EVALUATION OF THE POTENTIAL TO IMPROVE ALFALFA FOR PRODUCTION UNDER LESS THAN OPTIMUM MOISTURE CONDITIONS

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ABSTRACT

The use of alfalfa was explored as a means of conserving New Mexico's supplies of fresh water. Alfalfa is grown on approximately one-fifth of New Mexico's irrigated acreage. Competition for water has been increasing. The rising cost of energy has also led to increased concern over the use of fresh water supplies for agricultural production. Plant breeding procedures were used to increase alfalfa's yield potential when given limited quantities of irrigation. The purpose was to increase alfalfa's ability to survive and grow under less than optimum irrigation and to increase its ability to respond to irrigation and/or rainfall when available. Field, greenhouse, and laboratory experiments were conducted to find techniques that would: identify germplasm sources for these traits; evaluate and identify individual genotypes within these sources; evaluate the potential of the techniques and the new populations developed; and evaluate irrigation management techniques that would maximize the yield potential of the selected populations with less than optimum amounts of irrigation. Germplasm sources, selection techniques, elite genotypes, and irrigation management techniques were developed. The result is that water conservation is feasible with alfalfa with little sacrifice in yield potential. The selected populations produced more forage than unselected populations when given the same amount of water. The advantage of the selected populations was greatest at the lower levels of irrigation. Alfalfa appeared to have a greater response to water applied early in the growing season than late. The combination of selected populations and irrigation management allows for maximum water conservation with alfalfa.

Key words: drought, plant breeding, selection, irrigation, forage, management

JUSTIFICATION

Water

Water is the most limiting factor to crop production in the world (CAST Report No. 95). The lack of rainfall, inconsistent surface water supplies, depletion of aquifers, increasing energy costs for pumping, competition for available surface and ground water from industry and urban users, and water-limiting legislation have forced a reevaluation of cultivar selection and irrigation management schemes for modern crop production. Current economic situations demand a reevaluation of the maximum yield with maximum input philosophy as contrasted to one of production with fewer inputs with a minimum effect on crop productivity. Irrigation is necessary to obtain the high production levels required for agricultural survival under existing economic constraints. Cultivars capable of high production with less water and/or improved irrigation management would reduce energy requirements for pump irrigation. Energy savings for alfalfa as compared to row crops have been shown to be significant due to the perennial nature of alfalfa. A small reduction in the amount of water required for irrigation of alfalfa would be a significant savings in water and energy costs.

Urban sprawl and industrialization are also making increasing demands on available water, especially high quality water. One important way to conserve water resources is to utilize crop plant cultivars and irrigation management methods that will make lesser demands on irrigation water supplies and derive the maximum benefit from the water applied.

In an arid climate where evaporation claims over 90 inches of water per year while rainfall averages 12.2 inches per year, it is easy to see that water deficits can be a widespread problem in the Southwest. Many areas rely on runoff from other regions to supply surface waters or to recharge underground aquifers. All of New Mexico's 1,452,230 irrigated acres must rely on irrigation for the production of agricultural crops (Gerhardt and Hand 1985). It has been determined that over 95 percent of the water available for use in New Mexico is either used for agriculture or lost to evaporation. It is the goal of most agriculturalists to at least maintain production levels while conserving the inputs necessary for production. Any reduction of water use in agriculture would result in a significant savings of water for use by other resources in New Mexico. Enabling growers to maintain yield levels with less water would reduce direct costs for use and/or pumping and increase net profit. All inhabitants in New Mexico should directly or indirectly benefit from water savings in agriculture.

Alfalfa

Alfalfa is the primary perennial forage crop grown under irrigation in Arizona and New Mexico (Brantner 1985, Gerhardt and Hand 1985) as well as in most arid and semi-arid agricultural regions throughout the world (Barnes and Schaeffer 1976). Among all forage crops, alfalfa consistently has the highest livestock feeding value, primarily because of its high protein and mineral contents. Alfalfa easily produces forage dry matter yields approaching 10 tons per acre per year (Brantner 1985). Alfalfa is a valuable crop in diversified agricultural ecosystems not only because of the high value of the harvested crop, but also due to the soil building function it performs during crop rotations (Staten et al. 1945). Alfalfa fits well into many crop rotation schemes. Primarily because of a long growing season, alfalfa yields in the Southwest are among the highest in the nation.

Alfalfa occupies approximately 250,000 acres in New Mexico and is the most important cash crop (Gerhardt and Hand 1985). The quoted cash values do not reflect income derived from livestock industries dependent upon the availability of alfalfa as a feedstuff. Adequate supplies of forage are necessary to maintain New Mexico's beef and dairy cattle industry. Alfalfa, beef cattle, and dairy cattle rank third, second, and first in terms of total cash receipts in New Mexico (Gerhardt and Hand 1985). If water availability limits alfalfa production in the state, these industries will also suffer. Reduced production would influence employment, consumer prices of foodstuffs, and income to the state.

Recent research has expanded alfalfa's potential benefits. Stahmann (1968) has consistently demonstrated that on an acre basis, alfalfa is far superior to any crop for protein production. Workers at the Western Utilization Laboratory have developed procedures to extract purified protein from alfalfa for human consumption (Bickoff and Kohler 1972). Heichel (1976) demonstrated that alfalfa is the most efficient user of energy in terms of energy produced versus energy consumed in production. Alfalfa produced 350 grams of protein per unit of cultural energy, whereas wheat, oats, corn and sorghum were only about one-third as efficient.

Water Use by Alfalfa

Irrigated alfalfa hay acreage in New Mexico increased significantly each year from about 1930 to the 1980's (from less than 80,000 acres to over 250,000 acres). Further expansion has been minimal because of the limited availability of irrigation water. In some areas, acreage reduction has been necessary to obtain enough water to produce economic yields. New Mexico's average alfalfa yield is about one-half the yield obtained in experimental plots. Cultivars and irrigation management schemes better suited to what is now considered to be less than optimum moisture should help to expand the alfalfa acreage or increase forage yields in areas where the amount of water for irrigation limits optimum crop production. Alfalfa with the capability of economic levels of production with less than optimum moisture may fit into several situations. Low prices for grain crops and high hay prices have forced a reevaluation of alfalfa as a dryland crop. Based on the present farm economic situation, the dryland and/or limited-irrigation alfalfa acreage could be expanded into the wheat and sorghum growing areas, and into permanent-pasture lands. This expansion could apply to eastern and northeastern New Mexico, Texas, Colorado, and Oklahoma. This expansion would benefit producers by providing another cash crop, a nearby source of winter feed, and winter pasture for livestock. It also would allow development of improved crop rotation sequences, and improve soil conservation. In 1976, in the San Jon, New Mexico area, dryland alfalfa forage yields ranged from 1.5 to over 2.0 tons per acre, plus a seed crop averaging 100 to 150 pounds per acre (Gunnels 1976). The gross value of this crop would be approximately equivalent to a 60-80 bushel wheat crop in an area that averaged 15 and 25 bushels per acre in 1984 and 1985, respectively (Gerhardt and Hand 1985). Alfalfa does not require annual soil preparation and planting required by annual crops.

Further interest has been expressed in the need for a drought tolerant legume for use in rangelands (Aamodt 1952). Approximately 200 million acres in the western United States would fall into this category. It has been considered that a legume would increase production by direct contribution of forage as well as furnish nitrogen for the increased production of the grasses present (Aamodt 1952).

Alfalfa uses more water per acre per year than any other agronomic crop in the Southwest. Alfalfa requires approximately 750 to 900 pounds of water to produce a pound of dry plant material (Bolton 1962, Bula and Massengale 1972). Hanson (1967) and Lehman et al. (1968) have shown yield increases with water application rates up to 94 acre inches if stand losses do not occur. However, many research reports have commented on the drought resistance of alfalfa (Aamodt 1952, Bolton 1962, Bula and Massengale 1972, Carter 1964, Kneebone 1959, Melton et al. 1966). These conflicting conclusions point out the apparent flexibility present in alfalfa. Alfalfa responds to adequate soil moisture, but also has the capacity to persist and grow under limited moisture conditions.

Breeding Alfalfa for Production Under Less Than Optimum Moisture Conditions

Alfalfa is the number one cash crop in New Mexico and is grown on a larger acreage than any other irrigated crop (Berger and Losleben 1980). Any decrease in the amount of water used for alfalfa production would produce a considerable savings of water. Recently, Wilson et al. (1981), Salter (1980), and Baltensperger et al. (1981), in a plant breeding program, demonstrated the potential to improve the productivity of alfalfa with less than optimum moisture, and have developed several improved plant populations. This demonstrated behavior in alfalfa illustrates the possibilities of genetic manipulation to develop cultivars that will perform better than others under conditions of moisture stress. In the past, alfalfa breeders have directed their efforts toward maximizing production under high-input management systems. This philosophy has encouraged the development of cultivars capable of utilizing large quantities of environmental resources, including water.

Drought tolerance in alfalfa is apparently due to its ability to produce an extensive root system; to harden and become semi-dormant during periods of moisture stress; to grow rapidly during periods when moisture is available; and to continue growth as soil moisture gradually becomes more limiting (Carter 1964, Cowett and Sprague 1962, Younis et al. 1963). In general, research toward improving productivity with less water or drought tolerance, by manipulating the various characteristics, has not been very successful.

Clearly, given the increased scarcity of water in the Southwest, there is a need to develop alfalfa cultivars that are able to remain productive under conditions of less than optimum water availability. Ideally, these cultivars would be as productive as currently available cultivars but would require less total irrigation water, thereby increasing overall production efficiency.

Water requirement or water-use efficiency, has been shown to vary among alfalfa cultivars, but larger differences have been found among plants within cultivars (Dobrenz et al. 1969). These differences are indicative of genetic variability for these traits that should allow crop improvement through selection and plant breeding. It has been found that the more productive plants are the most efficient users of water (Dobrenz et al. 1969, Kramer 1969). However, this does not mean they use less water. Kramer (1969) stated that the most promising way to increase water-use efficiency was to encourage production of dry matter rather than to decrease water use. Burton (1959) said that as productivity is increased through breeding or cultural practices on a given amount of water, the water-use efficiency is also increased. Thus drought tolerance in this situation may be more appropriately termed 'drought productivity.' This term refers to a plant that is able to survive and produce a greater amount of dry matter than another plant when grown under less than optimum moisture conditions.

Water requirements of plants are conditioned by inherent genetic qualities and the environmental factors to which they are exposed (Kneebone 1959). It has been found that plant productivity is proportional to water availability (Bolton 1962, Bula and Massengale 1972, Dobrenz et al. 1969, Hanson

1967, Kneebone 1959). This finding has usually discouraged research into less than optimum situations. However, due to the perennial nature of alfalfa, its ability to survive droughts, and to grow rapidly when soil moisture is available, alfalfa appears ideally suited for development of drought productivity in an economically important crop. Progressive improvement of the ability of alfalfa to be productive with less than optimum moisture will provide a basis for maintaining the monetary returns from alfalfa while conserving water. Existing data suggest that the perfect alfalfa cultivar is a long way in the future, but is obviously possible.

Alfalfa breeding is a relatively new field especially in the area of breeding for water use characteristics. Basic breeding behavioral information is lacking for these characteristics. Procedures that furnish a basis of evaluation for improving alfalfa's water use and yield relationships would remove some fallacies and wasted effort in these types of breeding programs. Theoretical expectations must always be verified in field performance tests. The accumulation of this type of information is a contribution to knowledge in itself, and should lead to the development of superior source material and new cultivars necessary to meet the producer's needs for cultivars that will respond to his particular water environment.

New Mexico is in an unusual situation. Because of its very southern location, high elevations, and its diversity of irrigation environments, alfalfa developed in other geographical areas seldom are well adapted in New Mexico (Melton et al. 1966). This emphasizes that cultivar development for New Mexico is best accomplished in New Mexico. This is further confounded by significant changes in alfalfa culture and water availability in the state. Alfalfa was previously regarded as a rotational crop with long time periods between the planting of alfalfa on a given field. Alfalfa is now a primary crop in some areas with fields being continuously cropped to alfalfa, with large areas containing only alfalfa, and the alternate crops being grown for a short period (if any) between plantings of alfalfa. Due to increasing water conservation efforts, irrigation is changing from flood to sprinkler to more efficiently utilize this precious resource.

Irrigation Management for Alfalfa

Because of economic constraints, many growers choose to reduce the amount of irrigation water applied to alfalfa during peak demand periods. The scheduling of irrigations in alfalfa is often imprecise, which may result in dessication during the latter portion of the irrigation cycle. These practices may place the plant under severe stress and lead to lower yields, decreased forage quality and overall stand decline. Data upon which to base practical irrigation management decisions are severely lacking in New Mexico. No data whatsoever are available upon which to base decisions concerning management of deficit levels of irrigation. However, observations made during previous research suggest that significant gains could be made through irrigation management.

The development of alfalfa germplasm with increased performance under deficient levels of irrigation provides a unique opportunity to match plant populations to specific irrigation management schemes for maximum productivity, water conservation, and water-use efficiency. The correct combination of improved plant population and management of deficient levels of irrigation should provide stability and protection of the forage/animal industry in New Mexico.

Usefulness of Irrigation Management Research

The results of plant breeding and irrigation management research will provide three important pieces of information relative to water savings and alfalfa production:

1) The results of the evaluation of selected alfalfa populations under various irrigation management regimes will aid the plant breeder in isolating the populations best suited for production in limiting and non-limiting moisture environments. If the level of production can be maintained with less water, water will be saved for other needs.

2) The results of irrigation management will provide forage crop producers with information that will aid in determining how to apply limitied supplies of water available for the growing season and subsequent seasons.

3) The combined results of all experiments will allow agronomists to recommend a package concept to the alfalfa grower. The package would include a cultivar that would be suited to a specific irrigation regime that is best adapted to the water limitations faced by the farmer.

Essentially no research has been conducted with alfalfa to evaluate the potential of developing alfalfa for production under less than optimum levels of irrigation or moisture. The purpose of the following experiments was to evaluate alfalfa for its production potential under less than optimum irrigation conditions and to determine forage yield levels that could be expected. Furthermore, methods of study and the techniques developed in this research should be applicable to other crops.

Finally, the combination of cultivar selection and irrigation management should provide for the highest level of forage production possible with the most limiting production input, water.

OBJECTIVES

The major objectives of the research conducted over the past seven years were:

1. To determine production levels that can be expected under limited irrigation conditions;
2. To determine if genetic variability exists for performance under limited irrigation conditions at four locations in New Mexico;
3. To establish laboratory, greenhouse, and field screening techniques that would be useful for screening large plant populations in order to identify genotypes that are more productive under less than optimum irrigation conditions;
4. To evaluate selected populations and individual plant progenies for forage production potential under less than optimum irrigation conditions; and
5. To determine the effects of timing and amount of flood applied irrigation on forage yield of alfalfa populations selected for increased performance under deficient levels of irrigation.

GENERAL FIELD TESTING METHODOLOGIES FOR ALL OBJECTIVES

The field irrigation experiments were conducted at the Leyendecker Plant Science Research Center, Las Cruces; the Agricultural Science Center at Artesia; and the Agricultural Science Center at Tucumcari. The dryland experiments were conducted at the Agricultural Science Center at Tucumcari and on private land near San Jon, New Mexico.

The experimental designs used were randomized complete block with four replications. The various irrigation levels were separated by earthen borders and fallowed land. Each irrigation level was replicated twice. Alfalfa cultivars and germplasms were replicated twice within each irrigation level. Plot areas were bordered by seven rows of alfalfa. Systematically arranged check plots of the cultivar 'Mesilla' were planted in alternate plots to facilitate statistical analyses. The irrigation levels ranged from a low of 16 inches to a high of 80 inches of water applied per season with adjustments made for rainfall. The earliest application of water was mid-February and the latest was early November (table 1). The water was applied in four-inch increments through gated aluminum pipe and measured with in-line flow meters.

Smaller plots containing the alfalfa cultivars and germplasms were planted within the limits of the earthen borders of each irrigation level. The plot dimensions were 3 by 5 feet or 3 by 10 feet and consisted of three rows with a one foot row spacing. The cultivars were chosen for these experiments based on their past performance in optimal irrigation experiments, their adaptation to the area, or their reported drought tolerance.

The experiments were fall planted in September or spring planted in March at a seeding rate of 20 pounds per acre. The fields received fertilizer (phosphorus) and herbicide (benefin) applications to aid alfalfa establishment. In all cases except for the dryland experiments, the alfalfa seedings were irrigated approximately three times to aid establishment. Irrigation levels were then imposed upon the experiments. The lowest irrigation levels (16-20 inches) would receive one irrigation prior to each harvest. The intermediate irrigation levels (40-48 inches) would receive two irrigations at two-week intervals prior to each harvest. The highest irrigation levels (60-80 inches) received three or four irrigations before the first harvest, two or three prior to each harvest, and two or three following the final harvest (table 1).

Forage yield was obtained by harvesting all aboveground plant material when plants in the highest irrigation level reached one-tenth bloom stage. Plants were cut with a sickle-bar mower at a stem height of two inches. Green weights were obtained immediately. Grab samples were taken for each irrigation level, weighed, dried in a forced-air drier for at least 72 hours at 60^{o}C, and reweighed to calculate percent dry matter in the forage. Results were expressed in units of tons of dry matter produced per acre for a one growing season time period.

Statistical analyses consisted of regression analyses to adjust individual plot yields within each irrigation border based on the performance of systematically arranged plots planted to a standard cultivar, Mesilla. The adjusted plot values were then analyzed by analysis of variance procedures. The least significant difference (LSD) was calculated to determine significant yield differences among irrigation levels or cultivars and germplasms.

Table 1. Typical irrigation schedule for field experiments using three irrigation levels, Las Cruces.

Date	Irrigation level-inches*		
	20	40	60
March 7			X
March 26		X	X
April 9	X	X	X
April 23			X
May 2	Harvest one		
May 9	X	X	X
May 23		X	X
June 7	Harvest two		
June 12	X	X	X
June 28		X	X
July 8	Harvest three		
July 15	X	X	X
July 29		X	X
August 12	Harvest four		
August 23	X	X	X
August 26		X	X
September 10			X
October 3	Harvest five		
October 15			X
November 1			X

X = 4 acre inches
*Rainfall was subtracted from subsequent irrigations.

RESULTS

Objective 1

The number of different water environments that exist in New Mexico and the Southwest are many and varied. To evaluate the performance of alfalfa under less than optimum moisture one must choose one or more levels of irrigation in order to define the environment. Originally 16, 48, and 80 inches of irrigation were chosen and were later changed to 20, 40, and 60 inches. These irrigation levels were chosen to produce high, intermediate, and low levels of moisture stress in field-grown alfalfa.

The average yields given in table 2 show the relative production levels that might be expected from application of these irrigation levels including rainfall. Water use efficiencies (WUE) were calculated as a measure of the efficiency of the applied irrigation in producing forage dry matter yield (table 2). It is proper to compare the yields and WUE within one location, but not between locations. There were many factors such as different cultivars, soil types, years, and rainfall amounts that were not controlled between locations.

The results show that the yields produced at the 16-20 inch levels were typically lower yielding than the 40-48 and 60-80 inch irrigation levels. There were no significant differences between the yields produced at the 40-48 and 60-80 inch irrigation levels. The yields produced with 16-20 inches of water ranged from 1.9 to 4.5 tons of dry matter per acre with a mean of 3.1 tons per acre. The yields produced in this irrigation level show a great deal of variability, which is probably due to the responsiveness of the alfalfa to the timeliness and amount of rainfall received during the growing season. The yields produced with 40-48 and 60-80 inches of water ranged from

4.3 to 6.1 tons per acre and 4.8 to 6.3 tons per acre with means of 5.5 and 5.8 tons per acre, respectively.

The WUE in the irrigation levels was highest at the 16-20 and 40-48 inch irrigation levels. On the average, the 16-20 inch irrigation level had the highest WUE producing 1.6 pounds of dry matter per 1000 pounds of water. The 60-80 inch irrigation level consistently had the lowest WUE, producing 0.77 pounds of dry matter per 1000 pounds of water. It was concluded that forage yield increase per unit of water applied is high, up to 40-48 inch, but declines beyond that point at least at the Las Cruces and Artesia locations. The Tucumcari location had lower yields and WUE due to a shorter growing season. Forage yield and WUE at this location was highest with 38 inches of water.

Sammis (1981) showed that alfalfa yield is a linear function of evapotranspiration. He also stated that in many studies yield did not proportionately increase with applied water because all water was not beneficially used by the crop; some became deep drainage water. In these studies it appears that yield does not increase proportionately with water application rates greater than 40-48 inches. These results indicate that an approximate maximum of 40 to 48 inches of water was adequate for approaching a maximum yield of alfalfa under the conditions of these experiments. Forage yields typically increased proportionately when water was increased from 16-20 to 40-48 inches, but only increased slightly when water was increased from 40-48 to 60-80 inches.

Water use efficiency was highest at 16-20 inches due to the yield produced relative to the small amount of water applied. Apparently a majority of the water was used by the plant with a minimum amount of water lost to drainage and evaporation. With 40-48 inches of water, water use efficiency decreased due to a decrease in yield relative to the increase in water applied. The drop in WUE indicates that some water was lost and not utilized by the plant for increased growth. With 60-80 inches of applied irrigation WUE decreases to its lowest value, indicating a considerable waste of water.

These results indicate that alfalfa may be a useful crop in situations where water savings are essential. It also indicates that irrigation rates for alfalfa above 40-48 inches may be in excess of what alfalfa can use, at least under the conditions of these experiments. Water management information would be useful to determine when irrigation should be applied and in what amounts to obtain the highest WUE from alfalfa.

Table 2. Forage yield and water use efficiency (WUE) of alfalfa produced at several locations and irrigation levels.

Test	Location	Irrigation level (inches)			L.S.D.(0.05)
1	Las Cruces (1978-80)				
		16	48	80	L.S.D.
	Yield *	1.9	6.1	6.3	3.0
	WUE **	1.09	1.17	0.73	
2	Artesia (1979-81)				
		16	48	80	L.S.D.
	Yield	4.5	6.1	6.1	ns
	WUE	2.59	1.17	0.70	
3	Las Cruces (1980-82)				
		20	40	60	L.S.D.
	Yield	2.2	5.3	6.0	2.7
	WUE	1.01	1.22	0.92	
4	Las Cruces (1984-85)				
		20	40	60	L.S.D.
	Yield	3.7	4.3	4.8	ns
	WUE	1.71	1.00	0.73	
5	Tucumcari (1984-85)				
		38	51		L.S.D.
	Yield	3.1	3.0		ns
	WUE	0.75	0.54		
Mean (Tests 1-4)		16-20	40-48	60-80	
	Yield	3.1	5.5	5.8	
	WUE	1.60	1.14	0.77	

* Yields are in tons of dry matter produced per acre.
** WUE are in pounds of dry matter produced per 1000 lbs of water.

Objective 2

Many cultivars and germplasms (entries) were tested at four locations and at several irrigation levels to thoroughly survey the performance of a broad genetic background in many water environments. A listing of cultivar and germplasm names, date of release, and originator are presented in table 3. A listing of those entries that produced the highest dry matter yields are presented in table 4. Several entries produced high forage yield at all irrigation levels. Other entries produced high forage yield in one or two of the irrigation levels. A complete listing of all entries and their forage yield are given in tables 5-11.

Farmers faced with choosing a cultivar may use this information to determine which entries had the highest yield in a water environment most similar to his own. Plant researchers may also use this information to choose cultivars for other types of research or for choosing cultivars or germplasms for development of more productive populations.

Of interest to the plant breeder is the entry C.V. This statistic was calculated as an estimate of genetic variability among the entries in the water environments. The entry C.V.'s varied more among experiments than among irrigation levels within one experiment (tables 5-9). Entry C.V.'s ranged from 10.9 to 52.0 percent, which means that the standard deviation of entry yield was 11 to 52 percent as large as the mean entry yield. This amount of variability is encouraging to the plant breeder who is interested in finding entries with higher yields in the various irrigation environments.

Table 3. Cultivar and germplasm names, date of release*, and originator* for entries evaluated in field irrigation experiments.

Name	Date of release	Originator
Apollo	1976	North American Plant Breeders
Baron	1981	North American Plant Breeders
Blazer	1979	Land O'Lakes, Inc.; Union Seed Co.
C-3	1975	USDA-ARS; Colorado State University
Carrizozo	----	Collected in New Mexico
Cimmaron	1978	Great Plains Research Co., Inc.
Cimmaron Hardy	----	Collected in New Mexico
Classic	1978	Farmers Forage Research Co-op
Cody	1959	Kansas AES; USDA-ARS, SEA
CUF101	1976	California AES; USDA-ARS
Dawson	1967	Nebraska AES; USDA-ARS
Dobrenz	----	Collected in Arizona
Dona Ana	1983	New Mexico AES
Dry Cimmaron	----	Collected in New Mexico
Dryland	----	Collected in New Mexico
El Unico	1973	Arizona AES; USDA-ARS, SEA
Epic	1979	Land O'Lakes, Inc.
Expo	1982	North American Plant Breeders
Florida 77	1980	Florida AES; USDA-ARS, SEA
G7730	1981	Funks Seed Int., Inc.; North American Plant Breeders
Hi-Phy	1978	Farmers Forage Research Co-op
Ladak 65	1966	Montana AES
Lahontan	1954	California, Nevada AES; USDA-ARS, SEA
MAN-5	1982	New Mexico AES
Mesilla	1969	New Mexico AES
Moapa 69	1971	Calfiornia, Nevada AES; USDA-ARS, SEA
MPH-3	----	New Mexico AES
NAPB-53	----	North American Plant Breeders
NC83-1	1973	(Pt. Intro. Sta.; Ames, Iowa)
NC83-2	1973	(Pt. Intro. Sta.; Ames, Iowa)
N.M. 36-1	----	New Mexico AES
N.M. Common	----	Collected in New Mexico
Nomad	unknown	E. F. Burlingham & Sons Seed Co.
Olympic	1976	North American Plant Breeders
Pike	1982	Northrup, King & Co., Inc.
Ranger	1940	Nebraska AES; USDA-ARS, SEA
Resistador II	1975	Northrup, King & Co., Inc.
Rhizoma	1948	University of British Columbia
Rincon	1975	New Mexico AES
Salt Lake City	----	Collected in Utah
Sandelin	----	Collected in New Mexico
San Jon Dawson	----	Collected in New Mexico
Thor	1971	Northrup, King & Co., Inc.
Turkistan	1898	Introduction; USDA-ARS, SEA
Turkistan Wild	----	Foreigh collection, location unknown
Utterback	----	Collected in New Mexico
Vangard	1976	North American Plant Breeders
Vernal	1953	Wisconsin AES; USDA-ARS, SEA

Table 3. (continued) Cultivar and germplasm names, date of release*, and originator* for entries evaluated in field irrigation experiments.

Name	Date of release	Originator
WL306	1970	Waterman-Loomis Research, Inc.
WL311	1975	" " " "
WL312	1978	" " " "
WL313	1979	" " " "
WL318	1975	" " " "
Zia	1957	New Mexico AES
Zia 81	1986	New Mexico AES

*Miller and Melton (1983).

Table 4. List of cultivar and germplasm names that produced high forage dry matter yields in various moisture environments at several locations. (Names are listed alphabetically).

Location (years)	Irrigation level-inches		
Las Cruces (1978-80)	16	48	80
	Lahontan Mesilla San Jon Dawson Turkistan Zia	Lahontan Mesilla NC83-2 Vangard Zia	Lahontan Vangard Zia
Artesia (1979-81)	16	48	80
	Dry Cimmaron Mesilla Vangard Vernal Zia	Dry Cimmaron Mesilla NC83-2 San Jon Dawson Turkistan	Cimmaron Hardy Dry Cimmaron Lahontan Mesilla NC83-1 NC83-2 Vangard
Las Cruces (1980-82)	20	40	60
	El Unico NC83-2 San Jon Dawson WL306 WL312	El Unico Mesilla Zia	El Unico Mesilla NC83-2 Ranger WL312 Zia
Las Cruces (1984-85)	20	40	60
	Baron Cimarron Florida 77 Mesilla Pike Zia	Baron Cimarron CUF 101 Florida 77 Mesilla Rincon Zia	Baron Cimarron Florida 77 Pike Rincon Zia
Tucumcari (1984-85)	Limited (38)	Full (51)	
	Expo Hi-Phy Mesilla WL313 WL318	Epic San Jon Dawson WL311 WL313 WL318 Zia 81	

Table 4. (continued) List of the cultivar and germplasm names that produced the high forage dry matter yields in various moisture environments at several locations. Names are listed alphabetically.

Location (years)	Irrigation level
Tucumcari - dryland (1981-85)	
Dobrenz	
Mesilla	
NC83-2	
San Jon Dawson	
Zia	
San Jon - dryland (1979-81)	
C-3	
NAPB-53	
Olympic	
WL306	

Table 5. Forage yield of alfalfa cultivars and germplasms at three irrigation levels, Las Cruces, 1978-80.

Entry	Irrigation level (inches)		
	16	48	80
	tons/A/year		
C-3	1.7	5.8	5.9
Carrizozo	1.3	5.0	4.5
Cimmaron Hardy	2.1	6.2	6.7
Dawson	2.1	5.3	6.1
Dry Cimmaron	2.1	5.5	6.3
Dryland	1.7	6.2	6.0
Lahontan	2.2	7.4	8.1
Mesilla	2.2	7.0	7.0
NAPB-53	1.3	5.5	5.8
NC83-1	1.9	6.5	6.6
NC83-2	2.1	7.3	6.9
Nomad	1.5	4.4	4.6
Olympic	2.0	6.8	6.6
Ranger	1.8	6.1	6.4
Rhizoma	1.5	5.4	5.4
Salt Lake City	2.1	6.5	6.7
Sandelin	1.7	5.6	6.0
San Jon Dawson	2.5	6.7	6.3
Turkistan	2.3	5.9	6.6
Turkistan Wild	1.0	4.2	4.8
Utterback	2.1	6.5	6.5
Vangard	2.0	7.0	7.9
Vernal	1.6	5.9	5.6
Zia	2.2	7.1	8.2
Mean	1.9	6.1	6.3
L.S.D. (0.05)	0.4	0.8	0.7
Entry C.V. (%)	33.5	24.5	26.4

Table 6. Forage yield of alfalfa cultivars and germplasms at three irrigation levels, Artesia, 1979-81.

Entry	Irrigation level (inches) 16	48	80
	---tons/A/year---		
C-3	4.6	6.0	6.0
Carrizozo	3.9	5.6	5.7
Cimmaron Hardy	4.7	5.9	6.4
Dawson	4.7	6.2	6.2
Dry Cimmaron	4.8	6.6	6.5
Dryland	4.5	6.1	5.8
Lahontan	4.7	6.0	6.4
Mesilla	5.2	6.4	6.4
NAPB-53	4.1	5.5	5.4
NC83-1	4.6	6.3	6.7
NC83-2	4.5	6.4	6.7
Ranger	4.5	6.3	6.3
Rhizoma	3.9	5.6	6.1
Sandelin	4.1	5.9	5.7
San Jon Dawson	4.6	6.5	6.2
Turkistan	4.7	6.5	6.1
Turkistan Wild	3.5	5.1	5.3
Utterback	4.6	6.3	6.2
Vangard	5.0	6.3	6.4
Vernal	4.8	6.1	6.0
Zia	5.2	6.3	6.2
Mean	4.5	6.1	6.1
L.S.D. (0.05)	0.5	0.4	0.5
Entry C.V. (%)	16.6	11.0	10.9

Table 7. Forage yield of alfalfa cultivars and germplasms at three irrigation levels, Las Cruces, 1980-82.

Entry	Irrigation level (inches) 20	40	60
	----------tons/A/year----------		
C-3	1.8	4.5	4.6
Cody	1.9	5.2	5.7
Dawson	2.0	5.3	5.8
El Unico	4.0	6.8	7.6
Mesilla	2.0	6.0	6.1
NC83-2	2.4	5.7	7.1
Ranger	1.6	5.0	6.1
San Jon Dawson	2.1	5.0	5.4
Vernal	1.5	3.9	4.3
WL306	2.5	4.8	5.5
WL312	2.4	5.0	6.7
Zia	2.0	6.9	6.7
Mean	2.2	5.3	6.0
L.S.D. (0.05)	0.7	1.0	0.8
Entry C.V. (%)	52.0	28.3	27.8

Table 8. Forage yield of alfalfa cultivars at three irrigation levels, Las Cruces, 1984-85.

Entry	Irrigation level (inches) 20	40	60
	-----------------	tons/A/year	-----------------
Baron	9.4	11.0	11.8
Cimmaron	9.1	10.5	11.6
CUF101	8.6	10.5	10.9
Dawson	8.6	9.9	10.2
Dona Ana	8.1	9.8	10.1
El Unico	8.3	10.1	11.3
Florida 77	10.0	11.1	12.2
G7730	7.5	8.8	10.4
Hi-Phy	8.4	9.9	11.1
Ladak 65	5.0	6.6	6.5
Mesilla	9.0	10.3	10.4
Moapa 69	8.3	8.7	9.2
Pike	9.3	10.0	11.5
Rincon	8.5	10.4	12.2
Thor	7.9	8.9	10.0
Vernal	6.2	8.0	8.9
WL312	8.1	9.5	11.3
Zia	9.8	10.8	12.0
Mean	8.3	9.7	10.7
L.S.D. (0.05)	1.1	0.9	0.9
Entry C.V. (%)	20.7	16.9	18.9

Table 9. Forage yield of alfalfa cultivars and germplasms at two irrigation levels, Tucumcari, 1984-85.

Entry	Irrigation level (inches) limited (38)	full (51)
	------tons/A/year------	
Apollo	3.0	3.0
Baron	2.3	2.6
Blazer	2.2	2.5
Classic	3.1	2.1
Epic	2.9	3.3
Expo	3.4	3.0
Hi-Phy	4.2	2.8
MAN-5	1.6	2.4
Mesilla	3.6	2.8
Resistador II	3.3	2.5
San Jon Dawson	3.3	3.4
Vangard	2.5	2.7
WL311	3.3	3.9
WL313	4.1	3.3
WL318	4.0	3.5
Zia 81	2.8	4.0
Mean	3.1	3.0
L.S.D. (0.05)	0.9	0.9
Entry C.V. (%)	33.2	25.5

Table 10. Forage yield of alfalfa cultivars and germplasms grown under dryland conditions, Tucumcari, 1981-85.

Entry	Five-year avg. yield
	tons/A/year
Cody	0.51
Dobrenz	0.57
Lahontan	0.55
Mesilla	0.62
NC83-2	0.57
Ranger	0.45
San Jon Dawson	0.58
Vangard	0.50
WL306	0.56
Zia	0.64
Mean	0.55
L.S.D. (0.05)	0.08
Entry C.V. (%)	25.7

Five year average precipitation (per year) 17.36 inches.

Table 11. Forage yield of alfalfa cultivars and germplasms grown under dryland conditions, San Jon, 1979-81.

Entry	Three-year Avg. yield
	tons/A/year
C-3	1.03
Carrizozo	0.60
Dawson	0.80
Dry Cimarron	0.87
Dryland	0.87
Lahontan	0.83
Mesilla	0.67
MPH-3	0.67
NAPB-53	0.97
NC83-1	0.80
NC83-2	0.77
NM36-1	0.67
N.M. Common	0.83
Olympic	0.93
Ranger	0.77
Rhizoma	0.80
Salt Lake City	0.80
Sandelin	0.80
San Jon Dawson	0.83
Vangard	0.73
Vernal	0.80
WL306	0.90
WL312	1.07
Zia	0.80
Mean	0.82
L.S.D. (0.05)	0.18
Entry C.V. (%)	24.4

Median rainfall in this area is 14.94 inches per year.

Objective 3

The objective was to develop laboratory, greenhouse, and field screening techniques that would identify genotypes with higher forage yield under less than optimum moisture conditions. Eleven screening techniques were developed and evaluated. Seven of these techniques were discontinued due to the inability of the technique to effectively detect differences among genotypes. However, four of the techniques were able to produce a differential response among the genotypes. The techniques were called the PEG test, the Field Capacity Test in Pots, the Field Capacity Test in Boxes, and the Field Stress Test.

The populations produced by these techniques produced a forage yield increase relative to the check cultivar Mesilla of -6 to 15 percent in field forage progeny tests (table 12). These results indicate that these techniques are capable of identifying genotypes whose progeny have higher performance under less than optimum irrigation. A brief description of the four techniques follow.

PEG Test. Small 11 milliliter test tubes were filled to capacity with a designated concentration of polyethylene glycol (PEG) solution and set 4 inches apart in a wooden rack. The PEG solution has varied from 6 to 100 grams of PEG 6000 per liter of distilled water. Alfalfa stems cut from field-grown plants in a vegetative growth stage were placed into containers of water for transport to the lab. In the lab, the base of each stem was laid on a board immersed in water and cut with a razor blade 10 cm below the terminal bud. Three cut stems from one plant were placed in separate test tubes containing the PEG solution. Florescent and incandescent lights were used to illuminate the stems and ensure that plant stomata remained open. A fan was used to circulate the air around the stems. The stems were left in the solution for 4 hours before they were scored on a one to five basis. A completely turgid stem with turgid leaves was scored as a one and progressively more wilted stems were scored as a two, three, four, or five. A stem scored as a five had wilted leaves and a limp stem. The final wilting score was determined for each individual plant by averaging the scores of the stems from a single plant. Plants with average scores less than 1.5 were selected.

Field Capacity Test in Pots. Three moisture regimes were based on estimates of 100 percent field capacity. These pots were watered when visual symptoms of wilting became apparent. Pots in the 100 percent field capacity regime were watered in excess of field capacity. Drainage water was collected and subtracted from the total amount of water applied. The difference was the amount required to bring the pot to 100 percent field capacity. The 40 and 60 percent field capacity regimes were watered at the same time with 40 and 60 percent of the amount of water required to bring the 100 percent field capacity pots to field capacity, respectively. Each seven-inch plastic pot contained four individually marked alfalfa plants. All plants were harvested when blooms appeared in the 100 percent field capacity treatment. The forage from each individual plant was cut, placed in a paper envelope, and thoroughly dried. After three to five harvests, the total amount of forage produced was weighed. The highest yielding plants in the 40 and 60 percent field capacity regimes were selected.

Field Capacity Test in Boxes. Nine wooden boxes measuring 10 feet in length, five feet in width, and two feet deep were used to increase rooting depth. A heavy layer of plastic was used to line the sides of the boxes and a layer was tacked underneath each box for collecting and measuring drainage water. The boxes were placed under a shadehouse with a translucent fiberglass roof. The boxes were filled with sandy loam soil underlain with one inch of gravel to facilitate drainage. Twelve to 14 rows were planted in each box with one border row along the sides and ends. The boxes were watered, harvested, and selection made as previously described for the Field Capacity Test in Pots.

Field Stress Test. This test used large field plots. The plant material was seeded in rows. The rows were spaced one or two feet apart. A seeding rate of 20 pounds per acre was used. The field plot was irrigated three times at two-week intervals to aid establishment. No further irrigations were applied. The plants were cultivated under severe moisture stress conditions for a period of one to three years before selections were made. A plant was selected if it was producing more growth than its neighboring plants. The color and the amount of topgrowth was also considered.

Table 12. Relative forage dry matter yield of alfalfa populations developed by four selection techniques and evaluated at two levels of less than optimum irrigation, Las Cruces, 1982-84.

Technique	Irrigation level (inches) 20	40
	-----relative yield (%)*-----	
PEG Test	94	115
Field Capacity Test in Pots	106	115
Field Capacity Test in Boxes	107	112
Field Stress Test	113	115

*Yield is relative to the best currently available cultivar in New Mexico, Mesilla.

Objective 4

General. To date, 43 populations have been developed with the objective of increasing the forage yield of alfalfa when grown with less than optimum levels of irrigation. The pedigrees of these populations are summarized in table 13. To evaluate the effectiveness of the selection techniques and the productiveness of the selected populations, the populations were field tested using methods described previously in this report. All of these populations were developed using phenotypic recurrent selection. The populations represent four selection techniques and one, two, or three cycles of selection.

The highest forage producing populations in the various irrigation levels are listed (table 14). The actual forage dry matter yields produced by these populations in each experiment appear in tables 15-19.

A genotypic recurrent selection program was begun in 1982. A 500-plant "mother plant" nursery was established and the individual plants were evaluated for seed yield potential. Thirty-one of these mother plants were evaluated further by testing the performance of their progeny in a limited irrigation field trial. This experiment followed similar methods as those mentioned previously, except that this trial had only one irrigation level of approximately 20 inches. The results for the progeny and the origin of each mother plant are presented (table 20).

In the alfalfa breeding program, a general rule of thumb is that: "a population or progeny must exceed the yield of the best currently available cultivar by at least 10 percent over a three year period before the population or progeny will be considered useful for further selection or for development and release as a cultivar."

Populations. All populations listed in table 14 have been tested for three-years and exceed the yield of 'Mesilla' by at least 10 percent. These populations warrant further selection, further study, and the most productive of these, Zia 81 and 9D11A, were released as a germplasm and a cultivar ('Wilson'), respectively.

Progenies. The progenies of individual mother plants are used to evaluate the genotype of each mother plant. Mother plants with the highest yielding progenies will be selected and crossed as 4 to 6 clone synthetics to produce synthetic cultivars for testing and eventual release as a cultivar for production with less than optimum levels of irrigation.

A four-clone synthetic crossing block has been planted and the seed will be evaluated in future field tests. Genotypic recurrent selection offers the advantage of knowing the field performance of each potential parent before they are used in crosses.

Table 13. Pedigrees of selected populations developed for production with less than optimum moisture, Las Cruces.

Population designation	Selection technique	Origin
9FC1	Field capacity-pots	C-3, Zia, Dawson, Carrizozo, Mesilla, NAPB-53, San Jon Dawson
9FC2	Field capacity-pots	Dawson, Zia, Ranger, Vangard, NAPB-53, Carrizozo, Vernal, Mesilla
9FC3	Field capacity-pots	San Jon Dawson, Carrizozo, C-3, Dawson, Mesilla, Zia, Vangard
9FC4	Field capacity-pots	Zia, C-3, NAPB-53, Carrizozo, Ranger, Dawson, Vernal, Mesilla, Vangard, San Jon Dawson
9S5	Field stress	Mesilla, NC83-2, Zia, Liberty, Utterback, Oklahoma Common, San Jon Dawson, Lahontan, Baker, Cody, Turkistan, Pilca Butta
9W6	Wilt	San Jon Dawson, Ranger, Carrizozo, Mesilla, C-3, Dawson, Vernal
9S7	Field Stress	Zia, NC83-2
9FC8	Field capacity-pots	Zia, C-3
9B9	Field capacity-pots Field stress	Zia Zia
9C10	Field capacity-pots Field stress Wilt	Mesilla Mesilla, San Jon Dawson, NC83-2 San Jon Dawson
9D11A	Field stress	Zia, Mesilla, Turkistan, Baker, NC83-2
9PEG11	PEG	Zia, C-3, Mesilla, San Jon Dawson, Dry Cimarron, Sandelin, Dawson, Lahontan, NC83-1, Utterback, Rhizoma, Turkistan Wild, NAPB-53, Salt Lake City
9PEGS12	PEG	Zia, Mesilla, Liberty, NC83-2, Utterback, Oklahoma Common, San Jon Dawson, Turkistan
9PEG13	PEG	Mesilla

Table 13. (continued) Pedigrees of selected populations developed for production with less than optimum moisture, Las Cruces.

Population designation	Selection technique	Origin
7W17	Wilt	Unknown
7FC18	Field capacity-pots	WL309, Zia, Vernal, Mesilla, Dawson, Dunning
0FC19	Drought box	Baker, Cimmaron, Cody, Dawson, NC83-2, San Jon Dawson, Vangard, Zia
0FC20	Drought box	Baker, Cimmaron, Cody, Dawson, NC83-2, San Jon Dawson, Vangard, Zia
0FC21	Drought box	Baker, C-3, Cimmaron, Cody, Dawson, Mesilla, NC83-2, San Jon Dawson, Vangard, Zia
0SGP24	Field stress	Zia
0S25	Field stress	Cody, Turkistan, Oklahoma Common, Utterback, Zia, San Jon Dawson, Pilca Butta, Mesilla, Liberty, NC83-2, Sandelin, Lahontan, Baker
0FC26	Field capacity-pots	9FC1, 9FC2, 9FC3, 9FC4, 7FC18
0PEG28	PEG	9PEG13
1S32 (Zia 81)	Field stress	Zia
1FC33	Drought box	0FC21
1FC34	Drought box	0FC20
1FC36	Drought box	9FC1, 9FC2, 9FC3, 9FC4, 9FC8, 7FC18, 0FC19, 0FC20, 0FC21
2FC37	Drought box	1FC33, 1FC34
3S38	Field stress	9S5, 9D11A
3M39	Field stress	9FC1, 9FC2, 9FC4, 9W6, 9FC8, 9B9, 9C10, 9PEG11, 9PEG12, 9PEG13, 7W17, 7FC18
SCST81	Field stress	Open-pollinated seed from 1981 field stress test

Table 13. (continued) Pedigrees of selected populations developed for production with less than optimum moisture, Las Cruces.

Population designation	Selection technique	Origin
3S40	Field stress	Zia, 9S5, 9S7, 9B9, 9C10, 9D11A, 9PEG12, 0SGP24, 0S25
3S41	Field stress	Unknown
3PEG42	PEG	ØPEG28
3FC43	Drought box	1FC36

Table 14. Lists of the highest yielding alfalfa populations selected for increased yield under less than optimum irrigation and evaluated under different irrigation levels and dryland conditions.

Location (years)	Irrigation level (inches)		
Las Cruces (1980-82)	20	40	60
	9S5	9FC4	9FC1
	9C10	9S5	9FC2
	9D11A	9FC8	9S5
		9D11A	9D11A
		9PEG11	
Las Cruces (1982-84)	20	40	
	9D11A	9FC8	
	0FC20	1FC33	
	1FC33		
	Zia 81		
Las Cruces (1984-86)	20	40	60
	3S38	9D11A	9D11A
	3M39	1FC33	1FC34
	Zia 81	2FC37	3M39
		Zia 81	Zia 81
		SCST81	
Las Cruces (1985-86)	Less Than Optimum Irrigation*		
	1FC33		
	2FC37		
	3M39		
	3S40		
	3S41		
	Zia 81		
Tucumcari (1984-85)	Dryland**		
	9D11A		
	1FC33		
	1FC34		

* This test received approximately 20 inches of irrigation and rainfall combined during the growing season in 1984 and again in 1985.

**This test received approximately 21 inches of rainfall in 1984 and 1985 for the complete year.

Table 15. Forage dry matter yield of alfalfa populations selected for increased yield with less than optimum levels of irrigation and evaluated under three irrigation levels, Las Cruces, 1980-82.

Population	Irrigation level (inches)		
	20	40	60
	-------tons/acre/year-------		
9FC1	2.1	6.5	7.4
9FC2	2.4	6.4	7.9
9FC4	2.2	6.9	6.7
9S5	2.9	7.0	7.4
9W6	2.1	6.0	6.1
9FC8	2.3	7.0	7.0
9B9	2.4	6.5	7.2
9C10	2.8	6.1	6.6
9D11A	3.5	6.8	8.2
9PEG11	2.6	7.3	6.6
9PEG12	2.3	5.3	5.5
9PEG13	2.7	6.3	6.8
7W17	2.0	5.2	6.4
7FC18	2.1	5.1	6.8
Mesilla	2.0	6.0	6.1
Mean	2.4	6.4	6.9
L.S.D. (0.05)	0.5	0.7	0.8
Population C.V. (%)	30.0	17.6	15.7

Table 16. Forage dry matter yield of alfalfa populations selected for increased yield with less than optimum levels of irrigation and evaluated under two irrigation levels, Las Cruces, 1982-84.

Population	Irrigation level (inches) 20	40
	-----ton/acre/year----	
9FC8	3.9	8.0
9D11A	4.9	7.2
9PEG13	3.3	7.4
0FC20	4.0	6.2
0FC21	3.6	7.3
0SGP24	3.7	7.5
0FC26	3.9	6.8
0PEG28	3.7	7.4
1FC33	4.3	8.3
1FC34	3.9	7.1
Zia 81	4.1	7.6
Mesilla	3.5	7.3
Mean	3.9	7.3
L.S.D. (0.05)	ns	1.0
Population C.V. (%)	18.7	12.9

Table 17. Forage dry matter yield of alfalfa populations selected for increased yield with less than optimum levels of irrigation and evaluated under three irrigation levels, Las Cruces, 1984-86.

Population	Irrigation level (inches)		
	20	40	60
	-------tons/acre/year---------		
9S5	6.1	8.6	7.6
9FC8	6.6	9.7	8.9
9D11A	6.3	10.7	10.0
9PEG13	6.5	8.6	9.0
OSGP24	6.7	9.4	8.6
1FC33	6.2	10.0	8.5
1FC34	6.6	9.5	9.1
1FC36	6.4	9.8	9.0
2FC37	6.6	10.1	8.7
3S38	6.8	9.8	8.7
3M39	7.3	9.8	9.3
Zia 81	7.4	10.2	9.9
SCST81	6.7	10.6	9.0
Mesilla	6.0	8.5	7.6
Mean	6.6	9.7	8.8
L.S.D. (0.05)	0.6	0.7	1.1
Population C.V. (%)	11.0	12.4	13.9

Table 18. Forage dry matter yield of alfalfa populations selected for higher yield with less than optimum levels of irrigation and evaluated under one level of less than optimum level of irrigation, Las Cruces, 1985-86.

Population	Yield
	tons/acre/year
1FC33	8.6
1FC36	8.1
2FC37	9.0
3S38	8.4
3M39	8.7
3S40	9.1
3S41	8.7
3PEG42	7.6
3FC43	8.4
Zia 81	9.4
NM Drought Bulk	7.1
Dona Ana	8.5
Mean	8.5
L.S.D. (0.05)	1.0
Population C.V. (%)	10.6

Approximately 20 inches of moisture was received by the test during the growing season each year, in the form of irrigation or rainfall.

Table 19. Forage dry matter yield of alfalfa populations selected for increased yield with less than optimum levels of irrigation and evaluated under dryland conditions, Tucumcari, 1984-85.

Population	Yield
	tons/acre/year
9D11A	1.02
9PEG13	0.91
OSGP24	0.86
1FC33	1.03
1FC34	1.03
1FC36	0.98
Zia 81	0.96
Tucumcari Dry Bulk	0.94
NM Drought Bulk	0.76
San Jon Dawson	0.88
Zia	0.93
Mesilla	0.95
Mean	0.94
L.S.D. (0.05)	ns
Population C.V. (%)	10.6

This test received approximately 21 inches of rainfall in 1984 and 1985 for the complete year.

Table 20. Forage dry matter yield of single alfalfa plant progenies evaluated, Las Cruces, 1985-86.

Mother plant designation	Origin of mother plant	Forage yield
		tons/acre/year
D102	9D11A-25	7.9
D108	9D11A-26	8.4
D113	C-3	7.6
D152	Cody	9.0
D203	9D11A-8	7.4
D204	9D11A-9	8.3
D209	9D11A-10	8.0
D210	9D11A-11	8.4
D214	9D11A-12	7.1
D216	9D11A-13	6.9
D219	9D11A-3	7.4
D225	9D11A-17	8.2
D226	9D11A-18	8.0
D231	9D11A-19	8.0
D246	San Jon Dawson	8.4
D313	Zia	7.9
D321	Zia	8.3
D323	C-3	8.3
D336	Unknown	8.6
D422	Mesilla	8.6
D450	NC83-2	7.6
D510	Zia	8.3
D518	Unknown	8.9
D530	Zia	8.6
D606	Zia	8.6
D642	Zia	8.0
D704	NC83-2	9.3
D740	Unknown	8.5
D749	Zia	7.5
D837	Unknown	9.2
D851	Mesilla	8.9
Dona Ana (ck)	Mesilla	8.5
Mean		8.2
L.S.D. (0.05)		1.2
Progeny C.V. (%)		10.2

Approximately 20 inches of moisture was received by this test during the growing season each year, in the form of irrigation or rainfall.

Objective 5

Methods Specific to Objective 5. The field-plot methods for this experiment were similar to those for the other objectives. However, one purpose of this experiment was to evaluate the rate and timing of flood applied irrigation. The experimental design consisted of a split-plot with four replications. The main plots were five irrigation levels selected to supply 20, 40, and 60 inches of irrigation annually. The 20 and 40 inch irrigation levels were duplicated in order that the amount of water in each treatment could be either applied early in the growing season or spread evenly over the growing season. The 1984 irrigation treatments were initiated on 21 June 1984 according to the schedule in table 21. The 1985 irrigation treatments followed the schedule shown in table 22. Irrigation was delivered to the plots as previously described. A full set of irrigations and harvests could not be completed in 1984 due to spring establishment of the experiment. However, in 1985 a full set of irrigations was applied.

The genetic material evaluated consisted of 18 alfalfa populations. Thirteen of these populations were developed using a particular screening technique and one or more cycles of phenotypic recurrent selection. Five populations were developed by the field capacity test: one was first, three were second, and one was third cycle. Seven populations were developed by the stress test: four were first and three were second cycle. One first cycle PEG test population was tested. Four check cultivars and one germplasm were included.

Table 21. Irrigation dates, rates, and frequencies applied to 18 alfalfa populations in five irrigation levels at Las Cruces, 1984.

Dates	Irrigation Treatments (inches) 20 early	20 spread	40 early	40 spread	60 spread	Rain-fall
	----------	----------	inches	----------	----------	----------
	Stand Establishment Irrigations					
4/19	4	4	4	4	4	
5/09	4	4	4	4	4	
5/30	4	4	4	4	4	0.08
6/18	Harvest 1					
6/21	4	4	4	4	4	1.06
7/05	-	-	4	4	4	
7/17	Harvest 2					
7/19	-	4	4	4	4	1.97
7/31	-	-	-	4	4	
8/22	Harvest 3					
9/05	-	-	-	4	4	2.36
9/21	-	-	-	-	4	
10/9	Harvest 4					
10/25	-	-	-	-	4	1.22
	Total Irrigation (inches)					Total rainfall
	16	20	24	32	40	6.69
	Total Irrigation + Rainfall (inches)					
	23	27	31	39	47	

Table 22. Irrigation dates, rates, and frequencies applied to 18 alfalfa populations in five irrigation levels at Las Cruces, 1985.

Dates	Irrigation Treatments (inches) 20 early	20 spread	40 early	40 spread	60 spread	Rain-fall
	----------	----------	mm	----------	----------	
3/7	4	4	4	4	4	
3/26	-	-	-	-	4	
4/9	4	-	4	4	4	
4/23	4	-	4	-	4	
5/2	Harvest 1					
5/9	4	4	4	4	4	
5/23	4	-	4	4	4	
6/7	Harvest 2					
6/12	-	4	4	4	4	
6/28	-	-	4	4	4	
7/8	Harvest 3					
7/15	-	4	4	4	4	
7/29	-	-	4	4	4	0.60
8/12	-	-	4	-	4	1.30
8/23	Harvest 4					
8/26	-	4	-	4	4	0.12
9/10	-	-	-	4	4	0.35
10/3	Harvest 5					
10/15	-	-	-	-	3	2.56
	Total Irrigation (inches)					Total rainfall
	20	20	40	40	55	4.93
	Total Irrigation + Rainfall (inches)					
	25	25	45	45	60	

General. The data were analyzed separately for 1984 and 1985 because of the difference in irrigation levels each year. The interaction between the irrigation level and populations was not significant in either year which indicated that all populations had the same relative performance in each irrigaiton level and timing. The lack of an interaction allows a simple interpretation of the irrigation levels and populations.

Irrigation levels. Significant differences were obtained between the early and the spread irrigation timing at the 20 and 40 inch levels in 1984 (table 20). This result was expected in the seeding year. The alfalfa was spring seeded and the production potential of the early irrigation timings were not allowed due to the establishment period. The spread timings had irrigation through the fall growing season for forage production.

The 20 inch irrigation level produced 62 percent as much forage as the 40 inch irrigation level (table 21). The 40 and 60 inch irrigation levels produced similar amounts of forage.

In 1985, (when the full set of irrigations was applied) there were no significant differences between the early and spread timings at either irrigation level. The 20 inch irrigation produced 53 percent as much forage as the 40 inch irrigation level. The 40 and 60 inch irrigation levels produced similar forage yields.

One can conclude that 40 inches of irrigation was close to optimum for maximum alfalfa forage production under the conditions of this experiment. The application of 20 inches produced high levels of moisture stress and reduced forage yield by approximately one half. The 60 inch irrigation level was intended to produce an environment where moisture was not a limiting factor. The timing of application did not affect forage production. One could then consider other economic factors in order to determine when to apply limited supplies of irrigation water.

Populations. The populations chosen for this experiment were the most productive populations from previous field studies. The populations with the high forage yields in both years are of the greatest interest. These populations were 9D11A, 1FC33, 2FC37, 3S38, 3M39, SCST81, and Zia 81 (tables 23 and 24). Two populations, 1FC33 and 2FC37, were developed with the field capacity technique. The remaining populations were developed with the field stress test. The cultivar Zia produced the most forage of the cultivars tested. The seven selected populations averaged 12 percent and the best population was 17 percent higher in forage yield than the check cultivar, Mesilla.

Significant progress has been made in developing alfalfa for performance under less than optimum irrigation. These populations will help to maximize the forage production potential of alfalfa per unit of water applied, regardless of the irrigation rate or timing of application.

Table 23. Total dry matter yield for 18 alfalfa populations from four harvests and five irrigation levels, Las Cruces, 1984.

Population	Irrigation level (inches)					
	20 early	20 spread	40 early	40 spread	60 spread	Mean1/
	tons/acre/year					
9S5	1.7	3.7	4.5	5.5	4.5	4.0
9FC8	2.5	4.5	4.7	5.6	5.0	4.5
9D11A	2.6	4.4	4.8	6.4	5.2	4.7
9PEG13	2.1	3.9	4.9	5.4	4.7	4.2
0SGP24	2.1	4.3	4.5	5.6	4.3	4.2
1FC33	2.5	4.4	5.1	6.4	4.9	4.6
1FC34	2.3	4.4	4.0	5.8	5.3	4.4
1FC36	2.5	4.0	4.3	6.1	4.9	4.4
2FC37	2.6	4.3	5.2	6.4	5.2	4.8
3S38	2.6	4.4	5.7	6.0	4.8	4.7
3M39	2.7	4.5	4.5	6.1	5.5	4.7
SCST81	2.6	4.7	5.3	6.4	4.9	4.8
Zia 81	2.7	4.7	5.4	6.8	5.5	5.0
Dawson	2.3	4.2	4.3	4.9	4.0	4.0
Dona Ana	2.0	3.5	4.3	5.5	4.3	3.9
Rincon	2.8	3.9	5.1	6.3	5.5	4.7
Zia	2.5	4.6	5.3	6.7	4.7	4.8
NC83-2	2.5	4.6	4.9	5.8	4.7	4.8
Mean2/	2.4	4.3	4.8	6.0	4.9	4.5

1/The L.S.D. value for the 0.05 significance level is 0.2 for the comparison of population means when averaged across irrigation levels.

2/The L.S.D. value for the 0.05 significance level is 0.6 for the comparison of the irrigation level means when averaged across populations.

Table 24. Total dry matter yield for 18 alfalfa populations from five harvests and five irrigation levels, Las Cruces 1985.

	Irrigation level (inches)					
Population	20 early	20 spread	40 early	40 spread	60 spread	Mean[1/]
	tons/acre/year					
9S5	5.5	6.1	11.3	10.2	9.6	8.5
9FC8	5.3	6.2	11.4	12.2	11.1	9.2
9D11A	6.1	6.0	12.5	13.3	12.1	10.0
9PEG13	4.8	6.5	11.5	10.0	11.4	8.9
OSGP24	5.4	6.7	11.0	11.3	11.0	9.1
1FC33	5.9	5.9	11.8	11.9	11.5	9.4
1FC34	5.5	7.0	11.5	11.5	11.9	9.5
1FC36	5.6	7.0	11.2	11.5	11.7	9.4
2FC37	5.6	6.6	11.7	11.9	10.9	9.3
3S38	6.5	6.7	11.9	11.3	10.4	9.4
3M39	5.8	7.3	11.1	11.4	11.5	9.4
SCST81	5.0	6.5	11.7	12.4	11.0	9.3
Zia 81	5.6	8.1	11.3	12.3	12.2	9.9
Dawson	4.6	6.5	10.2	10.2	8.1	7.9
Dona Ana	4.7	5.6	10.3	10.0	10.7	8.3
Rincon	5.6	5.8	10.9	11.1	11.3	8.9
Zia	7.9	7.8	11.8	12.0	10.9	10.1
NC83-2	5.5	5.5	11.0	11.3	10.5	8.7
Mean[2/]	5.6	6.5	11.3	11.4	11.0	

[1/]The L.S.D. value for the 0.05 significance level is 0.6 for the comparison of population means when averaged across irrigation levels.

[2/]The L.S.D. value for the 0.05 significance level is 1.9 for the comparison of the irrigation level means when averaged across populations.

PRINCIPAL FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

1. Based on the methods utilized in these studies, it was determined that approximately 3, 6, and 6 tons per acre of forage dry matter can be produced in southern New Mexico with 20, 40, and 60 inches of water. Alfalfa has been shown to produce higher yields at irrigation rates above 40 inches. However, in all studies there was no significant increase in forage yield at irrigation levels above 40 to 48 inches. Twenty inches of water produced about half of the forage produced with 40 inches. It appears that approximately 48 inches of water is adequate for optimum production of alfalfa. Any amount of water less than 48 inches should be considered less than optimum for maximum production of alfalfa in southern New Mexico.

2. Several cultivars and germplasms were identified that were best adapted for high forage yield with less than optimum irrigation. Some entries had high performance in the lower irrigation levels while others performed best in the higher irrigation levels. However, there were a few entries that had relatively high forage yields at all levels of irrigation. These later entries probably hold the most value to alfalfa producers and plant breeders. The alfalfa producer needs a cultivar that is adapted to a broad range of water environments due to the unpredictability of adequate supplies and rainfall. The plant breeder should concentrate on the broad adaptation and refrain from developing cultivars that have high performance in a narrowly defined set of environmental conditions.

3. Many selection techniques were evaluated. It appeared that the stress test, the field capacity test in pots, the field capacity test in boxes and the PEG test were all effective in isolating genotypes that met the

breeding objective. The stress test has produced the most productive populations, but requires more time per cycle than the other methods mentioned. There is still a great deal of study that should be given these techniques to improve the selection accuracy.

4. Many selected populations were developed and field tested. Several were consistently outstanding in forage yield. Two of these populations were chosen for release as products of this research. The first, Zia 81, was released as a germplasm for use by other plant breeders and researchers in developing and exploring similar characteristics in alfalfa. Zia 81 was developed from Zia parentage and 5 gram quantities of seed will be made available upon request. The second selected population, 9D11A, was released as a cultivar for use by southwestern alfalfa producers. The cultivar was named 'Wilson' in honor of Marvin Wilson who served NMSU and the state of New Mexico for over 30 years; was responsible for initiating this project; and was among the group that made the original selections that led to the development of this cultivar. Wilson is the first cultivar developed in the USA specifically for improved performance under deficit irrigation. Wilson was developed primarily from Zia and Mesilla parentage (table 13). Seed increase of Wilson will be on a four generation basis. Breeders seed will be maintained by the New Mexico Agricultural Experiment Station. Seed will be grown under the supervision of the New Mexico Crop Improvement Association, Box 3CL, New Mexico state University, Las Cruces, NM 88003. Foundation seed should be available in the fall of 1987.

5. The irrigation management experiment allowed an evaluation of the selected populations in five irrigation environments. The populations maintained their relative rank regardless of the irrigation level. The

timing of irrigation illustrated that similar forage yields could be produced with the water applied early in the growing season versus the same amount of water spread evenly throughout the growing season. However with limited supplies of irrigation water, early application would allow the level of yield to be produced in fewer harvests and at a time of year when hay prices and forage quality are typically at their highest.

SUMMARY

The goal of this research was to develop methodology that could be used to produce a cultivar with high forage yield potential with less than optimum irrigation levels. The initial experiments were conducted to determine what yield levels could be expected with various levels of applied irrigation. In conjunction with these experiments, cultivars and germplasm sources were evaluated to determine the genetic backgrounds and/or plant characteristics that are important to high forage yield potential with less than optimum irrigation levels. Many selection techniques were developed and the populations produced from plants isolated by these techniques were field tested. The results showed that certain techniques were more effective at producing populations with high forage yield potential. A few techniques have been chosen for future cycles of selection. Field testing methods were developed to evaluate the selected populations. Two outstanding populations were released for use by alfalfa producers, breeders, and researchers. The final experiments evaluated the potential of combining irrigation management with selected populations to find combinations that would maximize the forage yield potential of alfalfa.

The characteristics of higher forage yield potential with less than optimum moisture is a heritable trait. By concentrating the genes responsible for these characteristics into an adapted cultivar and manipulating the water environment in which this cultivar is grown, the greatest amount of forage dry matter may be produced with the greatest water savings.

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