but as the season advanced and the soil moisture was depleted the root activity moved as far down as the 2.13 m (7 ft) to 3.05 m (12 ft) area of the root zone. Bennett and Doss (1963) also studied soil moisture extraction throughout the season and found the soil moisture extraction patterns, which were near the surface early in the season and lower in depth as the season progressed, were a good indication of rooting depth.

Doss, Ashley, and Bennett (1960) observed a general decrease in rooting depth with an increase in the soil moisture level of several warm-season forage species. Garwood (1967) also noted the weight of root material from an irrigated treatment was less than that produced under dryland conditions. He hypothesized that the difference may have resulted from more rapid decay of dead roots with the increased moisture level of the irrigated soil.

Mitchell (1962) also reported a decrease in root growth of forage crops when supplemental irrigation was applied. But Weaver (1926) in early studies of alfalfa noted that at the end of 1 year irrigated plants had a larger root system than dryland alfalfa and the branch roots of the dryland alfalfa occurred nearer the surface than those of the irrigated alfalfa whose branches occurred at 61.0-91.5 cm (2-3 ft) and deeper.

Longnecker and Erie (1968) report that enough water should be added to cotton (Gossypium hirsutum L.) at each irrigation to replenish the root zone since roots will not grow into dry soil. The larger root system will not prevent moisture deficits during the day, but will allow the plant to recover at night.

Thorup (1969) studied the growth of tomato (Lycopersicum esculentum L.) roots under three moisture levels. One treatment was well below permanent wilting point, another slightly below permanent wilting point, and the third within the available range. Maximum root growth occurred when the moisture level was above the permanent wilting point, but there was root growth into the soil with the level of soil moisture below the permanent wilting point. This demonstrates that roots will develop and grow in soil with the moisture level below the permanent wilting point when a portion of the root system is in contact with soil moisture above the permanent wilting point.

McNeill and Frey (1969) found the root weight of oats was not affected by soil moisture level, but it was increased with higher levels of fertility.

Weaver (1927) described the root development of vegetable crops and stated that there are differences in the root system of varieties of the same species. Dittmer

(1959) studied thirteen species and observed that most variations in root systems were genetic rather than edaphic. Weaver (1926) found that root characters segregate according to Mendelian ratios in peas (*Pisum arvense* L.). Davidson (1969a) suggested that the ratio of root weight to shoot weight is similar in plants of a species.

Penfound (1931) studied the anatomy of Mammoth Russian sunflower (*Helianthus annus* L.) and water pepper (*Polygonum hydropiper* L.) and found that laterals, one-third of the distance from the main root, of plants grown in sunlight had larger xylem elements and a larger percentage of xylem in the vascular cylinder than those grown in the shade.

Al-Kawaz (1970) obtained a correlation coefficient of .658 between water-use efficiency and the number of xylem vessels in the leaf midvein of alfalfa in the vegetative stage. Plants with the highest number of xylem vessels were the least efficient in water usage.

MATERIALS AND METHODS

Four cultivars of alfalfa were grown at Tucson, Arizona, under three irrigation regimes to study the water-use efficiency of alfalfa. The cultivars Mesa-Sirsa, Moapa, Sonora, and El-Unico were planted in October, 1967. During the 1968 and 1969 growing seasons the irrigation regimes consisted of high, medium, and low treatments which were irrigated when 30, 70, and 90% of the available soil moisture was depleted to a depth of 91.4 cm (3 ft). In this study the high and medium regimes remained the same as those used in 1968 and 1969, but the low regime was not irrigated until 90% of the soil moisture was utilized to a depth of 121.9 cm (4 ft).

Three borders, 6.38 m x 55.93 m (21 ft x 380 ft), were used and each border represented an irrigation treatment. The cultivars were arranged in a randomized complete block with four replications. Each plot was 3.2 m x 8.53 m (10.5 ft x 28 ft).

Soil moisture was determined gravimetrically and the amount of moisture used to produce each harvest was calculated by adding the net change in soil moisture between the beginning of the period and the end to the amount of water added during the period through irrigation and rainfall. Soil moisture extraction patterns to a depth of 91.4 cm (3 ft), 121.4 cm (4 ft), and 154.2 cm (5 ft) from the high, medium, and low regimes respectively were determined by gravimetric samples taken approximately every 4 days from May 18 through October 28. All soil samples were taken with an Oakfield probe and dried at 120 C for 24 hr.

All harvests were made at 1/10 bloom except the fourth harvest which was delayed until 50% bloom to allow root reserves to accumulate. Seven and fifty-four hundredths sq m (82.12 sq ft) was harvested from each plot and total fresh weight production was measured. Random samples were taken from each plot and dried at 80 C for 24 hr to determine the per cent dry weight. Consumptive water-use efficiency was calculated by dividing kilograms of water used by the kilograms of dry matter produced.

Leaf/stem ratios and specific leaf weight were determined by sampling two replications from each cultivar within each treatment each time plots were harvested. Leaves were separated from stems and petioles and the dry weight of leaves divided by the dry weight of stems and petioles. The specific leaf weight was determined using the method of Robison and Massengale (1967).

Root Growth Measurement

Two studies were conducted to investigate the characteristics and rate of root growth of seedling alfalfa. The four cultivars used in the field study, Mesa-Sirsa, Moapa, Sonora, and El-Unico were used to study the rate of root growth of alfalfa seedlings. The techniques used were those of Kittock and Patterson (1959) with some modifications. Pyrex tubes 5.08 cm x 110 cm (2 in x 4 ft) were filled with sand and supported by a wooden rack made of 2 x 4's covered with .159 cm (1/16 in) exterior grade masonite to eliminate light (Fig. 1). The tubes were inclined approximately 30° so the roots would be visible along the side of the tube. The sand was watered with Hoagland's nutrient solution. Alfalfa cultivars were arranged in a randomized complete block design with six replications. Five seeds were planted in each tube 5 mm (.20 in) and covered with 3 cm (1.18 in) of finely ground styrofoam to prevent drying of the surface. The tubes were thinned to one healthy seedling per tube 14 days after planting.

Fluorescent lights were used to lengthen the photoperiod to 16 hr. The first measurement of root length was taken after the plants were thinned to one per tube. Additional measurements of the height of the shoot and length of the roots were made at 5-day intervals throughout the remainder of the experiment. The test was concluded when the roots reached the bottom of the tubes. The tubes were watered as needed using Hoagland's solution. The plants were also sprayed regularly with "Cygon"

Fig. 1. Plexiglass tubes and wooden rack used to study the root and shoot growth of four alfalfa cultivars.

(O,O-Dimethyl s-(N-methylcarbamoylmethyl) phosphorodithicate) to control spider mites (<u>Tetranychus cinnabarinus</u>).

Roots were washed from the tubes and the dry weights (80 C for 24 hr) of the roots and shoots were determined. Root to shoot ratio of each cultivar was calculated on a dry weight basis.

The cultivar Mesa-Sirsa was used in the second experiment to determine the root growth and water-use efficiency of seedling alfalfa grown under three irrigation regimes.

The plants were grown in stove pipes 17.78 cm (7 in) wide and 91.4 cm (3 ft) long (Fig. 2). The pipes were filled with 26,900 g of air dry clay loam. The soil level was 8-10 cm (3-4 in) from the top of the pipe to allow water application. The soil was brought to field capacity and 10 seeds were placed in each container. Plants were thinned to one seedling per pot.

The treatments consisted of three soil moisture levels; a high, medium, and low. The treatments were arranged in a randomized complete block design with a border row of stove pipes around the five replications.

"Irrometers" 45.72 cm (18 in) in length were used to indicate the moisture status of the treatments and the time of irrigation. The irrometers were placed in each treatment of the first, third, and fifth replications.

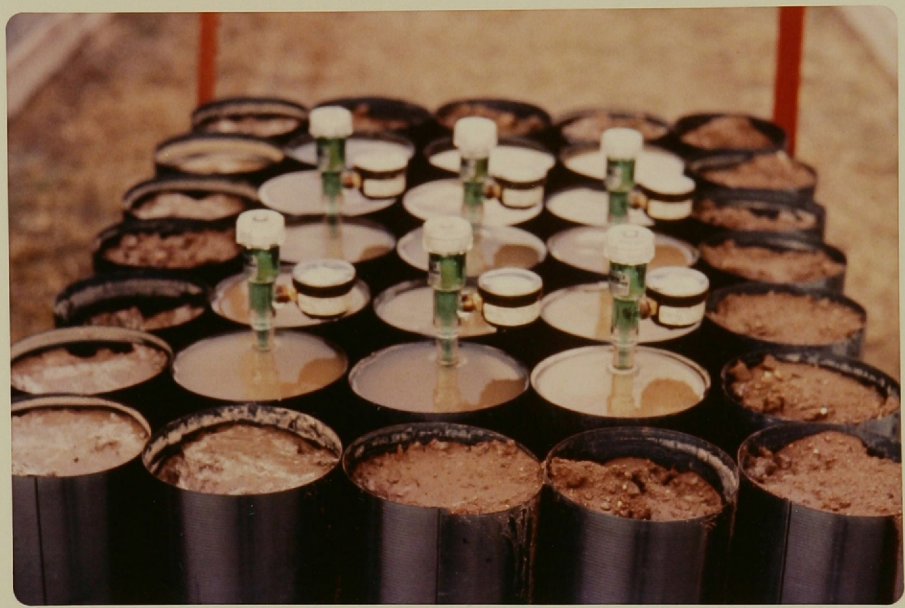

Fig. 2. Stovepipes and irrometers used to study the root growth of Mesa-Sirsa alfalfa.

The high regime was irrigated when the irrometer reached a reading of 20 centibars (35% available soil moisture depleted), the medium was irrigated when a reading of 40 centibars (76% available soil moisture depleted) was obtained, and the low moisture level was not watered following establishment of the seedlings. All treatments were watered frequently during establishment. The soil moisture was returned to field capacity at each irrigation.

The plants were harvested and the roots were collected at the full bloom stage 110 days after planting. Soil moisture samples were taken and the roots were washed from the pipes with a pressurized stream of water. The washing was over a screen to catch the roots that were washed from the pipe. The roots and shoots were dried and weighed and the root/shoot ratio was calculated.

Sections of the root base, apex, and middle portions were collected for anatomical observation. They were fixed in FAA, embedded in paraffin, and stained according to the procedure outlined by Johansen (1940). The sections were photographed and the number and size of the xylem elements and the per cent vascular cylinder were determined.

The dry weight production, water-use efficiency, and anatomical data were statistically analyzed and the means of each treatment compared using the Duncan new multiple range test.

RESULTS AND DISCUSSION

Dry Forage Production

The mean dry forage production for the season ranged from 19.0 kg/plot for El-Unico to 17.4 kg/plot for Sonora (Table 1). El-Unico, Moapa, and Mesa-Sirsa were significantly higher in forage production than Sonora. The mean dry forage yield of the four cultivars was greater under the medium regime (70% depleted to 91.4 cm) than under the low (90% depleted to 121.4 cm) and the high (30% depleted to 91.4 cm) moisture regimes. Even though the stand density of the low regime (9.9 plants/.186 sq m) was greater than under the medium (5.8 plants/.186 sq m) and high (4.8 plants/.186 sq m) regimes the average dry weight production for the season was 19.3 kg/plot under the medium regime and 18.1 kg/plot under the high and low soil moisture regimes.

All harvests were significantly different with a range of 4.7 kg/plot for the second harvest (June 10) to 1.3 kg/plot for the seventh harvest (October 29) (Table 2). The dry forage production decreased rapidly during July and August with a slight increase in September but decreased again during the seventh harvest in October.

There were no significant differences between cultivars under the low moisture regime, but under the

Table 1. Average forage production (kg per plot) of four alfalfa cultivars grown under three irrigation regimes.

Cultivars	Irrigation regimes			
	Low	Medium	High	Means
El-Unico	18.3+	19.6	19.1	19.0 a*
Moapa	17.6	20.0	19.0	18.8 a
Mesa-Sirsa	18.6	19.0	18.2	18.6 a
Sonora	17.7	18.4	16.1	17.4 b
Means	18.1 b*	19.3 a	18.1 b	

*Means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

+Within table comparisons the LSD at .05 level equals 2.2.

Table 2. Forage production (kg per plot) at seven harvests of four alfalfa cultivars grown under three irrigation regimes.

		Harvest							
Irrigation regimes	Cultivars	May 16 1	June 10 2	July 3 3	July 27 4	Aug. 20 5	Sept. 19 6	Oct. 29 7	Means
Low	Mesa-Sirsa	4.1[+]	4.6	2.9	2.6	1.6	1.7	1.1	2.7 a*
	Moapa	3.1	4.1	3.1	2.6	1.7	1.7	1.4	2.5 a
	Sonora	3.2	4.1	3.1	2.7	1.7	1.6	1.3	2.5 a
	El-Unico	4.0	4.1	3.0	2.7	1.5	1.9	1.1	2.6 a
	Means	3.6** b	4.2 c	3.0 a	2.7 a	1.6 a	1.7 a	1.2 b	2.6 b
Medium	Mesa-Sirsa	4.1	4.7	2.9	2.5	1.6	1.7	1.5	2.7 ab
	Moapa	3.6	5.6	3.2	2.7	1.7	1.8	1.4	2.9 a
	Sonora	3.2	5.1	2.8	2.6	1.7	1.7	1.3	2.6 b
	El-Unico	4.0	5.0	3.0	2.8	1.5	1.8	1.5	2.8 ab
	Means	3.7 ab	5.1 a	3.0 a	2.6 a	1.6 a	1.8 a	1.4 a	2.8 a a
High	Mesa-Sirsa	4.1	4.6	2.7	2.4	1.4	1.6	1.4	2.6 a
	Moapa	3.5	4.6	3.3	3.0	1.5	1.7	1.3	2.7 a
	Sonora	3.4	4.0	2.6	2.3	1.3	1.4	1.2	2.3 b
	El-Unico	4.8	5.3	2.7	2.4	1.3	1.7	1.3	2.7 a
	Means	3.8 a	4.6 b	2.8 a	2.5 a	1.4 a	1.6 a	1.3 ab	2.6 b
	Harvest means	3.7 b*	4.7 a	2.9 c	2.6 d	1.5 f	1.7 e	1.3 g	

[+]Within table comparisons the LSD at .05 level equals .31.

*Means followed by the same letter are not significantly different at .05 level according to Duncan's Multiple Range Test.

**Comparison made within harvest.

medium and high regimes differences were found. Under the medium regime Moapa produced more than Sonora and under the high regime Moapa, El-Unico, and Mesa-Sirsa produced more dry forage than Sonora.

Differences between irrigation regimes were found during the first, second, and seventh harvests. During the first harvest (May 16) less forage was produced under the low moisture regime than the medium and high regimes. The medium regime produced the most forage during the second harvest (June 10) and the low produced the least amount of forage. The low regime yielded less forage than the medium regime during the seventh harvest (October 29).

Additional water was most beneficial when applied early in the spring or during the fall when the weather was cool. Water applied during the summer months had little effect on the dry forage production.

Consumptive Water-Use Efficiency

Differences in the consumptive water-use efficiency were found among cultivars, harvests, and irrigation regimes. Mesa-Sirsa, Moapa, and El-Unico were more efficient than Sonora for the season under the three irrigation regimes (Table 3). The values ranged from 763 for Sonora to 692 for El-Unico.

Table 3. Average consumptive water-use efficiency of four alfalfa cultivars grown under three irrigation regimes.

	Irrigation regimes			
Cultivars	Low	Medium	High	Means
El-Unico	497+	628	951	692 a*
Moapa	516	639	934	696 a
Mesa-Sirsa	525	647	971	714 a
Sonora	505	691	1,093	763 b
Means	511 a*	651 b	987 c	

*Means followed by the same letter are not significantly different at the .05 level according to Duncan's Multiple Range Test.

+Within table comparisons the LSD at .05 level equals 41.

Within the low moisture regime there were no differences in the water-use efficiency of the four cultivars. Significant differences were found within the medium and high regimes. El-Unico and Moapa were more efficient than Sonora under the medium regime, while El-Unico, Moapa, and Mesa-Sirsa were more efficient than Sonora under the high moisture level. A significant interaction was found between cultivars and irrigation regime.

The consumptive water-use efficiency ranged from 452 for the second harvest (June 10) to 1,127 for the seventh harvest (October 29). All harvests were significantly different except the fourth and fifth which were taken July 27 and August 20 (Table 4).

The low moisture regime which was irrigated when 90% of the soil moisture was depeleted to a depth of 121.4 cm (4 ft) was the most efficient treatment followed by the medium and high regimes respectively (Table 4). One hundred two and seventy-four hundredths cm (40.5 in) of water was applied to the low moisture regime during the growing season. One hundred forty-three and sixty-four hundredths cm (56.6 in) was applied to the medium moisture regime and 222.48 cm (87.6 in) was applied under the high moisture regime (Table 5).

The differences in water-use efficiency between irrigations was mainly due to the loss of water through leaching during an irrigation. The application efficiency

Table 4. Consumptive water-use efficiency at seven harvests of four alfalfa cultivars grown under three irrigation regimes.

Irrigation regimes	Cultivars	Harvest May 16 1	June 10 2	July 3 3	July 27 4	Aug. 20 5	Sept. 19 6	Oct. 29 7	Means
Low	Mesa-Sirsa	530+	188	520	422	354	576	1017	525 a*
	Moapa	705	215	482	424	341	567	764	515 a
	Sonora	678	207	490	402	344	676	738	505 a
	El-Unico	540	209	507	400	370	750	872	499 a
	Means	613** b	205 c	500 c	412 c	352 c	645 b	848 c	511 c
Medium	Mesa-Sirsa	562	377	630	546	779	478	1154	647 ab
	Moapa	667	322	568	482	749	423	1226	639 b
	Sonora	722	353	635	558	759	468	1333	691 a
	El-Unico	575	304	605	517	827	512	1109	628 b
	Means	631 b	339 b	609 b	526 b	778 a	470 c	1205 b	651 b
High	Mesa-Sirsa	886	799	952	811	548	1560	1288	971 b
	Moapa	1019	813	769	647	527	1484	1309	934 b
	Sonora	1078	936	996	842	604	1592	1430	1093 a
	El-Unico	840	707	929	819	580	1593	1287	951 b
	Means	956 a	814 a	911 a	780 a	565 b	1557 a	1329 a	987 a
	Harvest means	734 c*	452 f	673 d	572 e	565 e	891 b	1127 a	

+Within table comparisons the LSD at .05 level equals 41.

*Means followed by the same letter are not significantly different at .05 level according to Duncan's Multiple Range Test.

**Comparison made within harvest.

Table 5. Dates and amount (cm) of rainfall and irrigation for three soil moisture regimes.

	Irrigation			Rainfall	
Date	High	Med.	Low	Date	Amount
Feb. 12	24.21			July 7	1.32
Feb. 26		23.98	21.79	July 19	1.40
April 2	25.98			July 20	2.29
April 20		23.01		July 22	.20
April 28	25.98			July 23	.05
May 4			28.04	July 25	.03
May 20	27.84	26.11		July 31	.08
June 3	27.84			Aug. 1	.25
June 15		24.51	24.89	Aug. 2	.08
June 23	27.84			Aug. 7	.25
July 15	20.93			Aug. 10	.91
Aug. 4		23.01		Aug. 11	2.31
Sept. 1	20.93			Aug. 14	1.52
Oct. 6	20.93	23.01		Aug. 18	1.17
Oct. 21			28.04	Aug. 23	1.60
				Sept. 3	1.70
Total irrigation	222.48	143.64	102.74	Sept. 4	3.05
water applied	(87.59 in)	(56.55 in)	(40.46 in)	Sept. 5	4.32
				Sept. 6	.18
+ Rainfall	23.83	23.83	23.83	Sept. 12	.71
Total Water	246.31	167.47	126.57	Oct. 2	.41
Added	(96.97 in)	(65.93 in)	(49.84 in)		23.83
					(9.38 in)

($\frac{\text{water stored}}{\text{water applied}}$) was 22% for the high regime, 43% for the medium regime, and 52% for the low regime. The storage efficiency ($\frac{\text{depth stored}}{\text{depth of root zone}}$) was 100% for the high, 95% for the medium, and 94% for the low moisture regime. The distribution efficiency

$$\left(\frac{\text{average deviation in depth of water stored from average depth stored during irrigation}}{\text{average depth water stored during irrigation}}\right)$$

was also determined with values of 100, 83, and 70% for the high, medium, and low moisture regimes, respectively.

The advance, theoretical recession, and actual recession curves for the water applied to each border during an irrigation are shown in Fig. 3. The theoretical recession was calculated on the basis of the amount of water needed to fill the root zone to field capacity and the infiltration rate. The difference between the advance and theoretical recession curves is the time required to fill the root zone to field capacity. The water that infiltrated during the period of time represented by the difference between the actual and theoretical recession curves was lost through leaching. Where the theoretical recession exceeds the actual recession curve the root zone was not filled to field capacity. The irrigation efficiency of the three borders could be improved by using a larger stream flow or by putting a slight grade on the borders so the water will advance faster and cover the border more uniformly.

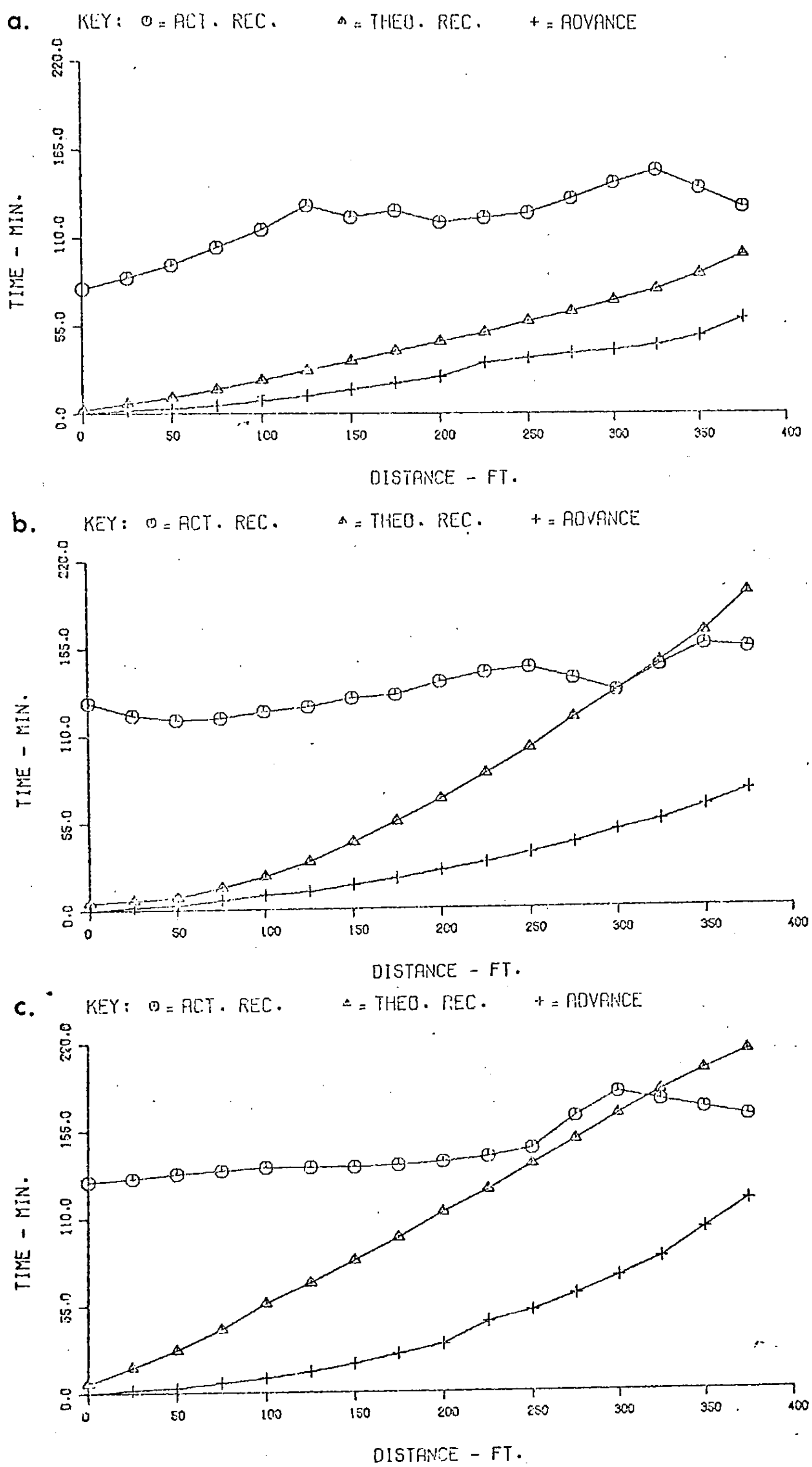

Fig. 3. Actual recession, theoretical recession, and advance of water during irrigation of high (a), medium (b), and low (c) moisture regimes.

The harvests with the highest production were not always the most efficient in this experiment. The number and timing of irrigations during a harvest period greatly affected the water-use efficiency of that period. Soil moisture extraction curves (Figs. 4, 5, and 6) for each irrigation regime over the season show that the plants were extracting water from the root zone at a slower rate during the summer months when growth was reduced as compared to the rate of extraction earlier in the season. The most rapid rate of water-use from the root zone occurred during the second harvest period. This was probably due to the high production and greater leaf area index of that harvest.

The efficiency of water-use during the summer was high because the rate of moisture extraction decreased as the dry weight production and leaf area index decreased. Note the difference in the rate of soil moisture extraction from May 18 to June 10 and the rate of use later in the growing season. The water-use efficiency varies greatly with the amount of dry forage production and the leaf area index of the crop.

The medium and low regimes were similar in their soil moisture extraction patterns. The crop grown under the high moisture regime obtained most of the water from the top 91.4 cm (3 ft) of the root zone. The low and medium regimes utilized water to a deeper depth than the

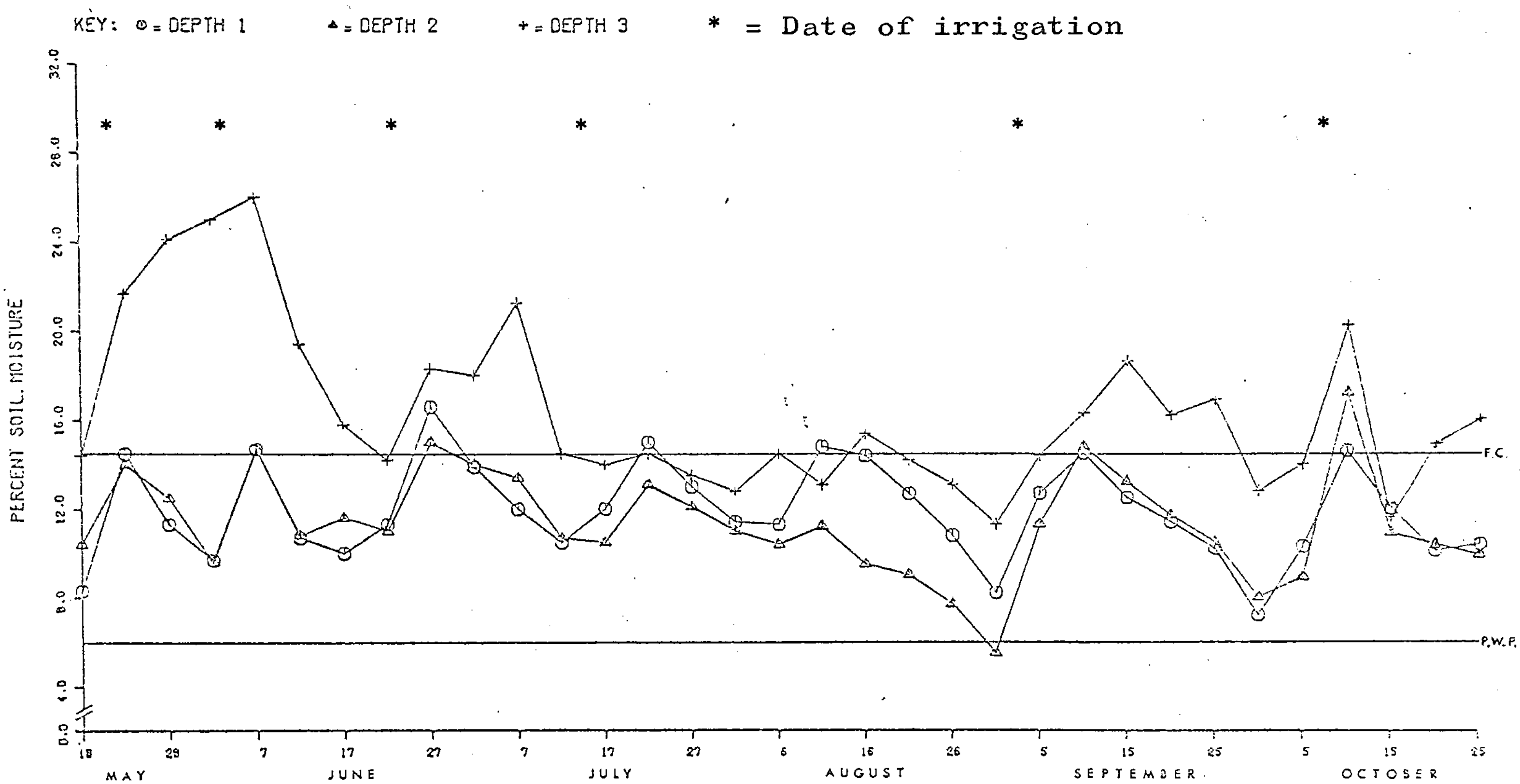

Fig. 4. Soil moisture extraction pattern from upper 91.4 cm (3 ft) of the root zone by 30.48 cm (1 ft) increments under the high moisture regime.

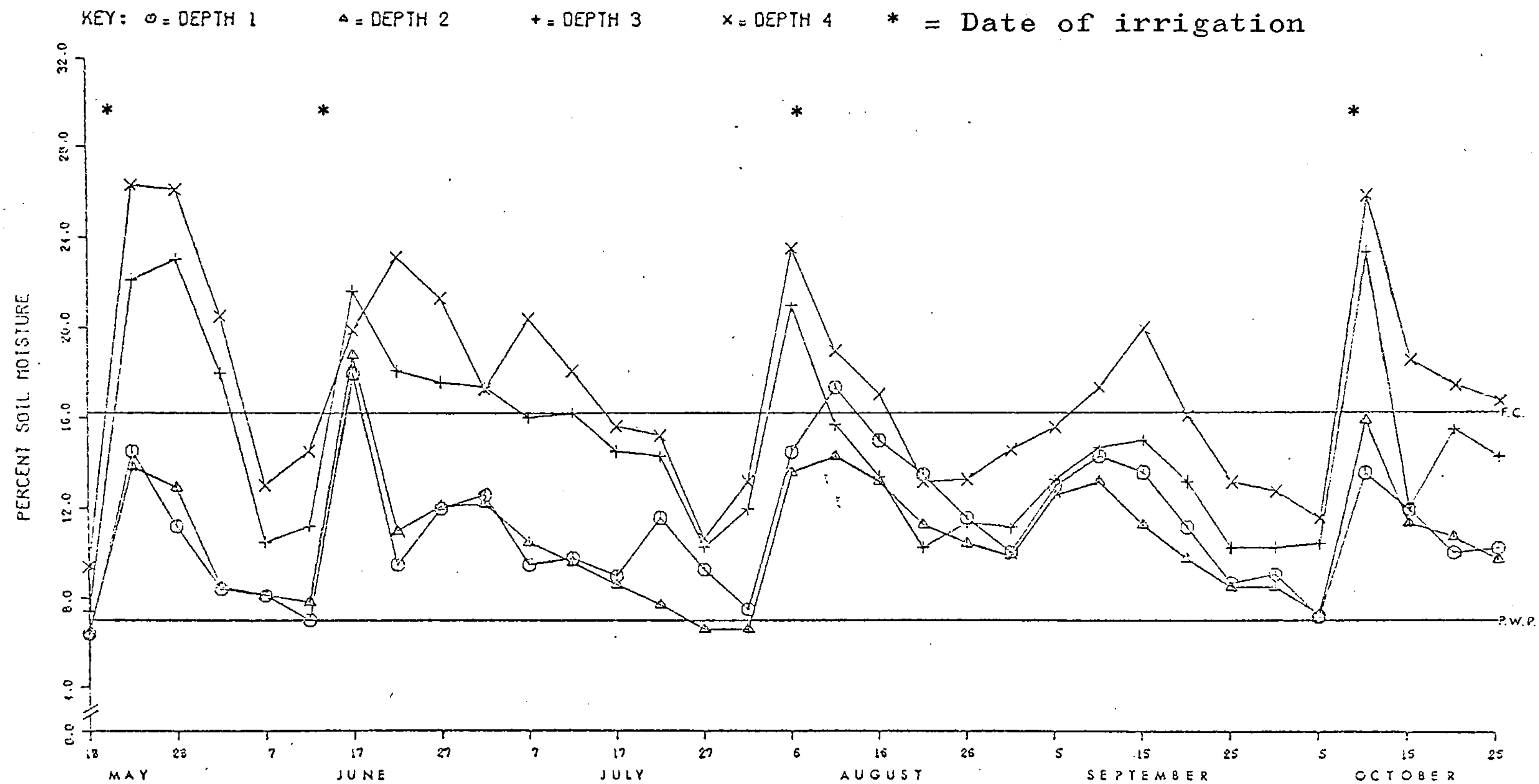

Fig. 5. Soil moisture extraction pattern from upper 121.4 cm (4 ft) of the root zone by 30.48 cm (1 ft) increments under the medium moisture regime.

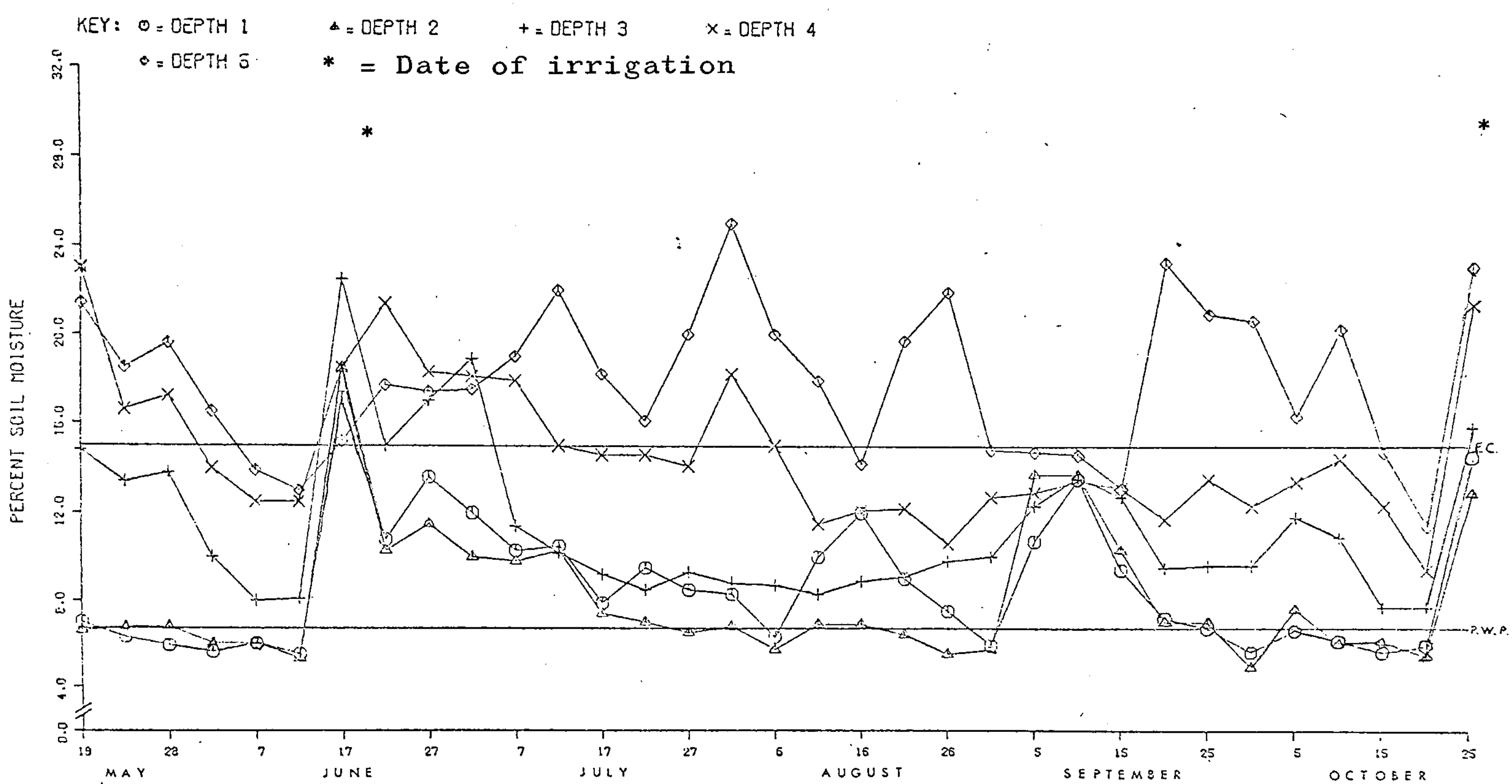

Fig. 6. Soil moisture extraction pattern from upper 152.4 cm (5 ft) of the root zone by 30.48 cm (1 ft) increments under the low moisture regime.

high regime. Water was utilized to the deepest depth under the low regime and the upper portions of the root zone of the low moisture regime were at or near the permanent wilting point for much of the growing season. Even though the upper 91.4 cm (3 ft) of the root zone under the low moisture regime was near the permanent wilting point for an extended period of time there were no significant differences in dry weight production during this period. The values for permanent wilting point and field capacity are average values for the entire root zone of each border; therefore, the actual values are lower than the average near the surface and higher than the average deeper in the root zone. This is due to the increased clay content of the soil deeper in the root zone.

Leaf/Stem Ratio

Differences were found in the leaf/stem ratio over the growing season, but no differences were found between irrigation regimes. The highest leaf/stem ratio (.93) occurred during the seventh harvest (October 29) and the lowest ratio (.49) occurred during the third harvest (July 3) (Table 6). No significant differences were found between the first (May 16) and fifth (August 10) harvests and the third (July 3) and fourth (July 27) harvests.

The leaf/stem ratios of cultivars were not different when grown under the low and medium irrigation

Table 6. Leaf/stem ratio at seven harvests of four alfalfa cultivars grown under three irrigation regimes.

Irrigation regimes	Cultivars	Harvest May 16 1	June 10 2	July 3 3	July 27 4	Aug. 20 5	Sept. 19 6	Oct. 29 7	Means
Low	Mesa-Sirsa	.61+	.57	.51	.55	.76	.76	1.01	.68 a*
	Moapa	.73	.51	.46	.49	.72	.64	1.07	.66 a
	Sonora	.78	.59	.49	.51	.65	.73	1.05	.68 a
	El-Unico	.74	.49	.45	.49	.76	.69	.97	.66 a
	Means	.72** a	.54 a	.47 a	.51 a	.72 a	.70 a	1.03 a	.67 a
Medium	Mesa-Sirsa	.55	.51	.49	.45	.67	.79	.83	.61 a
	Moapa	.75	.60	.46	.51	.56	.66	.87	.63 a
	Sonora	.84	.59	.52	.50	.63	.77	.79	.66 a
	El-Unico	.59	.49	.47	.57	.61	.83	.85	.63 a
	Means	.68 a	.55 a	.48 a	.50 a	.62 b	.76 a	.84 c	.63 a
High	Mesa-Sirsa	.63	.52	.55	.46	.65	.74	.97	.65 b
	Moapa	.67	.58	.48	.39	.66	.83	.93	.65 b
	Sonora	.80	.62	.52	.54	.72	.85	1.01	.72 a
	El-Unico	.50	.49	.48	.52	.59	.65	.79	.58 c
	Means	.66 a	.55 a	.50 a	.48 a	.65 a	.77 a	.92 b	.65 a
	Harvest means	.68 c*	.55 d	.49 e	.50 e	.66 c	.74 b	.93 a	

+Within table comparisons the LSD at .05 equals .06.

*Means followed by the same letter are not significantly different at .05 level according to Duncan's Multiple Range Test.

**Comparison made within harvests.

regimes. Under the high moisture regime Sonora had a mean value of .72 which was greater than the other cultivars. No significant difference was found between Mesa-Sirsa and Moapa, but El-Unico with a value of .58 was lower than the other cultivars tested. Sonora also had the lowest dry forage production of the cultivars tested when grown under the high moisture regime.

Specific Leaf Weight

The specific leaf weight was highest early in the season and decreased during the hot summer months until the weather cooled. The first harvest had a specific leaf weight of 4.25 mg/cm^2 (Table 7) which was higher than all other harvests. The lowest specific leaf weight occurred during the third harvest (July 3) which was not significantly different from the values obtained during the fourth (July 27) and fifth (August 20) harvests. No significant differences were found between cultivars except under the medium regime where Sonora had a value of 3.79 mg/cm^2 which was greater than the other cultivars. Sonora also produced the smallest amount of dry forage over the season under the medium moisture regime.

Leaf Area Index

Differences in the leaf area index were found between harvests, but no differences existed between the

Table 7. Specific leaf weight (mg/cm^2) at seven harvests of four alfalfa cultivars grown under three irrigation regimes.

Irrigation regimes	Cultivars	May 16 1	June 10 2	July 3 3	July 27 4	Aug. 20 5	Sept. 19 6	Oct. 29 7	Means
Low	Mesa-Sirsa	4.35[+]	3.86	2.75	3.29	3.21	3.18	3.88	3.50 a*
	Moapa	3.98	4.17	3.08	3.43	3.45	3.62	3.69	3.63 a
	Sonora	4.26	4.41	3.00	3.39	3.29	3.78	3.98	3.73 a
	El-Unico	3.69	4.24	2.98	3.37	3.52	4.11	3.73	3.66 a
	Means	4.08** a	4.17 a	2.95 a	3.37 a	3.37 a	3.68 a	3.82 a	3.63 a
Medium	Mesa-Sirsa	4.44	3.53	2.66	2.82	2.69	3.54	3.17	3.26 b
	Moapa	4.33	3.74	3.42	3.20	2.75	3.53	3.03	3.43 b
	Sonora	4.67	4.58	2.86	3.54	2.96	3.83	4.14	3.79 a
	El-Unico	4.29	3.42	3.06	3.21	3.21	3.53	3.20	3.42 b
	Means	4.43 a	3.81 ab	3.00 a	3.19 a	2.90 b	3.61 a	3.39 b	3.47 a
High	Mesa-Sirsa	4.76	3.28	3.16	3.52	2.44	3.53	3.54	3.46 a
	Moapa	4.16	3.87	3.10	2.69	2.79	3.80	3.80	3.45 a
	Sonora	3.93	4.34	2.94	2.97	3.01	4.13	3.40	3.53 a
	El-Unico	4.22	3.51	2.73	3.35	2.96	3.15	3.85	3.40 a
	Means	4.27 a	3.75 a	2.98 a	3.13 a	2.80 b	3.65 a	3.65 ab	3.46 a
	Harvest means	4.25 a*	3.91 b	2.98 d	3.23 d	3.02 d	3.64 bc	3.61 bc	

[+]Within table comparisons the LSD at .05 level equals .26.

*Means followed by the same letter are not significantly different at .05 level according to Duncan's Multiple Range Test.

**Comparison made within harvests.

irrigation regimes or cultivars. The second harvest (June 10) with a value of 5.76 was significantly greater than all other harvests (Table 8). All harvests were significantly different except the sixth (September 18) and seventh (October 29). Generally, the harvests with the highest dry weight production had the highest leaf area indices.

Root Study

There were no significant differences between the dry weight production of the shoot or roots for the four cultivars tested. The average dry weight production of the shoots was .182 g and .199 g for the roots.

There were significant differences betwee the root/shoot ratios of the four cultivars when calculated on the basis of dry weight of the roots and shoots (Table 9). El-Unico was significantly greater than Sonora with values of 1.18 g and .86 g, respectively.

No significant differences in the root/shoot ratios of the four cultivars were found when calculated on the basis of length, but there were differences in the root/shoot ratio over time (Fig. 7). The root/shoot ratio calculated on the basis of length remained constant until 10 days following planting and then increased rapidly until 25 days following planting. The root/shoot ratio then declined until 35 days following planting when it increased again. In the establishment of these four

Table 8. Leaf area index at seven harvests of four alfalfa cultivars grown under three irrigation regimes.

Irrigation regimes	Cultivars	May 16 1	June 10 2	July 3 3	July 27 4	Aug. 20 5	Sept. 19 6	Oct. 29 7	Means
		Harvest							
Low	Mesa-Sirsa	4.30+	5.64	4.25	3.92	2.92	3.01	2.01	3.72 a*
	Moapa	5.42	4.76	4.90	3.84	3.68	2.23	1.96	3.83 a
	Sonora	4.74	4.64	4.19	3.35	2.64	2.39	2.42	3.48 a
	El-Unico	6.82	4.79	4.51	3.57	3.25	1.74	2.02	3.81 a
	Means	5.32** a	4.96 b	4.46 a	3.67 a	3.12 a	2.34 a	2.10 a	3.70 a
Medium	Mesa-Sirsa	4.71	5.96	4.70	3.50	3.41	2.82	3.26	4.05 a
	Moapa	4.95	7.04	4.04	3.87	3.44	2.87	3.08	4.18 a
	Sonora	4.71	5.04	4.58	3.24	3.07	2.55	1.94	3.59 a
	El-Unico	5.02	6.62	4.17	3.83	2.76	3.00	3.14	4.08 a
	Means	4.85 a	6.16 a	4.37 a	3.61 a	3.17 a	2.81 a	2.85 a	3.97 a a
High	Mesa-Sirsa	4.25	6.94	4.19	3.15	3.09	2.41	2.41	3.78 a
	Moapa	6.09	6.20	3.73	3.26	2.30	2.63	2.44	3.81 a
	Sonora	4.97	4.97	4.71	3.91	2.96	1.95	2.73	3.74 a
	El-Unico	5.56	6.48	3.52	3.13	2.87	2.91	2.30	3.82 a
	Means	5.23 a	6.15 a	4.04 a	3.36 a	2.80 a	2.47 a	2.47 ab	3.79 a
	Harvest means	5.13 b*	5.76 a	4.29 c	3.55 d	3.03 e	2.54 f	2.47 f	

+Within table comparisons the LSD at .05 level equals .60.

*Means followed by the same letter are not significantly different at .05 level according to Duncan's Multiple Range Test.

**Comparison made within harvests.

Table 9. Shoot weight, root weight, and root/shoot ratio* of four alfalfa cultivars 45 days following planting.

Cultivars	Shoot wt.	Root wt.	R/S ratio
Mesa-Sirsa	.187 a	.217 a	1.18 ab
Moapa	.138 a	.154 a	1.12 ab
Sonora	.218 a	.209 a	.86 b
El-Unico	.185 a	.215 a	1.32 a

*Means followed by the same letter are not significantly different at .05 level according to Duncan's Multiple Range Test.

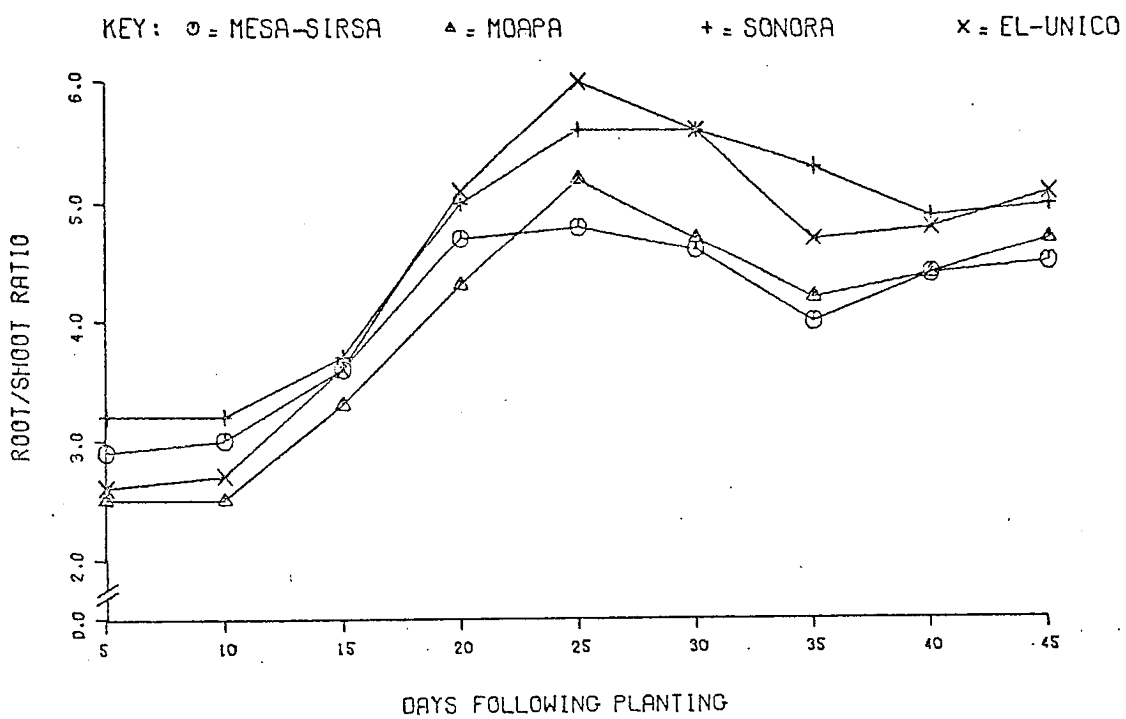

Fig. 7. Root length to shoot length ratio of four alfalfa cultivars up to 45 days following planting.

cultivars the roots grew in length much faster than the shoots which allowed the plants to become well established with an adequate moisture supply from the lower depths of the root zone in a relatively short period of time. The average root length at the end of the study was 65.5 cm (25.8 in) and 13.2 cm (5.2 in) for the shoots (Fig. 8). Although there was a large difference between the length of roots and shoots, the dry weight production of the roots and shoots did not show this because many of the shoots were branched while little branching occurred in the roots.

There were significant differences in dry weight production under the three soil moisture regimes. The high regime produced 8.04 g/pot which was significantly higher than the medium and low regimes which were also significantly different from each other with values of 5.35 and 2.23 g/pot, respectively. The root weight under the high regime was signficantly greater than under the low regime with values of 2.23 and 1.62 g/pot, respectively. The low moisture level had a significantly higher root/shoot ratio than the high and medium regimes which were not significantly different from each other. This agrees with Tanner (1968) who stated that the plant part farthest from a deficient factor of growth will be most affected by its deficiency. In this case the low soil moisture decreased the shoot production much more than the root production. Under the medium and high regimes the shoot

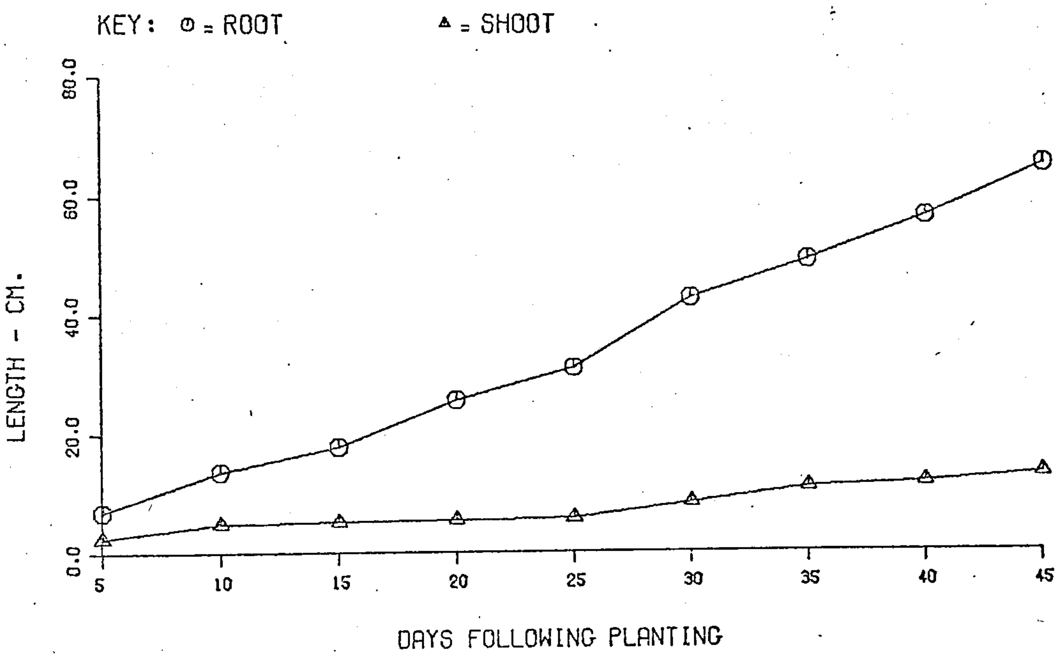

Fig. 8. Average length (cm) of roots and shoots of four alfalfa cultivars up to 45 days following planting.

growth increased more than root growth with the additional water. Thus, under dry soil conditions plants will establish similar root systems as those established under a higher soil moisture level, although the shoot production is greatly reduced under the drier conditions.

The anatomical studies of the roots grown under the three moisture regimes revealed no significant differences in the number of xylem vessels or in the per cent of the roots that was vascular tissue (Table 10). Although there were no significant differences in the xylem number between irrigation regimes, there were large differences in the size of the roots (Fig. 9). The larger roots had more and larger sclerenchyma and parenchyma cells than the smaller roots grown under the low moisture regime.

Even though there was a difference in the diameter of the roots, the per cent vascular cylinder of the roots was not significantly different (Table 8). Therefore, because there were no differences in the number of xylem elements and per cent vascular cylinder between plants grown under the three moisture levels, no differences would be expected in the ability or efficiency of the root systems to conduct water if an adequate level of moisture was present.

Table 10. Shoot weight, root weight, root/shoot ratio, xylem number, and percentage vascular cylinder of Mesa-Sirsa grown under three irrigation regimes.

	Irrigation		
	High	Med.	Low
Shoot weight	8.04 a*	5.35 b	2.23 c
Root weight	2.23 a	1.92 ab	1.62 b
Root/shoot ratio	.28 b	.36 b	.75 a
Xylem number			
Base	873 a	854 a	761 a
Center	167 a	229 a	257 a
Apex	37 a	74 a	47 a
Per cent vascular cylinder			
Base	81 a	74 a	75 a
Center	72 a	71 a	68 a
Apex	42 a	67 a	45 a

*Means followed by the same letter are not significantly different at .05 level according to Duncan's Multiple Range Test.

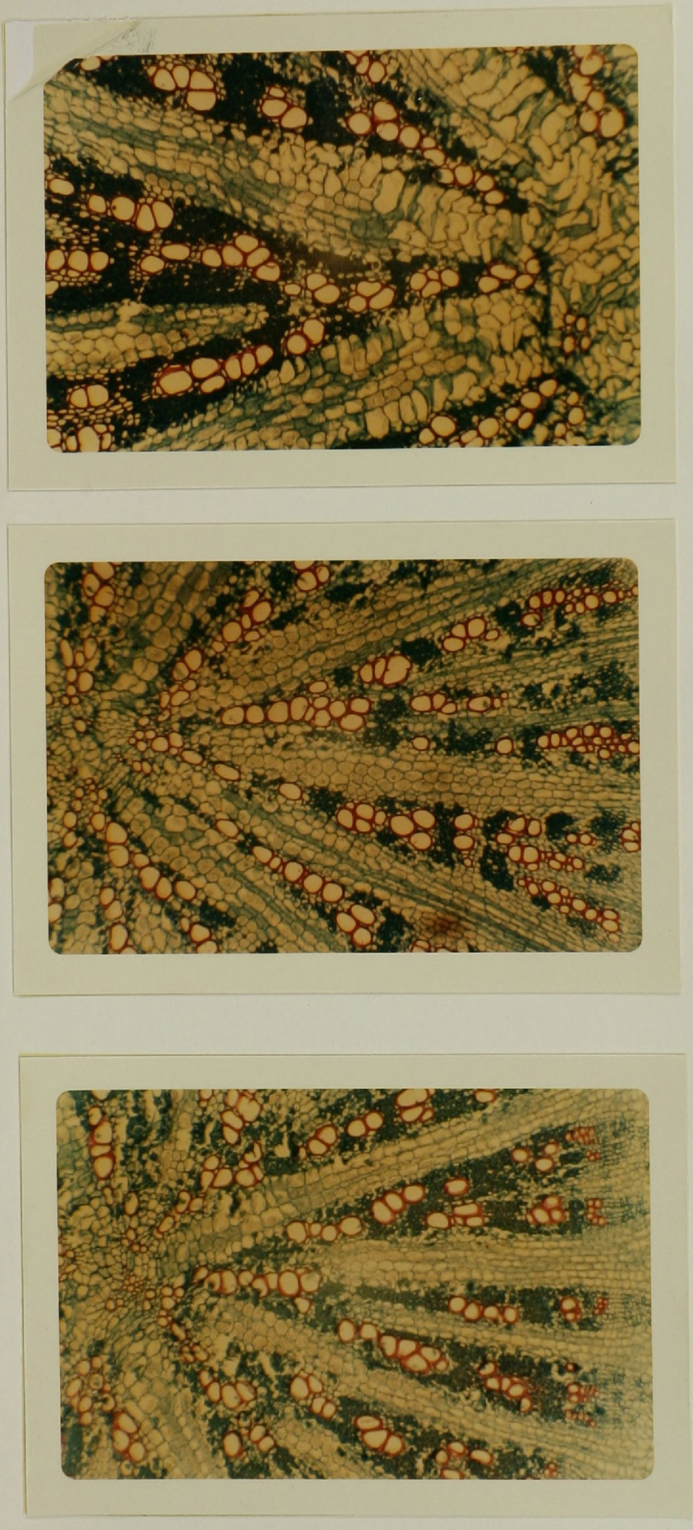

Fig. 9. Cross sections of roots of Mesa-Sirsa alfalfa grown under high (top), medium (center), and low (bottom) moisture regimes. (40 X)

SUMMARY

An experiment was conducted at Tucson, Arizona, to investigate the water-use efficiency, yield, leaf/stem ratio, specific leaf weight, and leaf area index of four commercial cultivars of alfalfa grown under three irrigation regimes. The cultivars were Mesa-Sirsa, Moapa, Sonora, and El-Unico. The moisture regimes were established by irrigating when 30% and 70% of the available soil moisture was depleted to a depth of 91.4 cm (3 ft) and when 90% of the moisture was depleted to 121.9 cm (4 ft) for the high, medium, and low regimes, respectively. Irrigation efficiency and moisture extraction patterns were also determined for each irrigation regime. Two additional experiments were conducted to investigate the root and shoot growth and anatomical characteristics of seedling alfalfa.

Significant differences in the water-use efficiency were found between cultivars, harvests, and irrigations. El-Unico, Moapa, and Mesa-Sirsa were significantly more efficient than Sonora. Plants were found to be most efficient under the low moisture regime followed by the medium and high regimes, respectively. The differences between irrigation regimes were due mainly to the inefficient irrigation system which did not allow for

replenishment of small quantities of water uniformly over the field.

Harvests were also significantly different with the most efficient production occurring during the second harvest followed by the harvests during the summer months when less water was applied. The least efficient alfalfa production occurred during the seventh harvest.

Significant differences were also found in dry weight production between cultivars, harvests, and irrigations. El-Unico, Moapa, and Mesa-Sirsa produced significantly more dry forage than Sonora. A significantly larger amount of dry forage was produced under the medium moisture regime than under the high and low regimes. The highest dry forage yield occurred during the second harvest and as the season progressed the yields steadily decreased. The lowest dry forage yield occurred during the seventh harvest.

The most variation in leaf/stem ratio, specific leaf weight, and leaf area index occurred between harvests. There were no significant differences in leaf/stem ratio between irrigations or between cultivars under the medium and low regimes. Under the high regime the leaf/stem ratio of Sonora was significantly greater than Moapa and Mesa-Sirsa, and El-Unico was signficantly lower than the other cultivars. Over the season the leaf/stem ratio was highest during the seventh harvest period, which had the lowest dry weight yield. The smallest value occurred during the hot summer months. The specific leaf weight values were highest early in the year and decreased throughout the season until the weather cooled. There were no significant differences in the irrigation regimes or cultivars under the low and high regimes. Sonora had a significantly greater specific leaf weight than Mesa-Sirsa, Moapa, and El-Unico under the medium regime. The leaf area index was highest during the second harvest and decreased throughout the remainder of the season. Generally, the harvests with the highest dry forage yield had the highest leaf area indices. There were no significant differences in the leaf area indices between cultivars or irrigations.

Differences in the dry weight production of roots and shoots were found in seedling Mesa-Sirsa when grown under three soil moisture levels. The shoot production was affected more by the moisture level than the dry weight yield of the roots. The number of xylem elements and the per cent of the root that was vascular cylinder did not vary significantly between the moisture levels.

No significant differences were found in the growth rates of roots or shoots of Mesa-Sirsa, Moapa, Sonora, and El-Unico in the seedling stage of development. The maximum root/shoot ratio was reached approximately 25 days following planting. In the early periods of development the root growth occurred much faster than shoot growth which allows the plant to become well established in a short period of time.

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