CONSUMPTIVE WATER-USE EFFICIENCY OF ALFALFA (*MEDICAGO SATIVA* L.) GROWN UNDER THREE IRRIGATION REGIMES

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ABSTRACT

Consumptive water-use efficiency of four alfalfa (*Medicago sativa* L.) cultivars was determined under field conditions at the Soil Conservation Service Plant Materials Center, Tucson, Arizona. The cultivars were 'Mesa-Sirsa,' 'Sonora,' 'El-Unico,' and 'Moapa.' The cultivars were grown under three irrigation regimes. Plants were irrigated when approximately 30, 60, and 90% of the available soil moisture was depleted from the upper 91.4 cm of root zone. These irrigation regimes were designated as high, medium, and low, respectively. Consumptive water-use efficiency, yield, percentage protein, leaf to stem ratio, percentage dry matter, and stand decline were determined on each cultivar grown under the three soil-moisture regimes.

Cultivars differed significantly in the units (kg) of water required to produce a unit (kg) of dry matter during 1968 but not in 1969. Average consumptive water-use efficiency values were 519, 524, 535, and 547 for El-Unico, Mesa-Sirsa, Sonora, and Moapa, respectively, in 1968. All cultivars were more efficient in water-use under the low soil-moisture regime. Average water efficiency values were 403, 493, and 698 for the low, medium, and high soil-moisture regimes, respectively, in 1968. Average water efficiency

values for the low, medium, and high regimes in 1969 were 541, 598, and 894, respectively.

Cultivars differed significantly in forage production in 1968 but not in 1969. El-Unico produced the most forage during both growing seasons. In 1968 plants grown under the high soil-moisture regime produced significantly less forage than plants under the low and medium regimes.

Percentage protein, leaf to stem ratio, and stand decline were not affected by soil moisture.

Alfalfa cultivars with the highest forage production were the most efficient in water-use under field conditions.

INTRODUCTION

Alfalfa (Medicago sativa L.) is the most important forage crop in Arizona. In 1968, 202,000 acres (81,810 ha) in Arizona were devoted to alfalfa hay-production. Alfalfa accounts for 92% of total hay production and 84.5% of the total hay acreage in the state (1).

In the irrigated areas of southern Arizona the demand for water by agriculture, industry, and urban users is depleting the underground aquifers. The cost of water is increasing as the supply diminishes, and the conservation and efficient use of water is of prime importance.

Although alfalfa is an important economic crop in the irrigated West, there appears to be little consistency in the amount of water used to grow the crop. Stanberry (63) surveyed irrigation schedules among growers. He found that 60% of the growers irrigated after each cutting, 25% whenever water was delivered, 10% on plant appearance, and 5% on soil moisture-depletion. Some growers in southern Arizona do not irrigate alfalfa during July and August because of increased demand for water by other crops at this time (52).

Alfalfa cultivar tests conducted by The University of Arizona at the Gila Project Farm received 25 irrigations yearly for a total of 106 acre-inches (10979 m^3) (57). A few years later after conducting an irrigation test on the Arizona Agricultural Experiment Station, Mesa Farm, it was concluded (58) that "The irrigation experiment indicated that contrary to popular opinion, alfalfa does not respond to irrigation application above a total of 5 acre-feet (6168 m^3) per season under Mesa conditions. The highest yields obtained were from a treatment given 59 acre-inches (6065 m^3). This program consisted essentially of one 5-inch (514 m^3) irrigation prior to each cutting."

Since there is a great variation in the amount of water used to grow alfalfa, emphasis should be given to increased efficiency of alfalfa production; that is, maximum production with a minimum amount of water.

The research reported here was designed to determine the most efficient use of water in alfalfa production under field conditions. The objective of this experiment was to determine the effect of three irrigation regimes on four alfalfa cultivars with regard to the following: (a) consumptive water-use efficiency, (b) forage yield (c) leaf to stem ratio, (d) percentage protein, (e) percentage dry matter, and (f) stand decline.

REVIEW OF LITERATURE

Factors Affecting Water-Use and Water-Use Efficiency

Some of the earliest and most extensive plant water-use experiments were conducted by Briggs and Shantz (11, 12, 14) and Shantz and Piemeisel (54). Plants were grown under a screened enclosure in large metal cans with lids to reduce evaporation from the soil surface. The water requirement of 288 sets of plants or 1,800 pots was determined. These included most of the economically important crops and their cultivars plus many weeds. Briggs and Shantz (11) used the term water requirement for their measurements and defined it as "the ratio of the weight of water absorbed by a plant during its growth to the weight of dry matter produced." Similar terms used by other workers include transpiration-ratio, water-use economy, and water-use efficiency.

Briggs and Shantz (12, 14) indicated that cultivars within the same species differed in their water requirement. They showed the water requirement of alfalfa varied from 890 ± 6 to 957 ± 18. Soil moisture content appeared to have little effect on water requirement. Variations in the water requirement of certain crops occurred between years depending on climatic conditions.

Cole (16) used methods very similar to those of Briggs and Shantz (12) to determine the water-use efficiency of seven alfalfa cultivars under greenhouse conditions. This work also showed significant differences in water-use efficiency among cultivars and genotypes. The water-use efficiency values of the seven alfalfa cultivars ranged from 502 to 587. Keller (37) found significant differences in the water requirement and yield of 16 genotypes of orchardgrass (Dactylis glomerata L.). Baker and Hunt (3), Hunt (33), and Downes (23) also found genotypic and varietal differences in water requirements.

Miller (48) summarized the water requirement of several plant species. Values for the amount of water required to produce 1 g of alfalfa forage varied from 657 to 1,068 g over a period of seven years.

Water-use varies greatly according to crop species. Most research has indicated that alfalfa used more total water than other agronomic crops. Studies by Erie, French, and Harris (26) in Mesa, Arizona, reported the seasonal consumptive use of water by alfalfa was 74.3 inches (7638 m^3). The same study reported the seasonal consumptive use of bermudagrass (Cynodon dactylon L.), blue panicgrass (Panicum antidotale Retz.), and barley (Hordeum vulgare L.) as 43.5 inches (4471 m^3), 52.3 inches (5376 m^3), and 25.3 inches (2600 m^3), respectively.

Shantz and Piemeisel (54) found that when 288 sets of plants were tested only a few had a water requirement as high as 800 to 900. All of the alfalfas tested were in this range except two cultivars of 'Grimm' which had a water requirement between 900 and 1,000.

Bolton (9) listed average water requirement of the following crops: alfalfa, 844; flax (Linum sp.), 783; oats (Avena sativa L.), 583; wheat (Triticum vulgare Vill.), 557; barley, 518; maize (Zea mays L.), 349; and grain sorghum (Sorghum vulgare Pers.), 304. He concluded that the water requirement of alfalfa was relatively high and that this was true for legumes in general. This agrees with Kiesselbach (38) who reported grasses to be more water efficient than legumes. Bolton (9) stated that with a water requirement ratio of 884, about 7.5 acre-inches (771 m^3) of water would be needed to produce 1 ton (908 kg) of dry matter.

Irrigation studies by The University of Arizona at Yuma, Mesa, and Safford indicated 6.5 acre-feet (8018 m^3) of water annually was the optimum for alfalfa forage production. For each acre-foot (1233 m^3) of water applied, 1.5 tons (1362 kg) of hay were produced (47). An earlier alfalfa study at Mesa showed maximum production was attained with 59 acre-inches (6065 m^3) (58). The difference in water-use between the two studies could be attributed to climatic differences as to location and year of study.

According to Criddle (17) the amount of water consumed by perennial crops was affected by many factors and the most important of these was climate. He listed the consumptive use of alfalfa at various locations in the West as follows: Bonners Ferry, Idaho, 24 inches (2467 m^3); Logan, Utah, 25 inches (2570 m^3); Prosser, Washington, 36 inches (3700 m^3); and Mesa, Arizona, 52.5 inches (5397 m^3).

Researchers working in widely separated regions have reported different consumptive use values for alfalfa. This was probably due mainly to climate. In Australia, Jackson (34) reported the annual requirement of water by alfalfa was 90 inches (9252 m^3) under arid conditions. A daily use of .22 inch (22 m^3) was found in Canada by Krogman and Lutwick (41). Hanson (29) found that alfalfa required .32 inch (32 m^3) per day in New Mexico while Peck, Vittum, and Miller (49) reported the maximum daily water use of alfalfa in New York as .17 inch (17 m^3). The greatest use of water is in regions with a long growing season, high temperature, and low humidity.

Climate can also affect the water use of crops at a given location. Researchers have found consumptive use highest at certain months during the growing season (6, 26, 53, 64) and to vary from one growing season to another at the same location (14, 54). Evapotranspiration rates for alfalfa are usually low during early spring and increase as the season progresses. Erie et al. (26) found the greatest consumptive use by alfalfa in central Arizona was between mid-June and mid-July. Bennett and Doss (6) indicated June as the month of maximum evapotranspiration in Alabama. Tovey (66) reported that seasonal plant growth and climatic factors affect yield and change the water requirement.

The effect of available soil moisture on plant water-use and water requirement is evident from a review by Stanhill (65). He reviewed 80 papers that dealt with the effect of different moisture regimes on plant water-use and plant growth. Of these, 66 papers reported that plant growth responded to differences in soil moisture-regimes. Yields of most crops increased with an increase in soil moisture-level.

Criddle (17) suggested that water should be applied as needed to keep the crop growing at or near a maximum rate. He proposed that such practices will give high crop yields with a relatively great use of water per unit area.

Hanson (29) and Drabelbis and Harrold (24) observed that irrigation treatments which provided relatively high soil-moisture levels produced the greatest water-use efficiency. Hanson (29) stated that yield has relatively little influence on consumptive use. Consumptive use was highest on the infrequently irrigated plots which received the least amount of water and produced the lowest. Other authors (6, 7, 22, 32, 40, 64), however, observed that daily evapotranspiration was directly related to soil moisture-levels. Bennett et al. (7) postulated that increased evapotranspiration rate at the higher moisture levels was due to increased evaporation. Research by Ekern (25), Slatyer (59), and Veihmeyer and Hendrickson (71) indicated that both transpiration and evapotranspiration decreased as soil moisture decreased.

Although research indicates that most plants are more efficient in water-use at high moisture levels, this principle does not hold for all crops. Bourget and Carson (10) grew alfalfa and oats under four irrigation regimes. While alfalfa was less efficient at low soil-moisture regimes, oats was more water efficient with decreased soil moisture. Van Der Paauw (68) obtained essentially the same results with oats. Working with several grass species common to the Southeast, Burton, Prine, and Jackson (15) found that the most drought-tolerant species were more efficient under moisture stress than when water was abundant.

Lucey and Tesar (44) grew alfalfa at four moisture regimes: 60, 40, 20, and 0% of field capacity. Greater production was realized with plants grown above 40% available moisture as compared to plants grown below 20% available moisture. They theorized that water was not equally available to the plant between field capacity and the permanent wilting point This agrees with Thornthwaite, according to Denmead and Shaw (18). However, Veihmeyer and

Hendrickson (70) suggested that soil moisture was equally available to plants between field capacity and permanent wilting point.

Factors affecting yield such as disease, nutrition, and management will change the water requirement of any crop. Viets (72, 73) and others (15, 28, 55, 60, 62) reported that well-fertilized plants were more efficient than nutrient deficient plants. This was explained by the increased dry matter production with little or no increase in consumptive water-use. Singh, Singh, and Singh (56) found higher yielding plants were more efficient in their use of water. Bever (8) showed that rust (*Puccinia striiformis* West.) disease could increase the water requirement of wheat and barley.

Plant growth stage is an important factor in determining water requirement. Singh et al. (56) showed that the water requirement was highest at the seedling, flowering, and seed formation stages. As plants reach maturity their water requirement usually increases (20, 56, 67). Dillman (20) determined the water requirements of many agronomic plants on the northern Great Plains. In most cases, the water requirement increased as plants reached maturity. Alfalfa had a water requirement 28% higher when cut after seed set than when cut at 2-week intervals during vegetative growth. Bennett (5) demonstrated that clipping affected moisture use. Moisture use of forages in Georgia dropped from .25 inch (25 m^3) per day prior to clipping to .13 inch (13 m^3) per day after clipping. Height of cutting has also been shown to influence water-use (3, 13). Dennis, Harrison, and Erickson (19) worked with alfalfa and sudangrass (Sorghum sudanese [Piper] Staph) and reported that cutting frequencies had little effect on water-use but that frequent cuttings reduced yields. Greenhouse studies have shown that alfalfa clipped frequently will use less total water but will have the same water requirement (62).

Crop yield in relation to water-use determines water requirement or water-use efficiency. Henderson, Hagan, and Mikkelson (31) summarized how water-use efficiency was influence: (a) if vegetative yield was reduced proportionately less than water-use, then water-use efficiency increased; (b) if change in yield and water-use was proportionately the same, then water-use efficiency did not change; (c) if yield was decreased proportionately more than water-use, then water-use efficiency decreased.

Factors Affecting Forage Quality

Although low soil-moisture has a detrimental effect on water-use efficiency of alfalfa, it increases forage quality.

Jensen, Massengale, and Chilcote (36) reported that low soil-moisture regimes were associated with reduced yields of a higher quality alfalfa forage. Plants grown under the low-moisture regime had less fiber and lignin and significantly more protein than plants not stressed.

Gifford and Jensen (27) grew alfalfa in containers under different degrees of moisture stress and soil compaction. With each decrease in soil moisture there was a corresponding increase in crude protein and decrease in crude fiber of the forage. Van Riper (69) reported an increase in protein in grasses and legumes when grown under low available soil-moisture conditions.

Longnecker and Lyerly (43) conducted an alfalfa field experiment that included three irrigation regimes and three rates of P_2O_5. Plants under the low irrigation regime were shorter but had thinner stems and a higher leaf to stem ratio.

Factors other than soil moisture affect quality. Maturity at harvest, cultivar, and plant nutrition are important. The greatest percentage of protein is found in the leaves and the highest percentage of leaves is obtained by harvesting alfalfa at the bud stage. Keisselbach and Anderson (39) found that the leaf content of the forage declined as the number of days between harvests increased. However, harvesting repeatedly before alfalfa plants flower depletes food reserves and causes deterioration of stand. Robison and Massengale (51) in Arizona and Kust and Smith (42) in Wisconsin have shown frequent harvesting depletes total available carbohydrates.

Until a cultivar is developed that can withstand frequent harvesting, alfalfa forage quality cannot be increased to a great extent by harvesting before the plants flower. Dobrenz, Schonhorst, and Thompson (21) determined the percentage protein and leaf to stem ratios of seven non-hardy alfalfa cultivars. There were no significant differences among cultivars as to percentage protein in leaves or or stems when each was analyzed separately. On a whole plant basis, cultivars with a higher leaf to stem ratio had more protein. Cultivars with more leaves will have more protein since most of the protein is contained in the leaves. When total protein was calculated on a plot basis, yield also became important. The higher yielding cultivars contained less protein on a whole plant basis; however, they produced proportionately more forage and actually produced the most protein per plot.

Hanson et al. (30) observed that cultivar, location, time of cutting, and year had an effect on crude fiber and protein of alfalfa forage. Wright (74) found an increase in percentage protein of blue panicgrass forage with increased applications of nitrogen.

The same factors affecting leaf to stem ratio and percentage protein also affect stand persistence and percentage dry matter of forage. Massengale et al. (45) and Barney (4) found that alfalfa stands decline with age. Schonhorst, Thompson, and Dennis (52) showed that irrigation management also has an effect on stand persistence. Alfalfa stands declined faster on summer-irrigated plots than on those not irrigated during the summer.

Matocha and Cowley (46) noted a difference in stand decline among cultivars during a 2 year alfalfa cultivar trial in Texas. They believed this was due to differences in maturity at harvest. Some cultivars matured earlier than others and were more mature at harvest.

Janes (35) reported that beans (*Phaseolus vulgaris* L.) receiving no irrigation had a higher percentage of dry matter than those that had been irrigated. Wright (74) showed that blue panicgrass forage had a lower percentage dry matter with increased nitrogen fertilization.

MATERIALS AND METHODS

This study was conducted at the Soil Conservation Service Plant Materials Center at Tucson, Arizona, for a 2-year period. Certified seed of the cultivars 'Mesa-Sirsa,' 'Moapa,' 'Sonora,' and 'El Unico' was seeded with a Brillion cultipacker seeder at the rate of 22.4 kg per ha on October 17, 1967. Prior to seeding, phosphate in the form of treble superphosphate was disked in at the rate of 179 kg per ha. Plots were irrigated immediately after seeding to insure sufficient moisture for germination and emergence.

On November 11, 1967, propham (isopropyl carbanilate) at 3.36 kg per ha was applied for postemergence control of grass seedlings. The plots were irrigated immediately after application to incorporate the propham. Trifluralin (*a*,*a*,*a*-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine) was applied on January 18, 1968, in the irrigation water at the rate of 1.12 kg per ha for the preemergence control of summer annual weeds. Dimethoate (*O*,*O*-dimethyl *S*-[*N*-methyl-carbamoylmethyl]phosphoradithioate) was applied January 24, 1969, at .28 kg per ha to control a severe aphid (*Macrosiphum pisi* Kaltenbach) infestation.

The soil at the experimental site is Comoro fine sandy loam. This is a deep, well-drained soil with a fine sandy loam to sandy loam surface and subsoil to approximately 76 cm. Fine sandy loam with stratas of very fine sandy loam are found below 76 cm. The soil pH range is 8.4 to 8.6. Available waterholding capacity of the upper 76 cm ranges from 10.0 to 12.5 cm per meter while below 76 cm it ranges from 12.5 to 15.1 cm per meter (61). Field capacity and wilting point values were determined in the laboratory using the pressure plate and pressure membrane method (50).

A split-plot design with six replications was used (Fig. 1). This consisted of three borders with each border representing an irrigation main-plot. The cultivars as sub-plots (3.4 m by 8.5 m) were randomized six times within each main plot. The irrigation treatments or main plots were stripped in the field design because the irrigation system provided for water application at one end of the field only. The three main plots measured 7.0, 7.3, and 6.2 m wide by 113.7 m long. A border ridge 91.4 cm wide at the base separated each main plot and retained the irrigation water. Harvests were taken within each sub-plot 2.6 m from the center of the border ridge to minimize effect from lateral movement of irrigation water. Alleys 91.4 cm in width separated each replicated sub-plot and were established immediately prior to each harvest to avoid border effect. A 3.7 m guard strip was left on both ends of each border.

Irrigation Regimes

3.7 M Guard Strip

Plot length: 8.5 M; 91.4 cm Alley between plots

Low		Medium		High		Replicated Plots
Sonora	Mesa-Sirsa	Moapa	Sonora	Mesa-Sirsa	Moapa	I
El-Unico	Moapa	El-Unico	Mesa-Sirsa	El-Unico	Sonora	
Moapa	El-Unico	Sonora	Mesa-Sirsa	Mesa-Sirsa	El-Unico	II
Sonora	Mesa-Sirsa	Moapa	El-Unico	Moapa	Sonora	
Mesa-Sirsa	Moapa	Sonora	Mesa-Sirsa	Moapa	Mesa-Sirsa	III
Sonora	El-Unico	Moapa	El-Unico	El-Unico	Sonora	
Moapa	El-Unico	Mesa-Sirsa	Moapa	Moapa	Mesa Sirsa	IV
Sonora	Mesa-Sirsa	Sonora	El-Unico	El-Unico	Sonora	
Sonora	El-Unico	Mesa-Sirsa	Moapa	Sonora	Mesa Sirsa	V
Moapa	Mesa-Sirsa	Sonora	El-Unico	El-Unico	Moapa	
El-Unico	Sonora	Mesa-Sirsa	El-Unico	Moapa	Sonora	VI
Mesa-Sirsa	Moapa	Sonora	Moapa	Mesa-Sirsa	El-Unico	

3.7 M Guard Strip

Fig. 1. Field design of four alfalfa cultivars grown under three irrigation regimes to investigate the efficiency of consumptive water-use.

Irrigation regimes were established after the first harvest by attempting to irrigate when 30% (high), 60% (medium), and 90% (low) of the available soil-moisture had been removed to a depth of 91.4 cm. Soil moisture was determined gravimetrically at 30.5 cm increments at or near the center of each main plot. Moisture determinations were made before each irrigation during the first growing season. During the second growing season determinations were made before each irrigation and immediately after each harvest. Tensiometers were used to indicate when irrigation was needed and to indicate when field capacity had been reached to a depth of 91.4 cm. After each irrigation an Oakfield probe was used to check various parts of the borders for moisture to 91.4 cm. Water was applied by flood-irrigating the plots at the rate of 92.5 m^3 per hour.

Consumptive use values were calculated for the first season using the total amount of water applied by irrigation plus rainfall. Consumptive use values for the second season also included water applied plus rainfall but differed slightly in that calculations were made after each harvest by subtracting the moisture remaining in the upper 91.4 cm of soil. Water-holding capacity in the upper 91.4 cm was averaged at 12.5 cm per meter. Efficiency of consumptive water-use was determined by dividing total consumptive use in kilograms per plot by total kilograms dry weight of forage per plot. The resulting value was the kilograms of water used to produce 1 kg of dry matter.

Forage yields were determined by harvesting an area 91.4 cm by 7.6 m within each replicated plot. Harvests were made when the alfalfa had reached the one-tenth bloom stage. A Milbradt mower which cut approximately 5 cm above soil level was used to clip the forage. Yields were calculated on an oven dry (85 C) basis. At harvest, a sample weighing approximately 500 g was taken from each plot and oven dried at 85 C. Samples were re-weighed to determine the percentage of moisture in the forage for dry weight calculations. Percentage dry matter of the forage at harvest was also calculated from these samples.

Samples were taken from two replications during the second growing season for leaf to stem ratio and percentage protein determinations. Leaf to stem ratio calculations were made by separating the leaflets from the stems and petioles. The leaves and stems with petioles were then dried separately for 24 hrs at 80 C. Leaflet weight was divided by the weight of stems and petioles to obtain leaf to stem ratio. The percentage protein was determined by using the micro-kjeldahl technique (2) after the forage had been ground through a 40-mesh screen of a Wiley mill.

Three plant counts of a .19 m^2 quadrat were made in December, 1967, February, 1969, and December, 1969 in each sub-plot on each date.

RESULTS AND DISCUSSION

Total rainfall plus irrigation water applied to alfalfa grown under the low, medium, and high soil-moisture regimes in 1968 were 4,626.0 m^3, 5,633.4 m^3, and 7,710.0 m^3, respectively. An average of 6% more water was applied in 1969 when the low, medium, and high regimes received 5,088.6 m^3, 5,540.9 m^3, and 8,511.8 m^3 of water, respectively. Rainfall accounted for 668.2 m^3 of the total water applied to all plots in 1968 and 494.5 m^3 in 1969.

Six irrigations which averaged 659.6 m^3 each were applied to the low regime during the first growing season. The alfalfa plants depleted 94% of the available soil moisture in the upper 91.4 cm before each irrigation (Table 1). Four irrigations which averaged 1097.1 cm^3 were applied to the low regime during the 1969 season. Eighty-seven per cent of the available soil moisture was used from the upper 91.4 cm at the time of irrigation the second year (Table 2).

The medium moisture-regime received 8 irrigations the first season and 6 irrigations the second growing season. Plants under the medium regime used 66% of the available soil-moisture from the upper 91.4 cm of root zone in 1968 and 71% in 1969 before irrigations were applied (Tables 1

Table 1. Irrigation and harvest frequencies for three soil-moisture regimes in 1968.

	Irrigations			
	High	Medium	Low	
Months	(36% Used)	(66% Used)	(94% Used)	Harvests
March	19	19	21	14*
April	6 29	29	29	25
May	13 30	23		28
June	7 21	14	4	29
July	5 18 26	5 26	5 26	22
August	23			19
September	18	9		14
October	10	10	10	19
November				
December				7

*Yield data not recorded from this harvest.

Table 2. Irrigation and harvest frequencies for three soil-moisture regimes in 1969.

	Irrigations			
	High	Medium	Low	
Months	(43% Used)	(71% Used)	(87% Used)	Harvests
February	26			
March		11		
April	8 28	26	25	3
May	20	31		10
June	9 23	30	14	5
July	7 31		21	3 25
August	23	4		20
September	8	8	8	11
October				11
November				24*
December				

*Yield data not recorded from this harvest.

and 2). The average irrigation under the medium moisture-regime was 620.7 m^3 in 1968 and 837.0 m^3 in 1969.

Plants grown under the high moisture-regime were irrigated when an average of 36% and 43% of available soil-moisture was depleted from the upper 91.4 cm of soil in 1968 and 1969, respectively. Thirteen irrigations were applied to the plants the first season (Table 1). Irrigations in 1968 averaged 541.7 m^3. In 1969 ten irrigations which averaged 791.8 m^3 were applied to plots under the high regime (Table 2).

Irrigation frequency reached a peak in July. This was most evident with the high moisture-regime. Plants grown under the high regime extracted comparatively little moisture below 91.4 cm. Gravimetric samples taken below 91.4 cm showed that the plants under the medium and low moisture-regimes extracted deep soil moisture. As the moisture tension increased in the upper 91.4 cm of soil, where a major portion of the roots were located, moisture became less available and was absorbed more slowly. Proportionately more moisture was then supplied by deeper roots. Soil moisture was not equally available between field capacity and permanent wilting point. This was also proposed by Lucey and Tesar (44).

The plots were harvested during each growing season at the dates shown in Tables 1 and 2. Individual harvests were made on the three moisture-regimes at the same dates since there was very little or no difference in plant maturity between moisture levels. The alfalfa plants grown under the medium and low soil-moisture regimes extracted deep moisture which enabled the plants to avoid the physiological moisture stress that would have promoted early maturity.

Consumptive Water-Use Efficiency

Significant differences in consumptive water-use efficiency were found between moisture regimes and among cultivars in 1968 (Table 3). Cultivar values averaged over moisture regimes ranged from 519 (El-Unico) to 547 (Moapa).

Cultivars were not significantly different in consumptive water-use efficiency when averaged over moisture levels in 1969 (Table 3). However, El-Unico was again the most efficient cultivar with a value of 669. Moapa, the least efficient cultivar in 1968, was the second most efficient in 1969.

Moisture regimes averaged over cultivars were significantly different for both years of the study (Table 3). Consumptive water-use efficiency values for the low, medium, and high regimes in 1968 were 403, 493, and 698, respectively. In 1969 these values were 541, 598, and 894 for the low, medium, and high soil-moisture regimes, respectively (Table 3).

Table 3. Average consumptive water-use efficiency of four alfalfa cultivars grown under three irrigation regimes in 1968 and 1969.

1968

Cultivars	Irrigation Regimes Low	Medium	High	Means
El-Unico	391*	469	696	519 a‡
Mesa-Sirsa	397	502	674	524 ab
Sonora	403	499	702	535 bc
Moapa	419	503	720	547 c
Means	403 a‡	493 b	698 c	

1969

Cultivars	Irrigation Regimes Low	Medium	High	Means
El-Unico	528+	602	876	669 a‡
Moapa	543	584	883	670 a
Mesa-Sirsa	547	609	893	683 a
Sonora	546	597	924	689 a
Means	541 a‡	598 b	894 c	

*Within table comparisons for 1968 the LSD at .05 level equals 17.

+Within table comparisons for 1969 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.

Consumptive use was probably successively greater from the low to the high soil-moisture regimes due to increased evaporation as suggested by Bennett et al. (7). However, the main reason for the increase in water applied from the low to the high moisture-regimes in this study was due to differences in irrigation efficiency. Each increment increase in water applied between irrigation regimes resulted in a corresponding decrease in consumptive water-use efficiency. To attain maximum irrigation efficiency of approximately 90%, the irrigation system was designed for water applications of more than twice the 92.5 m^3 per hour used in this experiment. It was necessary to apply an average minimum irrigation of 541.7 m^3 in order to adequately irrigate all the plots under the high moisture-regime. This was more than that needed to refill the plant root zone and water was lost through deep percolation. Irrigation efficiency for the high moisture-regime was estimated at 35% in 1969 and 50% in 1968. Irrigation efficiency of the low and medium soil-moisture regimes were believed to more nearly approach maximum because larger quantities of water were required to refill the plant root zone at each irrigation.

Consumptive water-use efficiency of all cultivars decreased as the amount of water applied was increased (Table 3). The rate of change in cultivar efficiency values due to irrigation treatments was significant. There was a significant cultivar by irrigation interaction in 1968. This interaction was not significant in 1969.

A comparison of cultivars within soil moisture-regimes showed that in 1968 El-Unico was significantly more efficient than Moapa under the low moisture-regime. Under the medium regime El-Unico was significantly more efficient than Mesa-Sirsa, Sonora, and Moapa. Mesa-Sirsa was the most efficient cultivar under the high regime during the 1968 season (Table 3).

El-Unico was significantly more efficient than Sonora but not significantly different than Moapa or Mesa-Sirsa under the high soil-moisture regime in 1969. Cultivars were not significantly different under the low and medium moisture-regimes in 1969.

Cultivars varied significantly in consumptive water-use efficiency between harvests. Briggs and Shantz (12) and Cole (16) also found that alfalfa cultivars varied in their water-use efficiency at different harvests during the growing season.

The consumptive water-use efficiency values shown in Fig. 2 are based on the amount of water applied prior to each harvest. The amount of water applied did not entirely correspond with the consumptive use data obtained by Erie et al. (26). For example, consumptive use generally reaches a maximum between June and July in Arizona (26). Since the June harvest yielded less forage than the May harvest

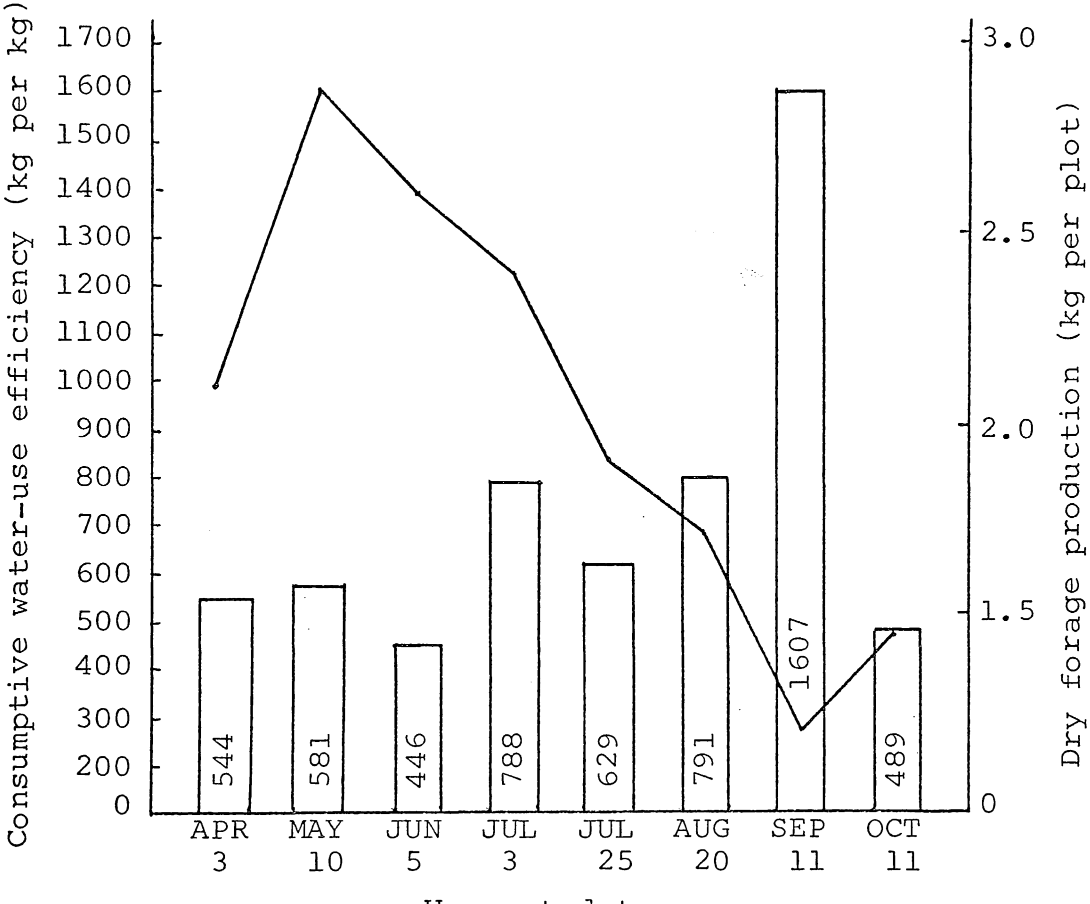

Fig. 2. Average consumptive water-use efficiency and dry forage production (kg per plot) at eight harvests of four alfalfa cultivars grown under three irrigation regimes in 1969.

(Fig. 2), the June harvest should have been less efficient. However, because more irrigations were applied under the three moisture-regimes prior to the May harvest, this harvest was less efficient. The September harvest was the least efficient for the 1969 season. Four irrigations, two under the high regime and one each under the medium and low regimes, were applied after the August 20 harvest and before the September 11 harvest (Table 2). These irrigations calculated with the lowest forage yield for all harvests made the September harvest the least efficient. Conversely, the October harvest yielded only .23 kg of forage per plot more than the September harvest but was the second most efficient harvest with a value of 489. This occurred because no irrigations were applied after September. When harvested in October, the plants were using moisture supplied to the soil prior to the September harvest.

The moisture remaining in the upper 91.4 cm of soil was measured after each harvest in 1969. However, this represented only approximately one-third of the plant root zone. Also, this did not account for the deep percolation losses incurred under the high irrigation regime.

Forage Yield

Cultivar forage yields averaged over moisture regimes were significantly different in 1968 (Table 4). These means ranked in a similar order as those for

Table 4. Average forage production (kg per plot) of four alfalfa cultivars grown under three irrigation regimes in 1968 and 1969.

1968				
	Irrigation Regimes			
Cultivars	Low	Medium	High	Means
El-Unico	2.54*	2.58	2.38	2.50 a‡
Mesa-Sirsa	2.51	2.41	2.46	2.46 ab
Sonora	2.45	2.45	2.36	2.42 ab
Moapa	2.38	2.41	2.30	2.36 b
Means	2.47 a‡	2.46 a	2.38 b	

1969				
	Irrigation Regimes			
Cultivars	Low	Medium	High	Means
El-Unico	2.09+	2.00	2.09	2.06 a‡
Moapa	2.00	2.04	2.09	2.04 a
Mesa-Sirsa	2.00	1.95	2.04	2.00 a
Sonora	2.00	2.00	2.00	2.00 a
Means	2.02 a‡	2.00 a	2.06 a	

*Within table comparisons for 1968 the LSD at .05 level equals 0.18.

+Within table comparisons for 1969 the LSD at .05 level equals 0.15.

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

consumptive water-use efficiency in 1968 (Table 3). Yield had a direct effect on water efficiency as reported by Singh et al. (56). Plants grown under the low and medium moisture-regimes in 1968 yielded significantly more forage than plants under the high soil-moisture regime (Table 4).

The interaction, cultivar by moisture regime, was not significant in 1968 or 1969. The interaction, moisture regime by harvest, was significant during the 1969 season but not in 1968.

Forage production per harvest averaged over cultivars ranged from 3.50 kg per plot (June 29) to 1.69 kg per plot (Dec. 7) in 1968 (Table 5). Forage production rose sharply from the first harvest in April, reached a peak in June, and then declined steadily.

The average forage production per harvest in 1969 followed much the same pattern as in 1968. Harvests were significantly different. The highest yield occurred in May with the four cultivars averaging 2.86 kg of dry forage per plot (Table 5).

In 1968 the cultivars did not react the same at each harvest. There was a significant cultivar by harvest interaction. An interaction occurred among cultivars between the April 25 and July 22 harvests. Moapa produced more forage per plot at the April 25 harvest than at the July 22 harvest. Moapa yielded 2.32 kg and 2.56 kg of forage per plot at the April and July harvests, respectively. The other three

Table 5. Average forage production (kg per plot) of four alfalfa cultivars at eight harvests in 1968 and 1969.

1968

Cultivars	Harvests 4/25	5/28	6/29	7/22	8/19	9/14	10/19	12/7	Means
El-Unico	2.81*	3.60	3.57	2.37	2.09	1.89	1.92	1.76	2.50 a‡
Mesa-Sirsa	2.86	3.36	3.45	2.54	2.18	1.82	1.82	1.68	2.45 ab
Sonora	2.59	3.36	3.45	2.32	2.13	1.86	1.91	1.73	2.42 ab
Moapa	2.32	3.14	3.52	2.56	2.16	1.79	1.78	1.62	2.36 b
Means	2.65 c‡	3.36 b	3.50 a	2.44 d	2.15 e	1.84 f	1.85 f	1.69 g	

1969

Cultivars	Harvests 4/3	5/10	6/5	7/3	7/25	8/20	9/11	10/11	Means
El-Unico	2.18+	2.96	2.54	2.50	1.82	1.73	1.23	1.50	2.06 a‡
Moapa	2.09	2.81	2.59	2.45	2.04	1.73	1.18	1.41	2.04 a
Mesa-Sirsa	2.22	2.91	2.45	2.41	1.77	1.68	1.18	1.45	2.00 a
Sonora	2.09	2.77	2.45	2.32	1.91	1.73	1.23	1.41	2.00 a
Means	2.15 d‡	2.86 a	2.51 b	2.42 c	1.89 e	1.72 f	1.21 h	1.44 g	

*Within table comparisons for 1968 the LSD at .05 level equals 0.51.

+Within table comparisons for 1969 the LSD at .05 level equals 0.25.

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

cultivars produced higher yields in April than in July (Table 5).

The cultivars ranked in a similar order at the eight harvests in 1969. This was verified by the non-significant interaction, cultivar by harvest.

A 17% reduction in total forage production occurred from 1968 to 1969. This was evident for cultivars under all moisture regimes. Temperature did not appear to be a factor associated with yield reduction. Average monthly maximum and minimum temperatures were similar for the 2 years (Table 6).

Stand Decline

Irrigation regimes had no effect on stand decline nor did cultivars differ significantly in stand density. Plant numbers declined substantially between 1968 and 1969 when averaged over moisture regimes and cultivars. The average stand density dropped 62% at the end of the first growing season and 82% after the second season. This reduction in plant density affected forage production during the 1969 season.

In December, 1967, two months after planting, the average number of plants per 0.0929 m^2 was 31.2. Fourteen months later in February, 1969, the stand had declined to 11.9 plants per 0.0929 m^2. Two years later in December, 1969, the stand density had dropped to 5.6 plants per

Table 6. Average monthly maximum and minimum temperatures recorded at the Plant Materials Center, Tucson, Arizona, in 1968 and 1969.

	Maximum		Minimum	
Months	1968	1969	1968	1969
January	65	67	38	41
February	71	65	46	39
March	72	69	45	39
April	80	85	48	47
May	92	95	54	58
June	103	100	64	63
July	100	100	72	74
August	96	101	69	73
September	98	98	65	66
October	91	84	52	49
November	73	72	43	45
December	64	66	32	38
Means	84	83	52	53

0.0929 m^2. Plant numbers declined 53% from February, 1969, to December, 1969. A similar trend in stand decline was reported by Schonhorst et al. (52) on alfalfa grown in Mesa, Arizona.

Percentage Protein

Soil moisture-regimes did not significantly affect percentage protein in 1969. Jensen et al. (36) and others (27, 69) found protein percentage of alfalfa increased as soil moisture was reduced. Plants under the low moisture-regime in this study were not stressed severely enough to significantly increase protein percentage.

Cultivars were not significantly different in protein percentage within moisture regimes when averaged across harvests (Table 7). However, Moapa averaged highest in protein under the three soil-moisture regimes. Both Mesa-Sirsa and El-Unico showed a decrease in percentage protein with an increase in available soil-moisture. Percentage protein values for Moapa were similar for the low, medium, and high moisture-levels. Sonora showed a slight increase in protein percentage under the high moisture-regime.

Alfalfa plants harvested on May 10 and July 25 yielded significantly less protein on a whole plant basis when averaged over cultivars and moisture regimes. A non-significant interaction, cultivar by harvest, indicated

Table 7. Percentage protein at eight harvests of four alfalfa cultivars grown under three irrigation regimes in 1969.

Irrigation regimes	Cultivars	Harvest dates 4/3	5/10	6/5	7/3	7/25	8/20	9/11	10/11	Means
Low	Moapa	23.5*	18.4	23.9	26.8	24.5	24.4	27.9	25.5	24.3 a+
	Sonora	26.4	18.1	27.2	24.0	18.6	22.8	26.7	23.7	23.4 a
	Mesa-Sirsa	24.8	15.5	25.2	24.2	22.3	22.8	28.7	24.2	23.5 a
	El-Unico	25.2	18.9	26.7	24.7	20.0	23.0	28.8	28.6	24.5 a
	Means	25.0	17.7	24.2	24.9	21.4	23.3	28.0	25.5	
Medium	Moapa	29.1	19.1	26.5	26.4	16.0	23.9	27.1	27.6	24.5 a
	Sonora	24.0	16.4	27.6	27.5	18.2	23.8	25.5	26.0	23.6 a
	Mesa-Sirsa	25.3	14.2	27.2	25.2	18.6	25.3	27.4	24.1	23.5 a
	El-Unico	26.5	11.7	25.8	24.0	17.9	24.8	28.3	23.1	22.8 a
	Means	26.2	15.4	26.8	25.8	17.7	24.5	27.1	25.2	
High	Moapa	26.2	16.4	27.0	30.4	13.7	24.6	27.7	28.7	24.3 a
	Sonora	24.7	15.2	28.2	28.3	18.1	25.5	28.8	24.5	24.2 a
	Mesa-Sirsa	24.2	12.8	25.9	24.2	16.7	23.1	26.6	20.2	21.7 a
	El-Unico	26.2	14.6	25.5	23.7	16.4	26.6	28.2	21.8	22.9 a
	Means	25.3	14.8	26.7	26.7	16.2	25.0	27.8	23.8	
	Harvest Means	25.5 a+	16.0 b	25.9 a	25.8 a	18.4 b	24.3 a	27.6 a	24.8 a	

*Within table comparisons the LSD at .05 level equals 6.1.

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

that the four cultivars ranked in approximately the same order at each harvest.

Mesa-Sirsa, Moapa, Sonora, and El-Unico contained 22.8, 24.4, 23.7, and 23.4% protein, respectively, when percentage protein was averaged over moisture regimes and harvests (Fig. 3). Protein production per plot was calculated with yield data from Table 4 and the average protein percentages for cultivars. Moapa produced the most protein per plot (Fig. 3). Moapa was the second highest forage producer in 1969 (Table 4) and was highest in percentage protein when whole plants were analyzed. El-Unico produced more protein per plot than Sonora (Fig. 3). Whole plants of El-Unico contained less protein than Sonora; however, El-Unico produced proportionately more forage per plot than Sonora. Forage yield was an important factor in protein production as observed by others (21).

Leaf to Stem Ratio

Mesa-Sirsa, Moapa, Sonora, and El-Unico were not significantly different in leafiness of forage when averaged over the entire 1969 growing season. However, Moapa had the highest leaf to stem ratio for all cultivars under each of the three soil-moisture regimes (Table 8). The leaf to stem ratios for El-Unico, Mesa-Sirsa, and Sonora averaged over harvests and moisture levels were 6.6, 6.1, and 2.4% below Moapa, respectively. Moapa produced a

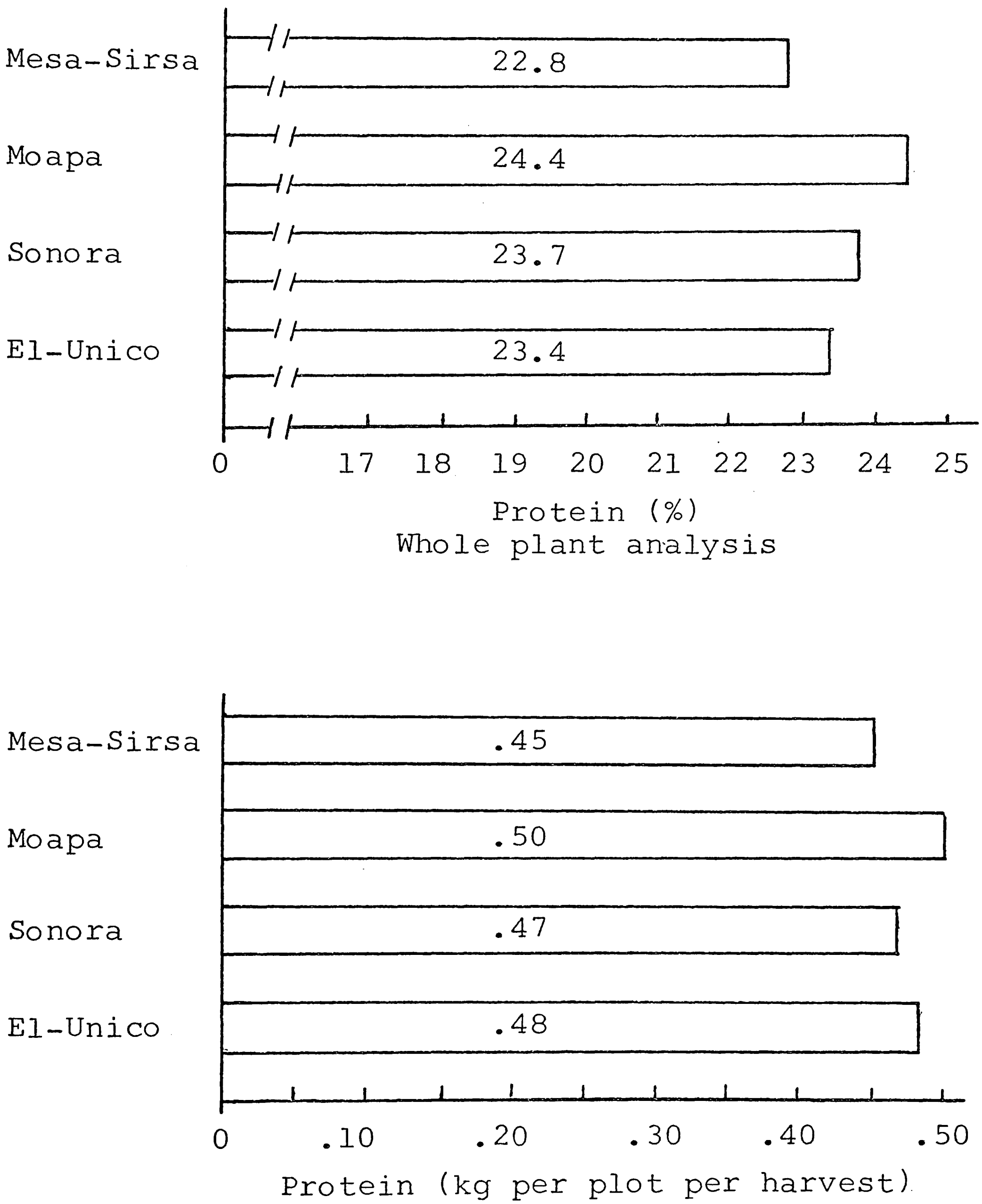

Fig. 3. Average percentage protein of whole plant and protein production of four alfalfa cultivars in 1969.

Table 8. Average leaf to stem ratios at eight harvests of four alfalfa cultivars grown under three irrigation regimes in 1969.

Irrigation regimes	Cultivars	Harvest dates 4/3	5/10	6/5	7/3	7/25	8/20	9/11	10/11	Means
Low	Moapa	1.51:1*	.77:1	.73:1	.68:1	.62:1	.72:1	.92:1	.99:1	.87:1 a+
	Sonora	1.37:1	.79:1	.64:1	.69:1	.53:1	.68:1	.93:1	1.02:1	.83:1 a
	Mesa-Sirsa	1.26:1	.68:1	.66:1	.56:1	.64:1	.84:1	.88:1	.94:1	.81:1 a
	El-Unico	1.08:1	.59:1	.69:1	.55:1	.65:1	.80:1	.83:1	.96:1	.77:1 a
	Means	1.31:1 a	.71:1 de	.68:1 ef	.62:1 f	.61:1 f	.76:1 d	.89:1 c	.98:1 b	
Medium	Moapa	1.30:1	.69:1	.75:1	.54:1	.59:1	.76:1	.93:1	1.00:1	.82:1 a
	Sonora	1.07:1	.74:1	.68:1	.66:1	.59:1	.75:1	.88:1	1.08:1	.81:1 a
	Mesa-Sirsa	1.16:1	.66:1	.65:1	.66:1	.66:1	.76:1	.89:1	.96:1	.80:1 a
	El-Unico	1.03:1	.57:1	.63:1	.69:1	.74:1	.75:1	.92:1	1.00:1	.79:1 a
	Means	1.14:1 a	.67:1 e	.68:1 e	.64:1 e	.65:1 e	.76:1 d	.91:1 c	1.01:1 b	
High	Moapa	1.13:1	.72:1	.73:1	.59:1	.62:1	.80:1	.92:1	1.02:1	.82:1 a
	Sonora	1.08:1	.57:1	.71:1	.70:1	.62:1	.74:1	.92:1	1.12:1	.81:1 a
	Mesa-Sirsa	.98:1	.62:1	.68:1	.64:1	.56:1	.68:1	.83:1	.98:1	.75:1 a
	El-Unico	1.07:1	.49:1	.70:1	.60:1	.72:1	.80:1	.91:1	.98:1	.78:1 a
	Means	1.07:1 a+	.60:1 d	.71:1 c	.63:1 d	.63:1 d	.76:1 c	.90:1 b	1.03:1 a	

*Within table comparisons the LSD at .05 level equals 0.13.

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

slightly leafier forage with no sacrifice in yield since cultivars did not differ significantly in forage production in 1969 (Table 4). Cultivars did not rank the same in leaf to stem ratio at all harvests. There was a significant cultivar by harvest interaction.

Plants grown under the low and medium regimes had higher average leaf to stem ratios than plants grown under the high soil-moisture regime. Longnecker and Lyerly (43) also found that alfalfa plants grown under the low irrigation regime had a higher leaf to stem ratio. However, differences in leaf to stem ratio among moisture regimes were not significant in this study. The low soil moisture regime did not produce enough moisture stress to significantly increase the leaf to stem ratio.

Leaf to stem ratio means for moisture regimes did not necessarily rank the same at each harvest when averaged over cultivars. This change in leaf to stem ratio was emphasized by the significant moisture regime by harvest interaction.

The leaf to stem ratio and dry forage production averaged over cultivars and moisture regimes for each harvest in 1969 are shown in Fig. 4. The alfalfa plants had more leaves per unit of dry matter at the first and last harvests and more stems during the period of peak forage production.

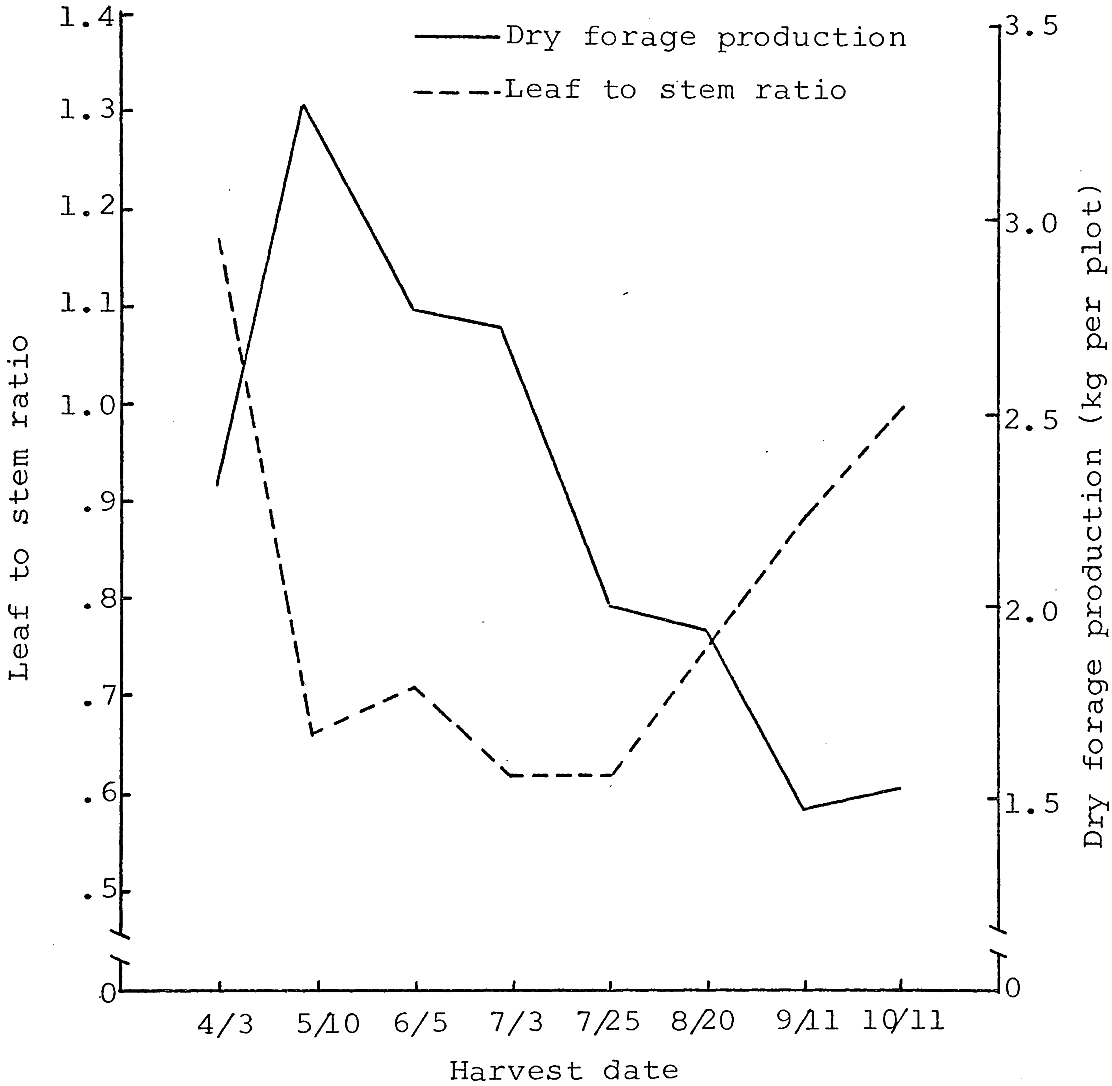

Fig. 4. Average leaf to stem ratio and dry forage production of four alfalfa cultivars grown under three irrigation regimes in 1969.

The average leaf to stem ratio dropped sharply from the April to the May harvests, remained low through July and increased with the fall harvests (Fig. 4). Reference to temperature data for 1969 (Table 6) showed that the average leaf to stem ratio was generally highest during the coolest months and lowest when temperatures were high. Temperature influenced the leaf to stem ratio of alfalfa. The trend in leaf to stem ratio and forage production as shown in Fig. 4 was similar to results obtained from alfalfa studies conducted in Mesa, Arizona (21).

Percentage Dry Matter

Plants irrigated infrequently during the 1968 and 1969 growing seasons were significantly higher in percentage dry matter than plants grown under the medium and high soil-moisture regimes. The interaction, cultivar by moisture regime, was significant which indicated that the cultivars did not maintain the same rank in dry matter percentage under the three irrigation regimes.

Percentage dry matter of the alfalfa forage was significantly different among harvests in 1968 when averaged over cultivars and moisture regimes (Table 9). Harvest means ranged from 21.5% for the December 7 harvest to 14.7% for the July 22 harvest. Forage produced at the July harvest in 1969 (Table 10) was also among the lowest in percentage dry matter for that season. The interactions,

Table 9. Percentage dry matter at eight harvests of four alfalfa cultivars grown under three irrigation regimes in 1968.

Irrigation regimes	Cultivars	Harvest dates 4/25	5/28	6/29	7/22	8/19	9/14	10/19	12/7	Means
Low	Moapa	20.9*	22.9	21.7	16.0	17.9	18.7	19.5	22.2	20.0 ab+
	Sonora	21.1	22.6	21.4	14.4	17.8	19.0	19.0	21.9	19.7 b
	Mesa-Sirsa	20.9	23.7	20.6	18.1	18.4	19.0	19.0	22.2	20.3 a
	El-Unico	20.4	23.6	20.4	14.2	17.0	18.0	19.0	21.4	19.3 c
	Means	20.8	23.2	21.0	15.7	17.8	18.7	19.1	21.9	
Medium	Moapa	20.4	19.3	20.3	15.2	18.0	18.4	19.1	21.5	19.0 a
	Sonora	19.6	19.7	20.4	14.1	17.4	18.4	19.0	21.1	18.7 a
	Mesa-Sirsa	19.3	17.7	19.0	14.3	17.7	17.2	18.8	21.8	18.2 b
	El-Unico	18.9	19.8	19.9	14.4	17.4	17.7	19.2	21.5	18.7 a
	Means	19.6	19.1	19.9	14.5	17.6	18.0	19.0	21.5	
High	Moapa	19.5	20.2	19.2	14.1	18.4	19.2	19.3	21.6	18.9 a
	Sonora	19.4	20.1	18.9	14.0	18.2	19.0	19.6	22.1	18.9 a
	Mesa-Sirsa	19.1	19.2	18.5	13.8	18.4	18.8	18.9	20.3	18.3 b
	El-Unico	19.0	18.8	19.1	13.5	18.7	19.2	19.6	20.6	18.5 b
	Means	19.3	19.6	18.9	13.9	18.4	19.1	19.4	21.2	
	Harvest means	19.9 c+	20.6 b	19.9 c	14.7 g	17.9 f	18.6 e	19.2 d	21.5 a	

*Within table comparisons the LSD at .05 level equals 1.2.

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

Table 10. Percentage dry matter at eight harvests of four alfalfa cultivars grown under three irrigation regimes in 1969.

Irrigation regimes	Cultivars	Harvest dates 4/3	5/10	6/5	7/3	7/25	8/20	9/11	10/11	Means
Low	Moapa	20.1*	19.9	18.3	18.3	18.0	17.9	16.8	20.0	18.7 a+
	Sonora	21.0	19.9	19.0	17.8	17.6	18.2	16.9	19.5	18.8 a
	Mesa-Sirsa	19.0	19.3	17.7	17.3	16.6	18.3	16.3	19.2	18.0 b
	El-Unico	18.4	19.1	17.5	17.8	16.6	18.4	16.0	19.4	17.9 b
	Means	19.6	19.6	18.1	17.8	17.2	18.2	16.5	19.5	
Medium	Moapa	18.3	20.3	17.2	17.8	17.2	19.2	16.9	19.4	18.3 a
	Sonora	18.1	20.0	17.4	17.9	17.0	18.0	17.1	19.4	18.1 a
	Mesa-Sirsa	16.1	19.4	16.3	17.3	15.8	17.9	16.0	19.1	17.2 b
	El-Unico	16.9	19.2	16.6	17.2	16.1	18.2	16.4	19.1	17.5 b
	Means	17.4	19.7	16.9	17.6	16.5	18.3	16.6	19.3	
High	Moapa	18.7	19.4	17.1	17.7	17.0	18.0	16.6	19.4	18.0 ab
	Sonora	19.1	19.7	16.7	17.8	16.6	19.4	16.8	19.3	18.2 a
	Mesa-Sirsa	17.8	18.6	15.8	16.9	16.6	19.1	15.7	17.5	17.2 c
	El-Unico	17.4	19.6	16.7	18.2	16.6	19.3	16.0	18.7	17.8 b
	Means	18.3	19.3	16.6	17.7	16.7	19.0	16.3	18.7	
	Harvest means	18.4 c+	19.5 a	17.2 e	17.7 d	16.8 f	18.5 c	16.5 g	19.2 b	

*Within table comparisons the LSD at .05 level equals 0.9.

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

cultivar by harvest and irrigation by harvest, were significant for both growing seasons.

In 1969 the cultivars Moapa and Sonora were significantly higher in percentage dry matter than Mesa-Sirsa and El-Unico. The interaction, cultivar by moisture regime, was significant (Table 10). Although the cultivars ranked the same under the low and medium soil-moisture regimes, they ranked in a different order under the high regime. Harvest values averaged over cultivars and moisture regimes were significantly different in 1968 and 1969.

SUMMARY

An alfalfa field study was conducted at the Soil Conservation Service Plant Materials Center at Tucson, Arizona, in 1968 and 1969. The purpose of the study was to determine the effect of three irrigation regimes on the consumptive water-use efficiency, forage production, stand decline, percentage protein, leaf to stem ratio, and percentage dry matter of four alfalfa cultivars. The cultivars were Moapa, Mesa-Sirsa, Sonora, and El-Unico.

Significant differences in consumptive water-use efficiency were found among cultivars in 1968 but not in 1969. The cultivar El-Unico was the most efficient in water-use in both years. Plants grown under the low soil-moisture regime were the most efficient in water-use while plants grown under the high moisture-regime were the least efficient. Differences in consumptive water-use efficiency among moisture regimes were due mainly to differences in irrigation efficiency. Irrigation efficiency was higher on the low and medium soil-moisture regimes than on the high regime. Consumptive water-use efficiency varied considerably among harvests. In 1969 plants harvested in June were the most efficient while the least efficient harvest occurred in September.

Forage production was signfificantly different among cultivars in 1968. El-Unico produced the most forage during both growing seasons; however, in 1969 differences in forage production among cultivars was not significant. Plants grown under the high soil-moisture regime in 1968 produced significantly less forage than plants under the low and medium regimes. Moisture regimes did not affect forage production in 1969. Forage yields varied significantly among harvests. Highest yields were attained at the June harvest in 1968 while the most forage was produced at the May harvest in 1969.

Moisture regimes did not affect stand decline and no differences were found among cultivars in stand density. Plant numbers averaged over moisture regimes and cultivars dropped from 31.5 to 5.6 plants per 0.0929 m^2 from December, 1967, to December, 1969. This represented a plant reduction of 82% over the 2-year period.

Moisture regimes had no significant effect on either percentage protein or leaf to stem ratio. The low soil-moisture regime did not induce enough moisture stress to significantly increase percentage protein or leaf to stem ratio of the plants. Significant differences in percentage protein and leaf to stem ratio were not found among cultivars. However, Moapa had the highest leaf to stem ratio and protein percentage. Moapa also produced the most protein per plot.

Plants grown under the low soil-moisture regime were significantly higher in percentage dry matter during 1968 and 1969. The cultivars Moapa and Sonora were signficantly higher in percentage dry matter than Mesa-Sirsa and El-Unico in 1969. Cultivars did not differ significantly in percentage dry matter during 1968.

Alfalfa cultivars with the highest forage production were the most efficient in water-use under field conditions. Water was wasted when more was applied than that amount removed from the plant root zone by evapotranspiration. This illustrated the importance of operating irrigation systems at maximum efficiency. Relatively small increases in consumptive water-use efficiency were achieved through more efficient cultivars. These small increases in water efficiency would be nullified if the plants were grown under an inefficient irrigation system.

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