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Assessment of Irrigation Water Management and Demonstration of Irrigation Scheduling Tools in the Full Service Area of the Dolores Project 1996-2000

Part III: Monitoring of Irrigated Alfalfa Fields Using the Watermark Moisture Sensor and ETgage Atmometer

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Knowledge to Go Places

Assessment of Irrigation Water Management and Demonstration of Irrigation Scheduling Tools in the Full Service Area of the Dolores Project: 1996-2000[1]

Part III: Monitoring of Irrigated Alfalfa Fields Using the Watermark Moisture Sensor and ETgage Atmometer

by

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Abstract

The irrigation water allotment for the Full Service Area of the Dolores Project in southwestern Colorado was exceeded in three of the 14 years from 1987 to 2000. A 1996 survey of farmers in the area indicated a need for information on irrigation scheduling methods and irrigation equipment. This study was conducted to further assess irrigation water management in the area and to demonstrate the use of Watermark moisture sensors and ETgage atmometers for irrigation scheduling purposes. Watermark moisture sensors were used to monitor soil moisture in 13 crop fields in 1997 and 12 alfalfa fields in 1998. ETgage atmometers were used to monitor evapotranspiration at five locations. Irrigation and rainfall amounts were measured with rain gauges. Water balance tables were constructed for each alfalfa field in each year. Generally, the water balance was positive to near zero at the first alfalfa cutting and negative at the second and third cuttings. There was good to partial agreement between the Watermark sensor readings and the water balance computations in 11 out of 17 alfalfa field by year sites. Where there were large discrepancies between the two methods, Watermark sensor readings appeared to better reflect water availability to the crop than did the water balance computations. Water supply in most fields was not enough to keep up with crop evapotranspiration and maintain adequate soil moisture. It is important to perform the alfalfa haying operations as quickly as possible in order to begin resupply of irrigation water as soon as possible. The root zone should be filled as early as possible, and attention should be paid to the design, operation, and maintenance of the irrigation system equipment. Watermark moisture sensors and ETgage atmometers are most useful for irrigation scheduling when used together.

Introduction

The Full Service Area (FSA) of the Dolores Project received irrigation water for the first time in 1987. Its full allocation is 27,920 acres and 55,200 acre-feet (AF). The current allotment of 1.88 AF/acre at the delivery box was exceeded in 1989, 1996, and 2000, which were all dry years. In the year 2000, the FSA exceeded its allocation by 2,179 AF although only 25,116 acres were irrigated. The main reason for this, in addition to drought, was the much higher than anticipated acreage in alfalfa (Berrada et al., 2001b).

Other reasons that the FSA exceeded its allocation may be related to water management, irrigation system design, and operation at the farm level. A 1996 survey revealed that a high percentage of respondents did not use sound irrigation scheduling methods to manage their water allocation. There were also indications of faulty irrigation system design such as undersized water supply lines and oversized sprinkler nozzles. More importantly, several respondents expressed the need for technical information on irrigation scheduling methods and irrigation equipment (Berrada et al., 2001b).

The objectives of this study were to:

1. Further assess irrigation water management in the FSA beyond what was achieved with the survey in 1996 (Berrada et al., 2001b), and
2. Demonstrate the use of Watermark moisture sensors and ETgage atmometers for irrigation scheduling purposes.

In addition to the objectives, several workshops and exhibits were organized to disseminate information on irrigation management (Berrada et al., 2001b).

Literature Review

Soil Water Availability

Soil water that is available to the plants is usually defined as the difference between soil water content at Field Capacity (FC) and the Permanent Wilting Point (WP). It is often referred to as the Available Water Capacity (AWC) of a soil. Field capacity or the upper limit of water availability is the amount of water remaining in the soil after it has been wetted thoroughly and free drainage (by gravity) out of the root zone becomes negligible (Cassel and Nielson, 1986). This usually takes one to three days, depending on the soil type. Obviously, drainage occurs faster in coarse-textured soils such as sandy soils than in fine-textured soils such as clay soils.

The permanent wilting point or lower limit of water availability is defined as soil water content at which plants wilt and fail to recover when placed in a water-saturated atmosphere. Wilting point varies with plant species, stage of growth, and other plant factors. At WP, water is held so tightly by soil particles that plants cannot extract it.

The most common method of estimating FC and WP is the pressure chamber method used in the laboratory. Small soil samples are placed on ceramic plates, soaked in water, and drained to the desired pressure head in pressure chambers (Klute, 1986). For fine-textured soils such as the ones prevalent in the FSA, 0.33 and 15.0 bar pressure heads are commonly used to determine soil water content at FC and WP, respectively. This method does not take into account water flow in and out of the root zone and the incomplete extraction by sparse roots in the lower part of the root zone (Ritchie, 1981). Discrepancies between field and laboratory measurements of the limits of water availability have been reported but research results suggest that the choice of 15.0 bar soil water potential for estimating WP corresponds closely to the field lower limit of soil water availability (Savage et al., 1996).

Irrigation Scheduling

Accurate determination of AWC is important for optimum water management, particularly in dry environments. An estimate of AWC is required for irrigation scheduling based on soil moisture measurements and/or water balance computations. Soil moisture can be estimated with the feel method or determined using various methods and instruments such as tensiometers, electrical resistance blocks, or neutron probes. The procedures for determining soil moisture and the advantages and disadvantages of each method are discussed in numerous publications, including one by Ley (1994). Additional information on the use of electrical resistance blocks such as the Watermark sensors is presented in Part II (Berrada et al., 2001a).

The timing and amount of water application can be based on soil water content and crop response to water stress. Water should be applied when water content in the root zone declines to a level beyond which a reduction in crop yield may occur. This is sometimes referred to as Management Allowable Depletion or MAD. It is expressed in percent of AWC and varies with the crop type and growth stage (Broner, 1989; Al-Kaisi and Broner, 1992). Most irrigation scheduling programs use a MAD value of 50% AWC for alfalfa. This means that when the available water in the root zone is reduced to half AWC, water should be applied to refill the root zone to field capacity thus avoiding water stress that is damaging to plants. For example if the AWC is two inches/ft. and the root zone is five ft. deep, then the total water available to the crop is 2 inches/ft. * 5 ft. = 10 inches. If half of this amount, five inches, has been depleted then an irrigation of five inches is needed to replenish the water in the root zone. More than one application may be necessary to provide five inches of water, depending on the irrigation system and soil conditions.

The water balance approach of scheduling irrigation is similar to the checkbook method. The starting balance is the amount of water available in the root zone at the beginning of the season or the first day of the water balance computations. Credits (deposits) are the amounts of water supplied through rain or irrigation. Debits (withdrawals) are the amounts of water extracted by the plant or lost through soil evaporation, runoff, or drainage (water percolation below the root zone). Runoff and drainage can be estimated from empirical equations or field measurements. Water extracted by the plant is equated with transpiration, which is the vaporization of liquid water contained in plant tissue and its loss to the atmosphere. Evaporation from the soil surface and transpiration occur simultaneously and are referred to as evapotranspiration (ET).

Reference ET is the evapotranspiration from an actively growing surface of grass (ET_0) or alfalfa (ET_r) that is fully developed and maintained at a fixed height and well watered. ET_0 can be measured in the field or estimated from meteorological data. Field measurements include the use of lysimeters and atmometers. Lysimeters provide the most accurate way of measuring ET_0, but they are expensive and time-consuming. Atmometers give a direct reading of reference ET and are inexpensive (Broner, 1990). The advantages and disadvantages of using the ETgage atmometer for measuring ET_r are discussed in Part II (Berrada et al., 2001a). Several methods of estimating ET_0 or ET_r from meteorological data have been developed. The preferred method is the Penman-Monteith equation, which calculates the evaporation from an open water surface using solar radiation, temperature, humidity, and wind speed data. This method has been developed further to compute ET_0 based on the type of crop surface (Allen et al., 1998). Crop

ET (ET_c) is calculated by multiplying ET_0 by a crop coefficient, K_c. K_c varies with the crop type, the climatic conditions, soil evaporation, and growth stage. K_c=0 before crop emergence and reaches 1.0 or above (1.0 to 1.5) at full crop cover ($K_c \leq 1$ if alfalfa is the reference crop).

Materials and Methods

A total of 13 fields in 1997 and 12 fields in 1998 were monitored in the FSA of the Dolores Irrigation Project. The fields were selected based on a number of criteria such as:

- Willingness of the farmer to cooperate in the study.
- Accessibility: All the fields were located within a 10-mile radius of the Southwestern Colorado Research Center.
- Representation: Most of the crops grown in the FSA were included in the 1997 sample. However, since alfalfa represents 80 to 90% of the irrigated acreage in the FSA only alfalfa fields were monitored in 1998. Irrigation systems and management practices were representative of the project area in both years.

Information on crops grown, soil type and available water capacity (AWC), and irrigation system is shown in Table 1. Only the data from the alfalfa fields will be discussed in this report.

Watermark sensors were installed at 1.0, 2.5, and 4.0 foot depths in 1997 and at the manufacturer's recommended depths of 1.0 and 3.0 feet in 1998. Sensors were installed at a representative location per field in 1997 and at three locations per field in 1998.

The procedure for installing the soil moisture sensors was as follows:

1. A three-inch diameter hand auger was used to dig a hole to the depth of the deepest sensor to be installed. The soil removed from the hole was kept segregated in 1-ft intervals to allow for the best recreating of the soil profile during backfilling.
2. Moistened soil was hand packed around each sensor before installing it at the desired depth. After lowering the sensor into the hole, soil (segregated during augering) from the

appropriate depth was then used to backfill the hole to the depth of the next sensor. The soil was packed during backfilling with a wood rod having a 1.0 x 1.5-inch tamping surface.

3. The wire leads from the moisture sensors were coiled and stored in a 5-inch (O.D.) PVC Schedule 40 cap. The PVC cap was installed so that the top was flush with the surrounding ground surface to avoid damage during alfalfa harvest. The cap was backfilled with soil to minimize accumulation of water that could infiltrate the soil profile at the location of the sensors.

Watermark sensors were read once or twice a week with a meter designed specifically for these sensors. The readings were plotted in Figures 1 through 17. Higher readings indicate drier soil conditions. The horizontal lines represent Watermark sensor readings at field capacity (FC), the management allowable depletion (MAD, 50% AWC), and the permanent wilting point (WP). They were derived from the calibration equations 1, 2, and 3 in Part II (Berrada et al., 2001a). An attempt to use FC and WP estimates from each field resulted in unusually low or unusually high readings, thus, the same limits were used for all the fields, which may or may not represent local soil conditions.

Evapotranspiration was monitored using the ETgage atmometers at various field locations and at the automated weather station at the Southwestern Colorado Research Center (SWCRC). The ceramic cup of the ETgages was covered with the Style # 54 canvas to simulate alfalfa reference ET (ET_r). Five ETgages were installed in the study area. Data were collected two or three times a week when fields were visited to monitor soil moisture and on a daily basis at the SWCRC weather station, except on weekends and holidays.

Each ETgage was mounted on one side of a 4-inch diameter wooden post and a Tru-Check™ rain gauge was mounted on the other side. The evaporation surface of the ETgage and the top of the rain gauge were two to three inches above the top of the post and approximately 39 inches above the soil surface. Ten rain gauges were installed in the study area to measure rainfall.

Irrigation application amounts at the location of the moisture sensors was also measured with a Tru-Check™ rain gauge. The height of the top of the gauge varied from 17 to 30 inches.

Differences in the height of the gauge were to accommodate crop height; the height of the aluminum (supply) pipe in the siderolls, and/or the height of drop tubes in the center pivots. Readings were taken from the irrigation gauges at the same time sensor data were collected. In addition, each farmer/field manager was asked to keep an accurate record of the irrigation application dates and duration. This information was checked against the irrigation system characteristics such as nozzle size and type to come up with an estimate of water application amounts for each field.

Daily soil water depletion was computed for each field using the formula:

$D = D_0 + ET_c - I - R$, where:

D is soil water depletion at the end of a given day. D=0 when the root zone is at field capacity or above (Crookston, 1987). We also imposed an upper limit of D=AWC since, theoretically, crop growth will cease once all the available water in the root zone is depleted and soil moisture reaches the permanent wilting point.

D_0 is soil water depletion for the previous day.

ET_c is crop evapotranspiration during the day. $ET_c = ET_r * K_c$ where ET_r is reference ET measured with the ETgage or obtained from CoAgMet (http://ccc.atmos.colostate.edu/cgi-bin/coag_sum.pl). K_c is the crop coefficient. Crop coefficient estimates were calculated by using the following formulas derived at Kimberly, ID (Hill, 1991).

Before cover:

$K_c = 0.3113 + 1.248r - 0.5599r^2$

where r is the fraction of time before effective cover

After each cutting:

$K_c = 0.245 + 0.0378d$

where d is days since the previous cutting

The limits of $0.3 \leq K_c \leq 1.0$ were imposed on both formulas.

I is net irrigation depth. The I value is obtained by multiplying the measured amount of irrigation water by the irrigation efficiency. This is the ratio of the amount of water that reaches the crop to that delivered by the irrigation system. A lower efficiency can be expected with linear-move sprinkler systems, i.e., 75%, than with center pivots (85 to 95%). The same water application efficiency of 85% was used in the water balance computations, since water was measured at slightly above the crop canopy, regardless of the irrigation system.

R is effective rainfall during the day. The measured amount of rain was substituted for R. Runoff and deep percolation were not accounted for in the water balance calculations.

The water balance is the difference between MAD (50% AWC) and water depletion in the root zone (five feet for established alfalfa). The available water was estimated as the difference between water content at 0.33-bar pressure (field capacity) and 15.0-bar pressure (wilting point) as determined in the laboratory. Alfalfa green up date was set as April 15 and April 20 in 1997 and 1998, respectively, based on climatic data and visual observations. The soil was at or near field capacity at green up in all fields for both years. Rain and ET_r totals from planting until the beginning of water balance computations were obtained from the CoAgMet weather station at Yellow Jacket, CO (http://ccc.atmos.colostate.edu/cgi-bin/coag_sum.pl). Rain gauge and ETgage measurements at or near the site were used afterwards.

Crop yields were evaluated using test plots and by gathering information from the field owner and/or operator when available. Alfalfa dry matter yield (air-dry basis) was determined at each cutting from three, nine square foot samples located within 10 feet of the location of the soil moisture sensors. A similar sampling scheme was used to count the number of alfalfa stems and plants in July 1997. Crop height was recorded each time the sensors were read. The occurrence of important crop growth stages was noted. Information on crop management and irrigation system design was gathered and reported when deemed appropriate.

Results, Summary, and Discussion

The water balance computations for each field are shown in Tables 4 to 20 and are summarized in Tables 2 (1997) and 3 (1998). Watermark sensor readings are plotted in Figs. 1 to 17. Appendix A contains a description of each field, an interpretive summary of the water balance and Watermark data, and suggestions for better water management. A synthesis of individual field results and a discussion of the relative merits of the water balance and Watermark soil moisture sensor methods are presented in this section.

Climatic Conditions and Alfalfa Growth in 1997 and 1998

Total precipitation from rain and snow at the Southwestern Colorado Research Center (located in the FSA) was slightly above average (16.6 inches) in 1997 and about average (15.6 inches) in 1998 (http://ccc.atmos.colostate.edu/cgi-bin/coag_sum.pl). There was twice as much precipitation during the alfalfa growth period (April to September) in 1997 than in 1998. The fields that were monitored averaged 8.1 inches in 1997 and 3.1 inches in 1998 during the measurement period (Tables 2 and 3). It was generally more windy and sunny in 1998 than in 1997, which led to a greater daily ET_r rate in 1998, except early in the season (April 15 to May 15).

The length of the alfalfa growing season averaged 160.0 days in 1997 compared to 142.5 days in 1998. Alfalfa green up started a few days earlier in 1997 than in 1998 due to warmer temperatures early in the season. The warmer conditions in 1998 promoted faster alfalfa growth and led to earlier second and third cuttings. In general, alfalfa hay yield declined with each cutting. The 1998 Relative Feed Value (RFV) data indicated excellent hay quality at the first cutting, poor to medium quality at the second cutting, and good quality at the third cutting (see field descriptions, Appendix A). A similar trend was observed in 1997. Alfalfa hay quality is determined by a number of factors, including the growth stage, e.g., percent bloom at the time alfalfa is cut, and the climatic conditions during alfalfa growth (temperature) and hay curing (rain) (Understander et al., 1994). Poor hay quality at the second cutting in 1997 resulted from rain damage and/or late cutting, also due to rain.

Most alfalfa in the FSA is cut three times in the year, except at low elevations (≤ 6000 ft.) where four cuttings are feasible[1]. Only one field (No. 6) was cut four times but the yield of the fourth cutting was very low, according to the owner. A large water deficit developed toward the end of the third growth period and persisted through the end of the season. The second and third cuttings occurred earlier than in all other fields, resulting in below average hay yields.

Water Balance

The water balance was positive to slightly negative at the end of the first growth period in five out of six fields in 1997 and in seven out of 11 fields in 1998. The root zone was at or near FC at the start of both seasons but was depleted faster in 1998 than in 1997 due to the drier conditions in April through June of 1998. The water balance at the end of the second and third growth periods was negative in all the fields in 1997 and in nine out of 11 fields in 1998. Field No. 1 received the highest irrigation amount in 1998 and ended the season with 2.43 inches above MAD (25% of AWC depleted). Field No. 2 had a positive water balance throughout the season due to adequate irrigation (22.7 inches) and a short growing season (134 days).

In most fields, water supply was not enough to keep up with crop ET and to maintain adequate soil moisture, i.e., at or above 50% AWC. Season precipitation (from rain and snow) was above average in 1997, but the amount of irrigation was substantially below the water allocation (22.5 inches per acre[2]) for the FSA. Only Fields No. 1 and 2 in 1998 used up their water allocation. Irrigation amounts averaged 14.8 inches (11.2 to 17.5 inches) in 1997 and

[1] The fields that were monitored in 1997 and 1998 were between 6500 and 7000 ft. in elevation (three cuttings).
[2] This amount is based on the irrigation system capacity for the FSA. However, the maximum amount of irrigation water a FSA farmer can use is determined each year by the Dolores Water Conservancy District (DWCD) Board of Directors based on availability and is adjusted throughout the irrigation season. As much as 31 inches/acre has been allocated to FSA farmers.

18.3 inches (15.1 to 24.3 inches) in 1998, but because of the lower rainfall in 1998, total season precipitation (rain plus irrigation) was substantially below crop ET in both years (Tables 2 and 3). The fields irrigated with siderolls received five to six water applications in 1997 and six to ten in 1998. As would be expected, irrigation frequency was much higher with center pivots than with siderolls since pivots apply less water (inches/hour) than siderolls. The abundant rains of late July and early August hampered the irrigation scheduling in 1997 by delaying the second cutting and/or the haying operation.

Data in Tables 2 and 3 indicate that irrigation was terminated up to four weeks (Fields No. 1, 7, 8, and 13) before cuttings and resumed up to 31 days (Field No. 11, 1998) after alfalfa was cut[3]. On average, irrigation water was shut off 16 to 19 days before cutting and resumed 18 to 20 days after cutting in 1997. The interval between the last irrigation and each cutting was much shorter in 1998, possibly because of the higher percentage of fields irrigated with center pivots. Several factors may affect deciding when to irrigate, such as the weather (rain) and the time it takes to cut, rake, bale, and remove the bales from the field. However, in many instances the time between irrigations and cuttings could have been shortened. This would have allowed one or more additional irrigation water applications and helped to reduce water deficits to a more manageable level than was the case in most fields, particularly during the second and third growth periods. There was also time for greater water application rates, particularly with center pivots, although there were several instances of pivots getting stuck in mud. Water application rates ranged from 0.75 inches to 1.2 inches per revolution in Fields No. 3 to 6 and 1.5 to 2.0 inches in Field No. 7. Soil type (medium infiltration rate) and field topography (2 to 12% slopes) limit water application rate in the FSA but it is possible to minimize runoff by properly designing the irrigation water delivery system. Most of the center pivots in this study were equipped with boombacks to prevent too much water from getting into the wheel tracks and a few pivots had pressure compensating sprinkler nozzles to adjust water flow along the variable topography.

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[3] The exact timing (start and end date) of each irrigation event was not always recorded, so the interval between irrigations is approximate.

Most irrigators in the FSA run siderolls in 10 to 11 hour sets, then move them approximately 60 ft. for the next irrigation set. At this rate, it takes 11 days to irrigate a 40-acre field with one sideroll or 160 acres with four siderolls. Farmers, who have more than one sideroll per 40 acres, on average, can irrigate their fields in less time and are more likely to meet alfalfa water demand than farmers who only have one sideroll per 40 acres. However, the more siderolls per unit area a farmer uses, the more likely he/she will exceed the water allotment of 1.88 AF/acre for the FSA. Occasionally, farmers will leave the water on for up to 24 hours to increase application depth and/or reduce labor costs. Low flow nozzles are recommended for extended periods of irrigation to minimize runoff. There was a large variation in nozzle size among fields and sometimes within the same sideroll. Nozzle sizes of 5.6 to 6.0 gpm meet the irrigation system design criteria for the FSA but larger nozzles, e.g., 7.0 gpm are more likely to satisfy alfalfa water requirements.

Four fields in 1998 (No. 3, 4, 7, and 12) were irrigated after the third cutting[4]. This is not a common practice in the FSA but some farmers do irrigate after the crop is harvested to store water in the ground for the next season (alfalfa), make it easier to perform tillage operations, or promote plant growth for grazing (alfalfa, oat, and others). The flow of irrigation water to the FSA is usually terminated during the first or second week of October[5], which does not leave many days for post-season irrigation, except when the crop is harvested early. Another constraint is water availability at the district and irrigator level. The practice of post-season irrigation needs to be investigated further, especially when the goal is to refill the root zone.

Watermark Sensor Readings

Watermark sensor readings give an indication of soil water availability, which is a function of soil properties, i.e., AWC and the flux of water in and out of the root zone (water balance). Watermark sensor readings were sensitive to changes in soil moisture from rain and irrigation.

[4] Post-season irrigation was not recorded in 1997.
[5] Could be a few days earlier if no one is irrigating and/or a hard freeze is expected.

As expected[6], the readings fluctuated much more at the 1.0 and 1.5 ft. depths than at 2.5, 3.0, or 4.0 ft. (Figs. 1 to 17).

With few exceptions, Watermark readings indicated good water availability at the start of the measurement period (mid to late May). The irrigation season in the FSA starts in early May but most farmers do not start irrigating until two to three weeks later for various reasons[7]. The readings in Fields No. 1, 3, 8, and 12 (Figs. 2, 5, 12, and 17) followed a similar pattern. The early readings were at or near FC, then they started going up in early June (late June for Field No. 12), and reached MAD in late June to early July. The month of June was very dry; in addition, there was a long time (four to six weeks) between the last irrigation before and the first irrigation after the first cutting. The irrigation following the first cutting brought the readings at 1.0 ft. down to within FC. Readings at 2.5 and 4.0 ft. kept going up until they reached WP by mid-July. Readings at 4.0 ft. stayed high for the remainder of the season, except in Field No. 8 where readings at both 2.5 and 4.0 ft. dropped to FC in early September after two irrigations and a rain event. Readings at 2.5 ft. in Fields No. 1 and 12 also dropped to within FC in late August (No. 12) to early September (No. 1).

There was fairly good agreement between the Watermark sensor readings and the water balance computations in Fields No. 1 (1997 and 1998), 3 (1997), 5 (1998), 6 (1998), and 8 (1997). Field No. 12 (1997) showed good agreement through early to mid-August. Subsequent readings at 1.0 ft. and 2.5 ft. indicated good water availability, while the water balance computations showed a large deficit throughout most of the third growth period. In Field No. 6 (Fig. 8), the shallow water applications were not enough to satisfy the crop needs and percolate to 3.0 ft. or even 1.5 ft., which would explain the high Watermark sensor readings (above MAD) in July through September.

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[6] Water moves sequentially in the soil, unless there are tunnels (root channels, gopher holes, cracks, etc.) or obstacles (compaction) that alter its course.

[7] Reasons for not wanting to irrigate early include:

- The farmer and/or irrigation system is not ready.
- There is still good moisture in the soil from winter and early spring precipitation.
- The chances of frost at night still exist and could damage the irrigation system if it is running.
- The cold water early in the season slows alfalfa growth.

In Fields No. 7 (1997) and 9 (1997), the readings at 4.0 ft. stayed below MAD through most of the measurement period, indicating that most water extraction may have occurred in the top 2.5 to 3.0 ft. Both fields were seeded (or re-seeded) in the spring of 1996; consequently, alfalfa roots may not have been fully developed in 1997 or even in 1998. There was some disagreement between the Watermark sensor readings and the water balance calculations in Fields No. 7 and 8. In Field No. 7 (1997), the Watermark sensor readings indicated more water availability than did the water balance calculations (Fig. 9 and Table 12) and are more representative of the high yield estimates in this field. Field No. 7 had a negative water balance during the third growth period (Table 12) but the Watermark readings indicated a deficit during the second and early third growth periods (Fig. 9). The Watermark readings for Field No. 9 (Fig. 13, 1997) indicated a neutral to positive water balance during the second and third growth periods, while the water balance calculations showed mostly a deficit during the same period (Table 16). Watermark sensor readings appear to better reflect water availability in Field No. 9, based on visual observations, and alfalfa yield estimates.

Low Watermark readings were recorded in Fields No. 2 and 11 throughout most of the 1998 measurement period, suggesting that there were no water deficits in these two fields. This was corroborated by the water balance calculations for Field No. 2 (Table 6) but not for Field No. 11, except early in the season (Table 18). Field No. 2 may have been over-irrigated and water may have percolated below the root zone. There was a large discrepancy between the information provided by the water balance calculations and the information provided by the Watermark sensor readings for Field No. 11. The water balance information showed a water deficit throughout the second and third growth periods, while the Watermark sensor information indicated soil water capacity below MAD for practically the entire season. The readings were consistent among the three Watermark stations, as were the precipitation (rain and irrigation) amounts. The Watermark readings were more indicative of the relatively high yield estimates from Field No. 11 than the water balance calculations.

There were also discrepancies between the Watermark readings and water balance calculations for Fields No. 3 (1998), 4 (1998), 8 (1998), and 10 (1998). There were large variations in sensor readings among the three stations in Field No. 3 in 1998, particularly during the third growth period at the 3.0 ft. depth. These variations could be due to sensor malfunction, differences in precipitation amounts (this did not appear to be the case in the fields monitored), differences in soil and topography (water will accumulate in low spots), or other unknown reasons. The readings for Field No. 8 in 1998 could be due to sensor malfunction or to preferential water flow since there was more variation in the readings at 4.0 ft., starting on July 17, than at 2.5 ft. Normally, water will reach the sensor at 2.5 ft. before it does the one at the 4.0 ft. depth.

The water balance information for Field No. 4 showed a severe water deficit during the second, and particularly the third growth period. In contrast, the Watermark sensor information indicated adequate soil water availability for practically the entire season. However, there were large variations in Watermark sensor readings among the three stations (Figs. 6b, 6c, and 6d). There was much less variation in the precipitation amounts (rain and irrigation water) among the three stations, which would indicate the possibility of sensor malfunction. Watermark sensor readings at Station No. 1 and particularly Station No. 3 appear to better reflect the precipitation events and water balance computations than do the readings at Station No. 2.

The water balance and the Watermark sensor readings for Field No.10 were somewhat in agreement for the period from August 7 to August 25 (Table 17 and Fig. 14). The water balance calculations showed large negative values for this period, while the Watermark sensor readings at 3.0 ft. also indicated negative water balance values (above MAD) and the reading on August 21 approached WP.

Comparison of the Water Balance and Watermark Sensor Methods

In light of the discrepancies between the information provided by the water balance and Watermark sensor readings, the question arises as to which method is more reliable or should be recommended for use in the FSA. Before answering this question, it is important to point out some of the shortcomings of this study. As stated in Part I (Berrada et al., 2001b), this was primarily a demonstration study that did not include all the checks and balances, e.g., replication and randomization, that are usually required in a research project. Furthermore, there was no attempt to verify the validity of the information provided by either the water balance or Watermark sensor by actually scheduling irrigation according to this information and comparing it to a control, e.g., the farmer's own irrigation scheduling. This was beyond the scope of this study and probably not easy to achieve on farmers' fields with the existing commercial irrigation equipment.

The water balance method gives an estimate of the water available to the crop at any time (depending on the scale used) during the growing season. It requires quantitative estimates of the terms of the water balance equation, namely,

- Reference ET (ET_r) can be generated using data from the nearest weather station. However, not all weather stations are equipped to measure all the parameters needed to calculate ET_r using Penman, Penman-Monteith, or similar equations. Furthermore, substantial variations in ET_r can occur due to changes in topography, elevation, and other conditions, which could influence the range of validity of the climatic data obtained at a particular weather station. Colorado State University has three automatic weather stations in southwestern Colorado (Cortez, Dove Creek, and Yellow Jacket), that provide daily ET_r values during the growing season. These can be accessed on the web (http://ccc.atmos.colostate.edu/cgi-bin/coag_sum.pl). There is a similar weather station at the Ute Mountain Ute Farm and Ranch Enterprise southwest of Towaoc, CO. An alternative would be to use the ETgage atmometer, which was shown to provide reliable estimates of ET_r in the FSA (Berrada et al., 2001a).
- Crop ET, $ET_c = ET_r * K_c * K_s$. Crop coefficient values were generated using an equation developed at Kimberly, ID for alfalfa (Wright, 1982). Soil dryness was not accounted for in this study (K_s). Estimates of K_c and K_s can be obtained from the literature if local estimates are not available. Al-Kaisi et al. (1999) found significant differences between local estimates of K_c values for irrigated beans in southwestern Colorado and those generated by the 'SCHED' irrigation scheduling program.
- The root zone for water balance calculations was assumed to be 0 to 5 ft. in this study. Alfalfa gets 75 to 90% of its moisture from the upper 4 ft. of soil (Hay, 1990). Abdul-Jabbar et al. (1982) found that the maximum alfalfa root mass correlated with an average

soil depth of 5.24 ft. Computer irrigation scheduling programs such as CropFlex simulate daily crop root growth based on empirical equations (Broner, 1999).

- The amount of water available in the root zone at the start of the water balance computations. Available water is total water content minus water content at WP. Water content can be measured directly or estimated using the probe and feel method. Soil availability indices such as WP and FC can be found in soil survey reports. If winter and early spring precipitation is average or above average, the root zone is likely to be at or near FC.
- The management allowable depletion (MAD) in this study was assumed to be 50% of AWC on average. In reality, MAD value varies with the crop growth stage (Al-Kaisi and Broner, 1992). Alfalfa appears to be more sensitive to water stress at the bud and flower growth stages than at the vegetative stage but will recover quickly when the stress condition is over (Halim et al., 1989; Guitjens, 1990). According to Hay (1990), alfalfa will maintain optimum growth when the soil moisture ranges from 35 to 85% of that available to plant growth. Consequently, a negative water balance using MAD = 50% AWC may not necessarily mean a stressful condition, as far as alfalfa growth is concerned. The magnitude of the water deficit is an important consideration.
- Accurate records of rain and irrigation amounts. Not all the precipitation reaches the crop canopy so a measure of the precipitation efficiency is needed. Estimates of irrigation efficiency can be found in the literature.
- Runoff and drainage were not accounted for in this study. Drainage (water loss below the root zone) is probably negligible in the FSA due to the nature of the soil (deep) and low precipitation. Runoff is probably more significant than drainage in the FSA due to the topography of the area, but there is no simple way of estimating runoff.

Watermark sensors provide an indirect measurement of soil matric potential. They can be calibrated to relate the readings to soil water content, but they are not usually used in this way (Berrada et al., 2001a). In the absence of local calibration, manufacturer's recommendations and other references can be used to determine when to irrigate and how much water to apply. Benchmark readings can also be established through experience and observation. Once the sensors are in place, they can be read any time. No computations are required but plotting the readings on a graph is a useful analytical and management tool, as shown in this report. It is important to place the sensors at representative depths and areas in the field. It is equally important to insure good contact between the sensors and the soil. Concerns about Watermark sensor accuracy were addressed in Part II (Berrada et al., 2001a).

If used properly, Watermark sensors are a simple and useful tool for managing irrigation water, particularly for perennial crops where the same sensors can be used for several years. Strategic placement of Watermark sensors at various soil depths will give an indication of water extraction and root growth.

Unlike the Watermark sensors, the water balance method takes into account both soil water availability and crop evaporative demand. It quantifies water depletion from the root zone, thus making it easy to schedule irrigation timing and amount. It should be the method of choice for irrigation scheduling if ET_r values are readily available. Estimates of ET for various crops can be provided by local extension and research centers. The water balance method is more prone to error than the Watermark sensor method due to the many parameters that need to be determined or estimated. With alfalfa, one also has to make adjustments to reflect cutting dates and the time it takes to cut, bale, and remove hay from the field. These were significant challenges during the computation of the water balance for the fields monitored in this study.

Watermark sensor readings were easy to plot and explain to the farmer-cooperators. Furthermore, it appears that the Watermark sensor readings were more indicative of the water availability, crop condition, and yield estimates in several of the fields monitored. Ideally, both methods should be used. Estimates of soil water content provided with the Watermark sensors or other, more direct methods, should be used occasionally to correct the water balance calculations.

Recommendations for Alfalfa Water Management in the FSA

The following recommendations are based on the results of this study and eight years of experience working with and observing irrigators in the FSA:

- Starting the growing season with a full soil moisture profile will make it easier to keep up with alfalfa water demand, particularly with center pivots. This can be readily achieved if winter and early spring moisture is plentiful. In a normal year, only the top two feet of soil may be at or near field capacity, while the rest of the profile is dry. Few alfalfa growers irrigate after the third cutting to replenish the soil profile; this is not a common practice in the FSA. Depending on when the third cutting takes place, usually mid to late September, farmers may or may not have enough time to irrigate their fields before the Dolores Water Conservancy District shuts the water off. The likelihood of frost also makes irrigation riskier later in the season. Most of the water applied after the third cutting will be stored in the soil since alfalfa growth stops or slows considerably in late fall through early spring. However, late irrigations may promote the growth of winter annuals such as dandelions and downy brome, which could decrease hay yield and quality, and increase production costs. Production costs will also increase due to higher water costs since the Dolores Project irrigators only pay for the amount of water they use plus (or including) a monthly minimum to cover Operations and Maintenance costs and the federal government repayment contract obligations.
- It is important to minimize the time it takes to cut, dry, bale, and transport alfalfa hay out of the field without lowering hay quality. The entire operation can take 8 to 10 days under optimal conditions (dry weather, efficient equipment). Dry weather is more likely to occur during the first cutting than the second or third cutting. The faster hay making is completed the sooner the farmer can irrigate again.
- Similarly, one should not turn the water off too early before cuttings because it is more difficult to catch up later. However, sufficient time should be allowed between the last irrigation and when the hay is cut to avoid soil compaction and promote good hay making conditions. Five days may be adequate for well-drained soils. However, the rolling topography in the FSA causes water to accumulate in low areas, which could delay soil drying, particularly early and late in the season due to cooler weather.

- As much water as the soil can take should be applied early in the season to fill the root zone. This would make it easier to keep up with alfalfa water demand in July and August when ET is high.
- Soil moisture and/or ET information should be obtained regularly to decide when to irrigate and how much water to apply. It is easy to encounter a water deficit situation if one does not know how much water is in the root zone or how much was used by the crop or is evaporated from the soil surface. Adopting a sound irrigation scheduling method is essential for managing the water allotment efficiently.
- Proper design, operation, and maintenance of the irrigation system are of paramount importance for optimum water management in the FSA.
- Rotating alfalfa with less water demanding crops such as dry bean or small grains will help Full Service irrigators stay within their water allocation, particularly in dry years when limitations on irrigation water use could be imposed.

Recommendations for Implementing an Irrigation Scheduling Program in the FSA

The results of this study underscores the need to continue research and education to:

- Develop crop coefficients adapted to the climatic conditions in southwestern Colorado.
- Develop a database for the major crops grown in southwestern Colorado that can be used in irrigation scheduling programs such as CROPFLEX. The database should include historic records and precise measurements of planting and harvest dates, dates of occurrence of key crop growth stages such as emergence, 100% ground cover, bud formation, flowering and heading, and the response to fertilizer and water applications.
- Determine the response of crops such as alfalfa to water deficit and develop strategies to address water shortages in the FSA of the Dolores Project (Agricultural Experiment Station Project COL00615, http://www.colostate.edu/Depts/AES/, 2001).
- Disseminate information on irrigation design, operation and maintenance, irrigation water management, and irrigated crop and soil management to farmers and ranchers in southwestern Colorado.

Colorado State University and the Dolores Water Conservancy District (DWCD) should team up to develop a pilot project to monitor crop water use and soil moisture in the FSA of the Dolores Project. Currently, Colorado State University operates two weather stations within the FSA, one at Yellow Jacket, and the other at Dove Creek. Reference ET and crop ET values are generated daily during the growing season using data from these stations and are available on the Internet at the following address: http://ccc.atmos.colostate.edu/cgi-bin/coag_sum.pl. One or more new weather stations might be needed to represent the range of climatic and topographic conditions in the FSA. These stations could be linked to the Colorado Agricultural Meteorology (CoAgMet) network but it is essential that local estimates be used to calculate crop ET and make projections of crop water use. Watermark sensors or other soil monitoring tools could be installed in fields of participating farmers to determine soil water availability on a regular basis, e.g. weekly. Data from the weather and soil moisture monitoring stations would be transmitted to a central location in southwestern Colorado, operated by Colorado State University and/or DWCD, processed daily, and made available to irrigators in the FSA. Information and recommendations can be tailored to the needs of the participating farmers and news bulletins can be issued on a regular basis to alert irrigators in the FSA to situations of high crop water use and/or low soil moisture availability. The Northern Colorado Water Conservancy District (NCWCD) has been implementing an irrigation scheduling program for several years to assist its constituents in conserving water (Draper, 2000). It should be consulted before a similar program is put in place in southwestern Colorado.

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Table 1. Fields monitored in 1997 and 1998.

Field No.	Year monitored	Acres	Crop	Predominant soil series	AWC (inches/ft.)	Irrigation system
1	'97 & '98	64	Alfalfa	Wetherill	1.94	Sideroll
2	'98	60	Alfalfa	Wetherill	1.94	Sideroll
3	'97 & '98	120	Alfalfa	Wetherill	1.84	Center pivot
4	'98	130	Alfalfa	Wetherill	1.94	Center pivot
5	'98	120	Alfalfa	Wetherill	1.94	Center pivot
6	'98	100	Alfalfa	Cahona	1.94	Center pivot
7	'97 & '98	40	Alfalfa	Sharps-Cahona	2.16	Center pivot
8	'97 & '98	4	Alfalfa	Sharps	1.84	Sideroll
9	'97	76	Alfalfa	Cahona	1.74	Sideroll
10	'98	75	Alfalfa	Wetherill	1.74	Sideroll
11	'98	?	Alfalfa	Wetherill	1.74	Sideroll
12	'97 & '98	80	Alfalfa	Wetherill	1.74	Sideroll
13	'97	90	Spring wheat	Wetherill	1.94	Sideroll
14	'97	113	Oat	Wetherill	1.94	Center pivot
15	'97	125	Pinto beans	Wetherill	1.94	Center pivot
16	'97	40	Pinto beans	Sharps	1.84	Sideroll
17	'97	20	Pinto beans	Wetherill	1.94	Sideroll
18	'97	30	Spring wheat	Wetherill	1.94	Sideroll

Table 2. Alfalfa water balance summary for the 1997 season.

Field No.	Alfalfa seeding date	Alfalfa cutting date	Days to cutting	Alfalfa yield (t/a)	Alfalfa moisture (%)	Rain (in.)	Irrigation No.	Irrigation Amount (in.)	Days from Last irr. to cut	Days from Cut to 1st irr.	ETr (in.)	ETc (in.)	Ending water balance (in.)
1	Spring 1991	18-Jun	63	2.2	77	2.2	1	2.9	29.0	-	13.7	12.1	-2.6
		13-Aug	55	2.9	75	3.4	3	7.7	21.0	13.0	15.3	12.5	-4.8
		29-Sep	46	-	-	2.5	2	6.9	21.0	13.0	9.5	7.6	-3.9
		Total/Avg	164	-		8.1	6	17.5	23.7	13.0	38.4	32.2	
		Estimate*		5.4									
3	Spring 1995	18-Jun	63	3.1	80	2.0	6	5.0	14.0	-	13.5	11.1	-0.4
		11-Aug	53	1.6	84	3.8	4	4.2	23.0	19.0	15.0	10.8	-3.4
		29-Sep	48	1.4	82	2.1	4	5.7	21.0	15.0	9.1	7.0	-3.5
		Total/Avg	164	6.1		7.8	14	14.8	19.3	17.0	37.6	28.9	
		Estimate*		5.0									
7	Summer 1995 Reseeded Spring'96	16-Jun	61	3.0	80	2.1	3	3.3	14.0	-	11.6	8.9	1.4
		14-Aug	58	2.2	77	3.3	3	2.9	27.0	23.0	13.4	11.1	-5.4
		30-Sep	46	1.7	77	2.9	4	4.9	19.0	11.0	7.8	6.9	-4.9
		Total/Avg	165	6.9		8.2	10	11.2	20.0	17.0	32.8	26.9	
		Estimate*		5.0									
8	Spring 1992	16-Jun	61	3.5	81	2.1	1	3.5	23.0	-	12.0	9.3	0.2
		25-Jul	39	2.6	76	0.3	2	6.3	11.0	17.0	12.3	8.8	-2.9
		30-Sep	64	1.8	77	5.8	2	5.1	29.0	26.0	12.3	10.5	-3.3
		Total/Avg	164	7.9		8.2	5	14.9	21.0	21.5	36.6	28.5	
		Estimate*		-									
9	Spring 1995	02-Jun	47	2.3	83	2.0	1	2.5	13.0	-	9.4	7.8	0.6
		27-Jul	55	2.5	78	1.2	3	9.2	9.0	21.0	15.1	13.2	-3.7
		04-Sep	37	NA	-	2.8	2	4.8	5.0	25.0	8.0	7.1	-3.9
		Total/Avg	139	-		6.0	6	16.4	9.0	23.0	32.5	28.2	
		Estimate*		-									
12	1993	04-Jun	49	1.8	81	3.5	1	4.0	8.0	-	10.5	8.6	2.1
		25-Jul	49	1.7	77	1.0	3	5.0	7.0	18.0	13.7	11.4	-4.1
		30-Sep	66	1.7	77	5.9	2	5.1	22.0	28.0	12.2	10.9	-4.0
		Total/Avg	164	5.2		10.4	6	14.1	12.3	23.0	36.3	30.9	
		Estimate*		5.1									
Means		1st cut	57.3	2.7	80.3	2.3	2.2	3.5	16.8	-	11.8	9.6	0.2
		2nd cut	51.5	2.3	77.8	2.1	3.0	5.9	16.3	18.5	14.1	11.3	-4.0
		3rd cut	51.2	1.7	78.3	3.7	2.7	5.4	19.5	19.7	9.8	8.3	-3.9
		Total	160.0	6.5		8.1	7.8	14.8	17.6	19.1	35.7	29.2	
		Estimate*		5.1									

* Farmer's alfalfa hay yield estimate for the season.

Table 3. Alfalfa water balance summary for the 1998 season.

Field No.	Alfalfa seeding date	Alfalfa cutting date	Days to cutting	Alfalfa yield (t/a)	Alfalfa moisture (%)	Rain (in.)	Irrigation No.	Irrigation Amount (in.)	Days from Last irr. to cut	Days from Cut to 1st irr.	Etr (in.)	Etc (in.)	Ending water balance (in.)
1	Spring 1991	18-Jun	59	2.8	75	0.7	3	5.9	17	-	13.3	11.6	-1.0
		06-Aug	49	2.5	75	0.9	4	10.7	3	11	11.2	8.9	0.0
		11-Sep	36	1.6	80	0.1	3	7.7	8	7	5.5	4.3	2.4
		Total/Avg	144	6.9		1.7	10	24.3	9.3	9	30.0	24.7	
		Estimate*		5.9									
2	1992	05-Jun	46	1.6	86	0.7	2	6.7	8	-	10.6	9.1	2.2
		18-Jul	43	1.7	79	0.2	3	8.7	9	11	10.9	9.4	0.2
		01-Sep	45	1.5	81	0.9	4	7.4	8	5	7.8	6.9	0.5
		Total/Avg	134	4.8		1.7	9	22.8	8.3	8	29.3	25.4	
		Estimate*											
3	Spring 1995	15-Jun	56	2.4	81	0.7	6	7.3	4	-	13.1	11.2	0.2
		22-Jul	37	2.0	82	0.4	7	6.2	2	14	10.7	8.4	-2.5
		11-Sep	41	1.2	83	1.0	5	6.0	8	16	10.5	6.6	-3.1
		Total/Avg	134	5.6		2.0	18	19.4	4.7	15	34.3	26.3	
		Estimate*		5.8									
4	1996	11-Jun	52	2.7	81	0.7	6	5.7	7	-	12.0	10.2	0.2
		17-Jul	36	1.9	81	0.4	6	4.8	4	18	11.8	8.6	-4.3
		03-Sep	48	1.6	79	1.1	7	5.8	7	24	11.1	8.8	-4.9
		Total/Avg	136	6.2		2.1	19	16.3	6.0	21	34.8	27.6	
		Estimate*		4.8									
5	1997	11-Jun	52	2.3	76	0.7	5	4.5	2	-	13.0	11.0	-1.7
		20-Jul	39	1.6	81	1.0	7	7.2	3	15	11.5	8.2	-2.2
		07-Sep	49	1.5	79	1.2	7	7.3	6	22	10.0	7.9	-2.7
		Total/Avg	140	5.4		2.9	19	18.9	3.7	18.5	34.4	27.1	
		Estimate*		5.7									
6	Summer 1996	05-Jun	46	1.9	81	0.7	3	3.1	3	-	11.0	9.1	-0.9
		14-Jul	39	1.4	82	1.0	7	6.5	4	11	10.8	8.6	-3.0
		22-Aug	39	1.6	83	1.1	6	4.5	4	14	7.9	6.4	-4.5
		28-Sep	37	1.1	69	0.4	4	3.2	13	10	6.4	4.3	-4.9
		Total/Avg	161	6.0		3.2	20	17.3	6	11.7	36.1	28.4	
		Estimate*		4.40									

Table 3. Alfalfa water balance summary for the 1998 season (continued).

Field No.	Alfalfa seeding date	Alfalfa cutting date	Days to cutting	Alfalfa yield t/a	Alfalfa moisture %	Rain in.	Irrigation No.	Irrigation Amount in.	Days from Last irr. to cut	Days from Cut to 1st irr.	Etr in.	Etc in.	Ending water balance (in.)
7	Summer	08-Jun	49	3.1	79	0.7	3	4.8	6	-	10.0	8.4	1.8
	1995	21-Jul	43	2.5	79	0.8	4	6.0	7	15	12.0	9.8	-2.2
	Reseeded	14-Sep	55	1.9	75	2.3	4	5.9	13	24	12.0	8.5	-3.3
	Spring '96	Total/Avg	147	7.5		3.8	11	16.7	8.7	19.5	34.0	26.7	
		Estimate*											
8	Spring	09-Jun	50	2.2	76	0.7	1	2.0	14	-	10.2	8.4	-1.5
	1992	21-Jul	42	1.7	81	0.8	3	7.5	4	17	11.8	9.8	-4.1
		11-Sep	52	2.2	78	2.0	3	5.7	14	21	11.6	10.0	-4.6
		Total/Avg	144	6.1		3.5	7	15.1	10.7	19	33.6	28.1	
		Estimate*											
10	1997	03-Jun	44	2.8	76	0.7	1	1.8	8	-	9.9	8.1	-1.5
		17-Jul	44	2.5	80	0.9	2	6.0	15	20	11.9	9.6	-4.4
		22-Sep	67	2.1	76	2.7	3	8.9	11	28	12.6	10.8	-3.0
		Total/Avg	155	7.4		4.3	6	16.7	11.3	24	34.3	28.5	
		Estimate*		4.9									
11	1997	09-Jun	50	2.6	79	0.7	2	6.1	7	-	12.0	10.2	0.0
		02-Aug	54	2.2	77	2.9	2	6.5	9	31	14.1	11.1	-2.2
		22-Sep	51	1.7	77	0.8	3	8.2	4	19	9.8	7.4	-1.8
		Total/Avg	155	6.5		4.4	7	20.8	6.7	25	35.8	28.7	
		Estimate*											
12	1993	09-Jun	50	4.0	74	0.7	1	3.1	14	-	12.0	10.4	-2.7
		03-Aug	55	2.8	70	2.9	2	5.4	27	17	14.4	11.5	-4.4
		22-Sep	50	2.0	78	0.8	4	7.5	11	15	8.9	6.1	-3.3
		Total/Avg	155	8.8		4.3	7	15.9	17.3	16	35.3	28.0	
		Estimate*											
Means		1st cut	50.4	2.6	78.5	0.7	3.0	4.6	8.2	-	11.5	9.8	-0.4
		2nd cut	43.7	2.1	78.8	1.1	4.3	6.8	7.9	16.4	11.9	9.4	-2.6
		3rd cut	48.5	1.7	79.0	1.3	4.5	6.8	8.5	17.7	9.8	7.6	-2.6
		Total/Avg	142.5	6.4		3.1	11.7	18.3	8.2	17.0	33.2	26.8	
		Estimate*		5.4									

* Farmer's alfalfa hay yield estimate for the season.

Appendix A

Individual Field Descriptions and Commentary

Field No. 1

Field description: This is a 64 acre field that was seeded to 'Champ' alfalfa at 12 lb./acre in 1991. The predominant soil type is Wetherill loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs) with 1 to 3% slopes. This field was quite weedy in 1997 but had an adequate alfalfa stem (74/ft.^{2}) and plant (12/ft.^{2}) count. Water delivery system consisted of two 1338 foot long Wade Rain siderolls. Sprinkler heads were equipped with single nozzles rated 7.0 or 8.0 gpm. Few of the nozzles had a 3/16 inch orifice. Water use recorded at the delivery box was 111.77 AF (1.75 AF/acre) in 1997 and 160.70 AF (2.51 AF/acre) in 1998. Irrigation water measured at the Watermark stations was 17.51 inches (93.39 AF, 1.46 AF/acre) in 1997 and 24.27 inches (129.28 AF, 2.02 AF/acre) in 1998. These numbers indicated an irrigation system efficiency (does not account for possible losses above the rain gauge) of 83% and 80% in 1997 and 1998, respectively. The alfalfa samples that were taken at the Watermark stations indicated yields of 2.2 and 2.9 t/acre for the first and second cuttings in 1997; and 2.4, 2.0, and 1.5 t/acre for the first, second, and third cuttings in 1998. The third cut was completed before the yield plots were sampled in 1997. The owner's estimates for the whole field were 5.4 t/acre in 1997 and 5.9 t/acre in 1998. Relative Feed Values (RFV) were unknown.

Water balance: Water balance information for Field No. 1 (sideroll irrigated) is shown in Tables 4 (1997) and 5 (1998).

1997 season: Water was applied once, three times, and twice during the first, second, and third growth periods, respectively. Each irrigation set lasted 10 to 11 hours except the last one, which lasted 15 to 16 hours (information provided by the irrigator). A long time (29 days) elapsed between the only irrigation in May to June and the first cutting. A slight deficit developed in early June, grew larger in July and August, and persisted through

September. All available water was depleted on July 17 and August 18. Total precipitation (irrigation plus rain) was 25.6 inches during the season. Total crop ET was 32.2 inches. With the assumption that the root zone was at field capacity at the beginning of the season, a total of 32.6 inches (rain + net irrigation + AWC) would have been supplied. Not all the water was available to the crop due to surface evaporation and other potential losses.

1998 season: Irrigation measurements began on May 18. There were three irrigations for the first alfalfa crop, four for the second, and three for the third crop. No water was applied between the irrigation on June 1 and the first cutting. A slight deficit developed just before the first cutting in mid June but was negated by the first irrigation of the second growth period and by subsequent irrigations, which kept the balance around zero. Water balance remained above zero during the entire growth period of the third alfalfa crop. Total water applied (irrigation plus rain) for the three growth periods was 26.0 inches. Total crop water demand (ET_c) was 24.7 inches. Ending water balance, at the third cutting, was 2.4 inches.
<u>Watermark sensor readings:</u> Figures 1 and 2 show the Watermark readings, irrigation and rain amounts for Field No. 1 in 1997 and 1998, respectively. The numbers in 1998 represent the average of three stations.

1997 season: Low Watermark sensor readings were recorded early in the season but went up sharply in June due to extremely low rainfall, crop water use, and the lack of irrigation. The second irrigation helped bring the 1.0 ft. sensor reading to below field capacity (FC) but had little effect on the readings at the 2.5 ft. and 4.0 ft. depths. Subsequent irrigation and rain events kept the readings at 1.0 ft. below the management allowable depletion (MAD), except on August 22. The 2.5 ft. sensor readings peaked after the second cutting then dropped sharply to the same level as the 1.0 ft. sensor readings in early September after two water applications totaling 6.9 inches. Readings at the 4.0 ft. depth exceeded MAD on June 23 and the wilting point (WP) on July 11, dropped below WP on September 10, but remained well above MAD throughout the second and third growth periods.

1998 season: The field began the season at FC. Watermark readings reached MAD at about June 18. Irrigation on June 29 brought the readings down to about MAD, but it was not until the irrigation of July 9 that the sensors at 1.5 ft. came to FC and the sensors at 3.0 ft. reached below MAD. Water probably continued to percolate down to the 3.0 ft. sensors and they about reached FC with another irrigation on July 20. The soil profile continued to dry out, but subsequent irrigations kept the water content below MAD. The last irrigation on September 3 brought the 1.5 ft. deep sensors to FC, then the soil profile began another drying cycle.

Discussion and recommendations: There was good agreement between the water balance computations and Watermark sensor readings in 1997 and 1998. A longer growing season in 1997 led to greater crop ET (32.2 vs. 24.7 inches) than in 1998. There was more rain in 1997 (8.1 vs. 1.7 inches) but less irrigation water was applied in 1997 than in 1998 (17.5 vs. 24.3 inches), which led to the water deficit and high Watermark sensor readings in 1997. A second irrigation before the first cutting in 1997 would have kept the water deficit down to a manageable level. The water balance was at or above zero throughout most of the 1998 season. However, more time could have been allowed between irrigations during the first growth period and more water could have been applied during the second irrigation. Furthermore, the last irrigation could have been eliminated from the third alfalfa growth period, where the water balance was adequate, to help maintain water use near the FSA allocation level of 22.5 inches.

Field No. 2: This field was monitored in 1998 only.

Field description: This was a 60 acre field that was seeded with 'Ranger' alfalfa at 15 lb./acre in 1992. The predominant soil type was Wetherill loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs) with 1 to 3% slopes. The previous crop was irrigated beans that yielded 2500 lb./acre. The field was fertilized with N-P-K by dry broadcast in October 1997 at 200 lb./acre. The irrigation system consisted of an A&M sideroll, 900 ft. long, with six foot wheels and a four inch pipe. The system had been in service for 30 to 40 years. The 21 sprinkler heads were equipped with Nelson and Rainbird nozzles of various sizes, but the sizes approximated 0.25 or 0.19 inch. Water use recorded at the delivery box was 144.9 AF for 1998 (May to October). This was 2.41 AF/acre based on a 60 acre field. Average water applied at three Watermark stations was 22.78 inches (113.9 AF, 1.90 AF/acre). These numbers indicated an irrigation system efficiency of 79%. The alfalfa was cut in early June, mid July, and early September. The alfalfa yield sample estimates were 1.6, 1.7, and 1.5 t/acre for the respective cuttings. The farmer's estimate for the first cutting was 1.7 t/acre.

Water balance: Water balance information for Field No. 2 (sideroll irrigated) is shown in Table 6. Irrigation measurements began on May 19. There were two irrigations for the first alfalfa crop, three irrigations for the second, and three for the third crop. The entire season had a positive water balance. Total water applied (irrigation plus rain) for the three growth periods was 24.5 inches. Total crop water demand (ET_c) was 25.4 inches. Ending water balance, at the third cutting, was 0.5 inch.

Watermark sensor readings: Figure 3 shows the Watermark readings, irrigation and rain amounts for Field No. 2 (average of three stations) from May 20, 1998 through October 5, 1998. This field was apparently watered to excess. The irrigations, though infrequent, kept the soil profile near field capacity (FC) for almost the entire season. Only after the third cutting in early September did the soil profile begin to dry out.

Discussion and recommendations: Based on the water balance calculations and the Watermark sensor readings, it appeared that Field No. 2 was over watered. Given the low Watermark readings (near FC) for most of the season, it was possible that some water was lost due to deep percolation. The amount of water applied probably could have been decreased. This would have saved some water and lowered the production cost to the farmer.

Field No. 3

Field description: This field consists of a 120 acre circle of which approximately eight acres are in waterways and two to three acres are bare spots that were sprayed with Tordon 22K to control Canada thistle. The predominant soil type is Wetherill loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs). The topography is rolling with approximately 2 to

4% slopes. This field was seeded to alfalfa variety 'ML-330' in May 1995 at 17 lb./acre. It had a good stand of alfalfa in 1997 and 1998. The stand counts made on July 9, 1997 averaged 20 plants/ft.^{2} and 123 stems/ft.^{2}. No major weed, insect, or disease problems were noticed in this field. Nutrient management appeared to be adequate. The irrigation system consisted of a nine-tower, 1300 ft. long T&L center pivot equipped with drop tubes, spray nozzles, rotators, spinners, pressure regulators, and boom backs. Before 1997, the pivot was equipped with high-impact sprinkler heads. The new sprinkler package substantially improved water application efficiency by reducing losses due to evaporation and wind drift, according to the owner. The owner also noticed a reduction in the amount of water that runs along the wheel tracks and a lower incidence of the wheels getting stuck. He works the wheel tracks with a plow every spring and fills the lows spots with rocks and/or oat straw. Total water allocation for this field is 234 AF.

Water use recorded at the delivery box during the irrigation season (early May to early October) totaled 225.66 AF in 1997 and 268.60 AF in 1998. This was 1.88 (22.56 inches) and 2.24 (26.88 inches) AF/acre in 1997 and 1998, respectively, based on a 120 acre field. The cumulative amount measured at the Watermark stations was 14.83 inches (148.30 AF, 1.24 AF/acre) in 1997 and 21.21 inches (212.10 AF, 1.77 AF/acre) in 1998. The operator's records showed a total (based on center pivot settings) of 17.4 inches applied in 1997. These numbers would indicate a farm irrigation efficiency of 77% (17.4*100/22.6) and a center pivot irrigation efficiency of 85% (14.8*100/17.4) in 1997. Farm irrigation efficiency in 1998 was 79%. Operator's irrigation records in 1998 were incomplete. Alfalfa samples taken at the Watermark stations indicated hay yields of 3.1, 1.6, and 1.4 t/acre in 1997 and 2.4, 2.0, and 1.2 t/acre in 1998 for the first, second, and third cuttings, respectively. The farmer's estimates for the whole field and all three cuttings were 5.0 t/acre in 1997 and 5.8 t/acre in 1998. Relative feed values were, in order of cutting, 201, 142, and 201 in 1998 (RFV information was not available for 1997).

Water balance: Water balance information for Field No. 3 is shown in Tables 7 (1997) and 8 (1998).

1997 season: A slight deficit developed at the end of the first growth period, grew larger in July and August, and persisted through September. Cool temperatures (low evaporative demand) and frequent irrigations helped keep the deficit down during the first growth period. A long time (two to three weeks) elapsed between the first or last irrigation and alfalfa cutting. Water application depth varied greatly throughout the season. More water was applied on average per irrigation and in totality during the third growth period than during the second or first periods. Rainfall was scarce in June through July 20. Monsoonal rains in the latter part of July and early August delayed the second cutting by several days. It also took longer than usual (6 to 10 days) to cut the whole field, cure the hay, and bale it. A similar situation occurred during the third week of September leading to a lengthy alfalfa harvest time. Total water applied (irrigation plus rain) for the three growth periods was 22.7 inches. Total crop water demand (ET_c) was 28.9 inches. Ending water balance, at the third cutting, was – 3.5 inches, meaning that 1.1 inch (AWC – cumulative water depletion) of available water was left in the root zone.

1998 season: Irrigation measurements began on May 14. A deficit began after the first cutting and became quite large by the time of the second cutting. The deficit persisted through the third growth period but was not as large as in 1997. Total water applied (irrigation plus rain) for the three growth periods was 21.5 inches in 1998. Total crop water demand (ET_c) was 26.3 inches. Ending water balance, at the third cutting, was – 3.1 inches.

Watermark sensor readings: Figures 4 and 5 show the Watermark readings, irrigation and rain amounts for Field No. 3 in 1997 and 1998, respectively. The numbers in 1998 represent the average of three stations.

1997 season: The Watermark sensor readings hovered around FC through early June then started going up steadily as very little water was supplied until the irrigation of July 7. The readings at 1.0, 2.5, and 4.0 ft. reached MAD during the first week of July. Subsequent irrigation and rainfall events brought the sensor readings to below MAD at the 1.0 ft. depth but made little difference at the 2.5 ft. and 4.0 ft. depths. As would be expected, the Watermark sensor readings fluctuated much more at the 1.0 ft. depth than at the lower depths. It takes more water (and longer) to reach the lower sensors than the top one. The 2.5 ft. and 4.0 ft. sensor readings reached WP during the third week of July and remained high through September.

1998 season: The field began the season at field capacity (FC) and stayed near it because of the early irrigations. The field dried out a bit at the first cutting in mid June. Subsequent irrigations and rain kept the 1.5 ft. sensors near FC and the 3.0 ft. sensors below MAD until the second cutting in late July. The irrigation of August 24 brought the 1.5 ft. sensors back to FC and the following irrigations kept the 1.5 ft. sensors near FC and the 3.0 ft. sensors at MAD until the third cutting in mid September. A fall irrigation and rain on October 5 brought the 1.5 ft. sensors back to FC.

Discussion and recommendations: The Watermark sensor readings reflect more closely the water balance computations in 1997 than in 1998. There were large variations in sensor readings among the three stations in 1998, particularly during the third growth period at the 3.0 ft. depth. Less irrigation water was applied in 1997 than in 1998 but rain during the 1997 growing season more than made up for the difference in total precipitation (22.7 inches in 1997 vs. 21.5 inches in 1998). Crop ET was higher in 1997 than in 1998, mostly due to the longer growing season in 1997 (164 vs. 134 days). Water depletion in 1997 exceeded MAD throughout the second and third growth periods. The water deficit was less severe in 1998 due to the shorter growing season and more frequent irrigations. Alfalfa hay yield was higher in 1997 than in 1998 according to sample estimates, but less according to the farmer's estimates.

More frequent and/or greater water application depth could have helped keep the water deficit down in 1997. The time between the last irrigation and cutting should be shortened as much as possible, i.e., no more than eight days. Similarly, water should be turned on as soon as hay bales are removed from the field. The hay making process (cutting, raking, baling, and removal of the bales from the field) probably took longer than necessary although rain interfered with the second and third cuttings. In hindsight, the first cutting could have been done three to five days sooner and the third cutting could have been delayed until after September 22 to avoid rain damage.

Interestingly, the ending water balance in 1998 (– 3.1 inches) roughly equaled the amount of allocated water that was not utilized. The farmer's records show a center pivot speed of 3.5 days (1.2 inches of water) per revolution during the first irrigation and 2.7 to 3.0 days (0.9 to 1.0 inch) thereafter. An application rate of 1.2 inches at each irrigation event during the second and third growth would have supplied more than enough water ((16.8 inches – 12.2 inches) * 85% irrigation efficiency) to offset the deficit that developed during the second and third growth periods. An alternative would have been to start irrigating earlier after the first and second cuttings, provided the hay was baled and removed from the field quickly. This would have allowed for one to two additional water applications.

Field No. 4: This field was monitored in 1998 only.

<u>Field description:</u> This field had a rolling topography and consisted of a 130 acre circle of which 126 acres were alfalfa and four acres were grass. It was planted with 'Parade' alfalfa by broadcast in 1996 at 17 lb./acre. The predominant soil type was Wetherill loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs) with 3 to 12% slopes. The field was prepared for alfalfa by fall plowing in 1995, and field cultivated twice and roller packed once in spring 1996. The previous cover crop was oats that was planted at 18 lb./acre, harrowed, watered up, and yielded 120 bu./acre. The irrigation system consisted of a T & L center pivot, 1300 ft. long, with nine towers. It had been in service for seven years. Water use recorded at the delivery box was 268.9 AF for 1998 (May to October). This was 2.13 AF/acre based on a 126 acre field. Average water applied at three Watermark stations was 18.6 inches (195.3 AF, 1.55 AF/acre). These numbers indicated an irrigation system efficiency of 73%. The field was fertilized in May 1998 by a broadcast cart spreader with dry N-P-K (11-50-70). No pesticides were applied in 1998. The alfalfa on this field was cut in mid June, mid July, and early September. The alfalfa samples taken at the Watermark

stations indicated yields of 2.7, 1.9, and 1.6 t/acre for the respective cuttings. The farmer's estimates were 2.2, 1.4, and 1.2 t/acre for the respective cuttings and the relative feed values were 208, 118, and 155, respectively.

Water balance: Table 9 shows the water balance information for Field No. 4 (center pivot irrigated). Irrigation measurements began on May 14. There were six irrigations for the first alfalfa crop, six irrigations for the second, and seven for the third crop. A water deficit of 1.2 inches occurred after the first cutting on June 22. The deficit increased gradually during the second growth period and all available water was depleted during most of the third growth period. Total water applied (irrigation plus rain) for the three growth periods was 18.4 inches. Total crop water demand (ET_c) was 27.6 inches. Ending water balance, at the third cutting, was – 4.9 inches.

Watermark sensor readings: The Watermark readings, irrigation and rain amounts for Field No. 4 (average of two stations) from May 28, 1998 through October 5, 1998 are shown in Fig. 6a. This field also began the season at field capacity (FC) and, though it appeared to dry out a little after the first cutting, with the applied irrigations it continued to remain at FC until the second cutting in mid July. Irrigation resumed on August 10, which brought the 1.5 ft. sensors back to FC on August 17 and kept the 3.0 ft. sensors well below MAD. The field began another drying cycle with the third cutting in early September. The next two irrigations on September 28 and October 5 (with a little help from a rain event) brought the 1.5 ft. sensors again back to FC. However, the 3.0 ft. sensors continued drying out to above MAD.

Discussion and recommendations: There was a great discrepancy between the information provided by the water balance calculations and the information provided by the Watermark sensor readings for Field No. 4. The water balance information indicated a water deficit (negative values) throughout the second and third growth periods. Indeed, the calculations indicated that all available water in the soil profile was depleted for most of the third growth period. In contrast, the Watermark sensor information (average of three stations) indicated adequate soil water availability (positive water balance values) for practically the entire season. However, there was a large variation in Watermark sensor readings among the three stations (Fig. 6b, c, and d). There was much less variation in the precipitation amounts (rain and irrigation water) among the three stations, indicating the possibility of sensor malfunction. Station No. 2 had readings at or below FC at 1.5 and 3.0 ft. throughout the measurement period, even during periods of low water supply, i.e., at the end of August. Watermark sensor readings at Station No. 1 and particularly Station No. 3 appear to better reflect the precipitation events and water balance computations.

As with Field No. 3, a higher application rate during the second and third growth periods, i.e., 1.2 inches per irrigation event, would have supplied an additional 4.3 inches ((15.6 – 10.6) * 85%) of available water. There also appears to be room for an additional irrigation during the third week of June if the haying operations (cutting, raking, baling, and removing bales from the field) were completed sooner.

Field No. 5: Fields No. 5 and 6 were monitored in 1998 only.

Field description: This field consisted of a 120 acre circle serviced by a Valley center pivot, 1160 ft. long, with seven towers, poly drops, and rotators. It was broadcast seeded with the alfalfa variety 'AV 120' in 1997 at 20 lb./acre. The predominant soil type was Wetherill loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs) with 3 to 6% slopes. The seedbed was prepared by discing, field cultivating, and cultipacking. Fertilizer (28-135-80) was applied by dry spreader in fall 1997. No herbicides or insecticides were applied and the field was aerated at least once. The alfalfa was cut in mid June, mid July, and early September. The alfalfa samples taken at the Watermark stations indicated yields of 2.3, 1.6, and 1.5 t/acre for the respective cuttings. The farmer's estimates were 2.7, 1.5, and 1.5 t/acre respectively. The relative feed values, in order, were 212, 112, and 160. The last two cuttings were rain damaged and this resulted in lower relative feed values.

Water balance: Water balance information for Field No. 5 (center pivot irrigated) is shown in Table 10. Irrigation measurements began on May 26. There were five irrigations for the first alfalfa crop, seven irrigations for the second, and seven for the third crop. A deficit developed in the last ten days of the first growth period. The deficit became significant and persisted throughout the second and third growth periods. Total water applied (irrigation plus rain) for the three growth periods was 21.8 inches. Total crop water demand (ET_c) was 27.1 inches. Ending water balance, at the third cutting, was – 2.7 inches, indicating that approximately 78% (Depletion * 100/AWC) of the available water in the root zone was used up at the end of the season.

Watermark sensor readings: Figure 7 shows the Watermark readings, irrigation and rain amounts for Field No. 5 (average of three stations) from May 26, 1998 through October 5, 1998. The field began the season at field capacity (FC) and dried out to around MAD during the first cutting in mid June. Subsequent irrigations did not bring the 1.5 ft. sensors below MAD until July 10 while the 3.0 ft. sensors gradually dried out towards wilting point (WP). The 1.5 ft. sensors dried out towards MAD after the second cutting in mid July while the 3.0 ft. sensors stayed near WP. Irrigations began again on August 14 and the following irrigations kept the 1.5 ft. sensors well below MAD while the 3.0 ft. sensors were brought down to near MAD with the last irrigation on September 1. The soil profile again dried out during and after the third cutting in early September with 0.5 inch of rain on October 5 being of little help.

Discussion and recommendations: Based on the water balance calculations and the Watermark sensor readings, there appeared to have been some opportunity to apply more water in order to keep the water deficit down. Approximately 3.59 inches (22.50 – 18.91) of allocated water were not utilized. As long as the time constraints of baling and getting the bales off the field were not too restrictive, two additional irrigations, as soon as possible after the first and second cuttings, may have been helpful in keeping the water deficit more manageable. In addition, as long as the center pivot wheel movers were not hindered by mud, the smaller irrigation amounts may have been increased. This would hopefully have allowed more water to reach the deeper levels of the soil profile, as the 3.0 ft. Watermark sensors indicated they were quite dry.

Field No. 6

Field description: This field consisted of a 100 acre circle that was broadcast seeded to alfalfa in July 1996 with the variety AV 120 at 15 lb./acre. The predominant soil types were Cahona loam (fine-silty, mixed, superactive, mesic Calcidic Haplustalfs) and Wetherill loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs) with 3 to 12% slopes. The seedbed was prepared by discing and field cultivating. Two fertilizer applications were made by dry spreader: 11-52-0 was applied in fall 1996 at 130 lb./acre and 0-0-50 was applied in summer 1997 at 50 lb./acre. No herbicides or insecticides were applied and the field was aerated at least once. The irrigation system was similar to the one on Field No. 5. It had been in service for two years. Water use recorded at the delivery box was 182.4 AF for 1998 (May to October). This was 1.82 AF/acre based on a 100 acre field. Average water applied at three Watermark stations was 17.26 inches (143.8 AF, 1.44 AF/acre). These numbers indicated an irrigation system efficiency of 79%. The alfalfa was cut in early June, mid July, late August, and late September. The alfalfa samples taken at the Watermark stations indicated yields of 1.9, 1.4, 1.6, and 1.1 t/acre for the respective cuttings. The farmer's estimates were 1.5, 1.4, 1.3, and 0.2 t/acre respectively. The relative feed values for the first three cuttings were, in order, 218, 188, and 180. The alfalfa was only 11 inches tall at the fourth cutting and was not tested for quality. The growing season of 161 days was substantially longer than the average growing season, 142.5 days, of the alfalfa fields that were monitored in 1998. This was the only field where a fourth cutting was attempted.

Water balance: Table 11 shows the water balance information for Field No. 6 (center pivot irrigated). Irrigation measurements began on May 26. There were three irrigations for the first alfalfa crop, seven irrigations for the second, and six for the third crop. A water deficit began on June 2, just before the first cutting, and increased during the second growth period. The deficit remained high during the third growth period and almost all available water was depleted by the time of the third cutting. Total water applied (irrigation plus rain) for the four cuttings was 20.5 inches and total crop water demand (ET_c) was 28.4 inches. Ending water balance, at the fourth cutting, was – 4.85 inches (MAD equaled 4.85 inches).

Watermark sensor readings: The Watermark readings, irrigation and rain amounts for Field No. 6 (average of three stations) from May 26, 1998 through October 5, 1998 are shown in Fig. 8. Although the field began the season at field capacity (FC), frequent irrigations did not prevent the soil profile from reaching MAD on July 1. The field quickly dried out at the second cutting in mid July and apparently neared wilting point (WP). The irrigations and rains for the remainder of the season could not return the soil profile to MAD and the 3.0 ft. sensors hovered around WP.

Discussion and recommendations: Total precipitation (rain plus irrigation) was substantially below crop ET. Irrigation water application rate ranged from 0.5 to 1.0 inch (mostly 0.75 inch) per center pivot revolution, according to the operator. These shallow application rates did not provide enough water to satisfy the crop needs and percolate to 3.0 ft. or even 1.5 ft., which would explain the high Watermark sensor readings (above MAD) in July through September. Higher water application rates, e.g., 1.0 inch on average, and more frequent applications, particularly in early and late July, would have kept the water deficit from getting too high.

Field No. 7

Field description: This is a 40 acre field of which 30 acres were irrigated with a 650 ft. center pivot. The predominant soil series is Sharps-Cahona. Alfalfa variety 'Archer' was seeded in the summer of 1995 at 15 lb./acre and reseeded in the spring of 1996 to fill the gaps. Stand counts on July 8, 1997 averaged 20 plants/ft.^{2} and 120 stems/ft.^{2}. The alfalfa samples that were taken at the Watermark station showed yields of 3.0, 2.2, and 1.7 t/acre in 1997 and 3.1, 2.5, and 1.9 t/acre in 1998 for the first, second, and third cuttings, respectively. Farmer's estimates were not available.

Water balance: Water balance information for Field No. 7 (center pivot irrigated) is shown in Tables 12 (1997) and 13 (1998).

1997 season: Table 12 shows a positive water balance through June. A deficit developed in July and carried through September. All the available water was depleted at the end of the second growth period. A total of 11.2 inches of water was applied through the pivot in 10 applications. Total rainfall was 8.2 inches. Total crop ET was 26.9 inches. The soil at this site had the highest water holding capacity of all the fields monitored in 1997.

1998 season: Irrigation measurements began on May 17. There were four irrigations for the first alfalfa crop, four for the second, and four for the third crop. A significant deficit developed just before the second cutting and persisted throughout the third growth period. Total water applied (irrigation plus rain) for the three growth periods was 20.5 inches. Total crop water demand (ET_c) was 26.7 inches. Ending water balance, at the third cutting, was – 3.3 inches, indicating that approximately 81% of the available water was depleted.

Watermark sensor readings: Figures 9 and 10 show the Watermark readings, irrigation and rain amounts for Field No. 7 in 1997 and 1998, respectively.

1997 season: Readings at 4.0 ft. were below MAD throughout the season, somewhat similar to Field No. 9, which could be due to adequate soil moisture at the start of the season and low water extraction at 4.0 ft. Both Fields No. 7 and 9 had a young (two years or less) stand of alfalfa with a root system that may not have been fully developed in 1997. Readings at the 2.5 ft. depth stayed relatively low through the first cutting, went up sharply in July and August, and didn't drop back below MAD until after several rain and irrigation events in late August through mid September. Readings at 1.0 ft. fluctuated widely after each irrigation and/or rain event, but rarely exceeded MAD.

1998 season: The field appeared to not start the season at FC, and although the irrigations of May brought the shallowest sensor to FC, the 2.5 and 4.0 ft. sensors began to dry out. The soil profile generally reached MAD on June 19 and an irrigation on June 23 appeared to bring the entire profile to FC. A few days later the sensor at 2.5 ft. seemed to go to WP and the next irrigation on June 30 brought it back to FC. The 1.0 ft. sensor was kept near FC and the 4.0 ft. sensor around MAD with the following rains and subsequent irrigation on July 14. The 1.0 ft. sensor dried out to MAD on July 21 and the following rains combined with the irrigation on August 14 brought it back to FC. The next two irrigations appeared to bring the entire soil profile to FC by August 28, but the soil began the next drying cycle with the third cutting in mid September. A fall irrigation on October 5 returned the 1.0 ft. sensor to FC and kept the 4.0 ft. sensor at MAD, but the 2.5 ft. sensor appeared to return to WP. There was some disagreement between the water balance calculations and the Watermark sensor readings for this field. The water balance calculations mainly indicated a water deficit during the third growth period. In contrast, the Watermark sensor readings indicated the greatest water deficit during the second and early third growth periods.

Discussion and recommendations: Good winter and early spring precipitation combined with good soil water holding capacity helped maintain a positive water balance in May and June of 1997 and 1998. Crop ET was much higher than irrigation plus rain during the growing season in both years. Only about half of the water allotment for Field No. 7 was utilized in 1997. More irrigation water was applied in 1998 but it rained more in 1997, so that the sum of irrigation plus rain was similar. There was room for several additional water applications in July and early August in 1997. An additional six to seven inches of carefully scheduled water applications during the second growth period in 1997 would have eliminated the deficit that developed in July through September. The center pivot was slowed down substantially in 1998 allowing for a higher application rate (per revolution) than in 1997, but irrigation frequency was about the same. Rain in late July 1998 delayed hay raking and baling, which could explain why there was no irrigation in early August.

The water balance computations show a larger deficit in 1997 than in 1998, possibly due to the longer growing season in 1997 (167 vs. 147 days). The deficit is not indicative of the relatively high yield estimates in both years. Watermark sensor readings show more water availability than the water balance tables would indicate. Indeed, readings at both 1.0 and 4.0 ft. rarely exceeded MAD. Readings at 2.5 ft. fluctuated much more than those at 4.0 ft., especially in 1997, and reached the highest values (at or above WP) of all three sensors, e.g., during the second growth period. This could indicate that most water extraction occurred in the top 2.5 to 3.0 ft. It is possible that because of the relatively young alfalfa stand in Field No. 7 (alfalfa was planted in the fall of 1995 and re-seeded in the spring of 1996), alfalfa roots were not fully developed in 1997 and even in 1998.

Field No. 8

Field description: This is a small field of alfalfa (about four acres) located on the research center farm at Yellow Jacket. It is irrigated with a 610 ft. Wade Rain sideroll equipped with 6.0 gpm flow control nozzles. The predominant soil type is Sharps loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs). Alfalfa variety 'Belmont' was seeded in the spring of 1992 at a rate of 15 lb./acre. It had a fair stand of alfalfa with 17 plants/$ft.^2$ and 94 stems/$ft.^2$. The alfalfa samples that were taken at the one Watermark station showed yields of 3.5, 2.6, and 1.8 t/acre in 1997 and 2.2, 1.7, and 2.2 t/acre in 1998 for the first, second, and third cuttings, respectively.

Water balance: Water balance information for Field No. 8 (sideroll irrigated) is shown in Tables 14 (1997) and 15 (1998).

1997 season: A slight deficit developed shortly after the first cutting, was negated by the irrigation of July 3, reappeared on July 9 and persisted through the third cutting. Ending water balance, at the third cutting was – 3.3 inches, indicating that 85% of AWC was depleted. A total of 14.9 inches of water was applied in five irrigations. Rain supplied 8.2 inches. Total crop ET (ET_c) was 28.5 inches.

1998 season: Irrigation measurements began on May 26. There was one irrigation for the first alfalfa crop, three for the second, and four for the third, with a fall irrigation after the third cutting. Similar to Field No. 12, a deficit began just before the first cutting and persisted throughout the remainder of the season. According to the water balance calculations, all available water was depleted approximately one week before the third cutting. Total water applied (irrigation plus rain) for the three growth periods was 18.6 inches. Total crop water demand (ET_c) was 28.1 inches. Ending water balance, at the third cutting, was – 4.6 inches.

Watermark sensor readings: Figures 11 and 12 show the Watermark readings, irrigation and rain amounts for Field No. 8 in 1997 and 1998, respectively.

1997 season: The readings evolved in a similar fashion to Field No. 1, except late in the season. Both the 2.5 ft. and 4.0 ft. readings in this field dropped sharply after the last two water applications. In contrast, the 4.0 ft. readings remained high in Field No. 1 even after 6.9 inches of water was applied. Irrigation water depth in Field No. 8 was approximately 5 inches during the third period. However, more rain was recorded in Field No. 8 (5.8 inches) than in Field No.1 (2.5 inches) during the same period.

1998 season: Although the first irrigation on May 26 brought the 1.0 ft. sensor back to FC, the soil profile appeared to rapidly dry out, and all three sensors reached WP by June 19. The next irrigation brought the shallowest sensor to FC, but it was not until the irrigation of July 17 that the deepest sensor (4.0 ft.) was brought to FC. The sensor at 2.5 ft. remained near WP for the rest of the season and it is suspected of being faulty. The soil profile began another drying cycle and although the irrigations of August 11 and 14 brought the 1.0 ft. sensor back to FC, the 4.0 ft. sensor continued drying out until the irrigation of August 28 brought it to FC. The next drying cycle began, and the irrigation and rain of October 5 brought the 1.0 ft. sensor back to FC.

Discussion and recommendations: There was a total of five irrigations in 1997 and seven in 1998, but the total amount of water applied was about the same, approximately 15 inches. Total crop ET was also similar, even though the growing season was much longer in 1997 than in 1998 (166 vs. 144 days). Daily reference ET was generally higher in 1998 than in 1997 due to warmer and windier conditions in 1998. Substantially more rain was recorded during the growing season in 1997 than in 1998 (8.2 vs. 3.5 inches), which would explain the lower water deficit in 1997.

Watermark sensor readings were indicative of the water balance computations in 1997 but not in 1998. The readings in 1998 appear to be unreliable, particularly at the 2.5 and 4.0 ft. depths. The Watermark sensor readings reached WP around mid-June at the 1.0, 2.5, and 4.0 ft. depths. The shallow depth sensor reading dropped to below FC following the water application of June 26. The readings at 2.5 ft. hovered around WP (mostly above) for the remainder of the season, while the readings at 4.0 ft. fluctuated widely with each irrigation and rain event from July 17 forward. The opposite should be expected, since water should reach the 2.5 ft. sensor before it does the deeper one, unless there was preferential water flow or sensor malfunction.

Water did not appear to limit alfalfa growth during the first growth period in 1997, judging from the relatively high yield estimate (3.5 t/acre) and positive water balance. However, a second water application as late as possible before the first cut, and one shortly after the second cut, and better scheduling of subsequent irrigation events, could have helped maintain the available water in the root zone at or above MAD.

Field No. 8 had about 7.4 inches of allocated water that was not utilized in 1998. This would have been enough water for three additional irrigations. A good strategy would have been to add one irrigation before the first cutting, and possibly in early August, and to increase the amount of water applied per irrigation to the same level as in 1997 (3.0 inches on average). The additional water could have prevented the deficit from becoming so severe during the second and third growth periods.

Field No. 9: Field No. 9 was monitored in 1997 and Fields No. 10 and 11 were monitored in 1998.

Field description: This 76 acre field was seeded to ML 330 alfalfa in the spring of 1995 at 22 lb./acre. Three siderolls were used on this field. The predominant soil type is Cahona loam (fine-silty, mixed, superactive, mesic Calcidic Haplustalfs) with 2 to 3% slopes. This field had an excellent stand of alfalfa. It averaged 25 plants/ft.^{2} and 116 stems/ft.^{2} on July 8, 1997. Sample yield estimates were 2.3 t/acre at the first cut and 2.5 t/acre at the second cut. Third cut yield samples were not taken. Estimates from the owner/operator were not available. Alfalfa was cut early in June and September, which may have reduced hay tonnage compared to other fields but hay quality was excellent, according to the owner. Total season length was 139 days compared to 165 days on average for the other fields.

Water balance: Water balance information for Field No. 9 is shown in Table 16. This field was irrigated six times for a total application of 16.4 inches. Application depth ranged from 2.3 to 3.4 inches. Total irrigation plus rain was 22.4 inches. Total crop ET was 28.2 inches. Water balance computations show a slight deficit in mid to late June and a larger deficit in July and August. All available water was used up on August 26 but the irrigation of September 22 brought the water balance back to – 3.4 inches (88.5% AWC depleted). The field was cut on September 4.

Watermark sensor readings: Watermark sensor readings started close to FC at all three depths (Fig. 13). Readings at 1.0 ft. stayed at or below FC throughout most of the season, except for brief periods in mid-July and late August. The readings at 2.5 ft. started going up in early July and reached a maximum of 123 kPa on July 25, then dropped sharply after the monsoonal rains in late July to early August. The readings at both 1.0 and 2.5 ft. reached MAD on August 26 in spite of a water application of 2.5 inches on August 22, but dropped to around FC following a second irrigation on September 2. The readings at 4.0 ft. went up steadily in July and August, reached MAD on August 22 and remained close to MAD through the third cutting.

Discussion and recommendations: The Watermark sensor readings and water balance computations give a contradictory picture of water availability in Field No. 9, except early in the season. Both Table 16 and Fig. 13 show good water availability (positive water balance) in May and June. The Watermark sensor readings went up in July and August but rarely exceeded MAD, which would indicate a neutral to positive water balance during the second and third growth periods. Table 16 shows a negative water balance in July through September 4. The deficit was quite large on July 15 and August 26. An additional irrigation in early August would have been beneficial, except that hay curing and baling took longer than normal due to rain. Watermark sensor readings appear to better reflect water availability in Field No. 9, based on visual observations and alfalfa yield estimates.

Field No. 10

Field description: This 75 acre field was seeded with AV 120 alfalfa variety in 1997 by broadcasting at 20 lb./acre. The predominant soil type was Wetherill loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs) with 3 to 12% slopes. The previous crop was irrigated pinto beans that yielded 2300 lb./acre. The field was fertilized in the spring of 1998 with 16 lb. N, 75 lb. P_2O_5, 75 lb. K_2O, and 15 lb. S per acre. Butyrac 200 was applied at 1 pt./acre in September of 1997. The field was irrigated with a Lake sideroll, 1300 ft. long, with six foot wheels and a five inch pipe. It had 30, double Taylor nozzles sized at 7.0 and 8.0 gpm. Water use recorded at the delivery box was 133.5 AF for 1998 (May to October). This was 1.78 AF/acre based on a 75 acre field. Average water applied at three Watermark stations was 16.65 inches (104.1 AF, 1.39 AF/acre). These numbers indicated an irrigation system efficiency of 78%. This alfalfa field was cut in early June, mid July, and late September in 1998. The alfalfa yield samples indicated 2.8, 2.5, and 2.1 t/acre for the respective cuttings. However, the farmer's estimates were 2.3, 1.4, and 1.2 t/acre. The relative feed values were 193 for the first cutting and 209 for the second cutting.

Water balance: Water balance information for Field No. 10 (sideroll irrigated) is shown in Table 17. Irrigation measurements began on May 26. There was one irrigation for the first alfalfa crop, two for the second, and three for the third crop. A significant deficit began just before the first cutting. The deficit continued through the second and third growth periods with all available water depleted several times in each of the two periods. Total water applied (irrigation plus rain) for the three growth periods was 21.0 inches. Total crop water demand (ET_c) was 28.5 inches. Ending water balance, at the third cutting, was – 3.0 inches (85% of AWC depleted).

Watermark sensor readings: Figure 14 shows the Watermark readings, irrigation and rain amounts for Field No. 10 (average of three stations) from May 26, 1998 through October 5, 1998. As with most fields of the study, this field began the season at field capacity (FC). The field dried out almost to MAD after the first cutting in early June. The next irrigation on June 23 brought the 1.5 ft. sensors to FC but had little effect on the sensors at 3.0 ft. The sensors then continued drying out and the 3.0 ft. sensors reached MAD on June 30. The next irrigation on July 2 brought the entire soil profile back to FC. After the second cutting in mid July, the field dried out to about MAD by August 7. The following irrigation on August 14 brought the 1.5 ft. sensors back to FC, but again, the irrigation had little effect on the 3.0 ft. sensors. The field continued drying out and the 3.0 ft. sensors almost reached WP on August 21. The next irrigation on August 28 again brought the soil profile back to FC. The last irrigation on September 11 kept the soil profile at FC. The field began another drying cycle with the third cutting in late September and the 3.0 ft. sensors almost reached MAD by October 5.

Discussion and recommendations: It is difficult to make recommendations for Field No. 10 based on the water balance calculations and the Watermark sensor readings because of a similar discrepancy as was noted for Fields No. 4 and 11. However, the water balance calculations and the Watermark sensor readings did somewhat agree for the period from August 7 to August 25. The water balance calculations showed large negative values for this period, while the Watermark sensor readings for the 3.0 ft. sensors also indicated negative water balance values (above MAD) and the reading on August 21 approached WP (all available water depleted). Given the time constraints of raking and baling operations, if another irrigation could have been applied as soon as possible before the irrigation on August 14, the soil profile at 3.0 ft. may not have been so greatly depleted.

Field No. 11

Field description: This field was seeded to alfalfa in 1997 at 20 lb./acre. The predominant soil type was Wetherill loam (fine-silty, mixed, superactive, mesic Aridic Haplustalfs) with 6 to 12% slopes. The north section of the field that was monitored was watered with a sideroll equipped with single nozzle sprinkler heads. The field sloped down to the east, but the monitored area was fairly level. The alfalfa was cut in early June, early August, and late September. The alfalfa yield samples indicated 2.6, 2.2, and 1.7 t/acre for the respective cuttings.

Water balance: Table 18 shows the water balance information for Field No. 11 (sideroll irrigated). Irrigation measurements began on May 26. There were two irrigations for the first alfalfa crop, two for the second, and three for the third crop. A slight deficit began at the first cutting and grew large, with all available water depleted on July 21, during the second growth period. The deficit continued throughout the third growth period. Total water applied (irrigation plus rain) for the three growth periods was 25.1 inches. Total crop water demand (ET_c) was 28.7 inches. Ending water balance, at the third cutting, was – 1.8 inches. (70.5% of AWC depleted).

Watermark sensor readings: The Watermark readings, irrigation and rain amounts for Field No. 11 (average of three stations) from May 26, 1998 through October 5, 1998 are shown in Fig. 15. The field began the season at field capacity (FC) and although the 1.5 ft. sensors dried out to MAD by July 6, the irrigation and rains of early July brought the soil profile back to FC on July 10. The field appeared to be abundantly watered. Whenever the soil profile dried out to about halfway to MAD, or before, an irrigation brought it back to FC. The field ended the season with the soil profile near FC.

Discussion and recommendations: There was a great discrepancy between the information provided by the water balance calculations and the information provided by the Watermark sensor readings for Field No. 11. The water balance information indicated a water deficit (negative values) throughout the second and third growth periods, while the Watermark sensor information indicated soil water capacity below MAD (positive values) for practically the entire season. Only once, on July 6, did the Watermark sensors at 1.5 ft. reach MAD. The readings were consistent among the three Watermark stations, as were the precipitation (rain and irrigation) amounts. The Watermark sensor readings appear to better reflect the crop condition (no noticeable stress) during the growing season and the relatively high yield estimates than do the water balance computations.

Field No. 12

Field description: This 80 acre field was seeded to alfalfa in 1993 at 20 lb./acre. The predominant soil series is Wetherill. The section of the field that was monitored had a 1275 ft. sideroll equipped with single nozzle sprinkler heads. Nozzle size was mostly 5/32 inch but there were few 13/64 inch. After it was pointed out to the operator that he was not getting enough water, he changed the nozzles to 11/64 inch later in the season. This field had similar topography and soil type to Field No.1. Alfalfa stand counts on July 8, 1997 averaged 102 stems/$ft.^2$ and 16 plants/$ft.^2$. The alfalfa yield samples that were taken at the one Watermark station showed yields of 1.8, 1.7, and 1.7 t/acre in 1997 and 4.0, 2.8, and 2.0 t/acre in 1998 for the first, second, and third cuttings, respectively. The farmer's estimate for the whole field and all three cuttings was 5.1 t/acre in 1997. Farmer's estimates for 1998 were not available.

Water balance: Water balance information for Field No. 12 (sideroll irrigated) is shown in Tables 19 (1997) and 20 (1998).

1997 season: This field was irrigated six times for a total application of 14.1 inches. Rain amount was approximately 10.4 inches in 165 days. Water was applied in 22 to 23-hour sets during the first irrigation and 9 to 11-hour sets afterwards. The first (4.0 inches) and second irrigations (1.9 inches) and early first cutting helped maintain the water balance at or below MAD through June. The next two irrigations only averaged 1.5 to 1.6 inches each. Most of the available moisture was depleted in July due to low water application and high evaporative demand (warm and dry weather). The last two water applications averaged 2.6 inches due to the larger nozzle size (11/64 inch vs. 5/32 inch earlier) used but were not enough to maintain adequate soil moisture despite above average rainfall. Total crop ET was 30.9 inches and the ending water balance was – 4.0 inches (96% of AWC depleted).

1998 season: Irrigation measurements began on May 26. There was one irrigation for the first alfalfa crop, two for the second, and four for the third. According to the water balance calculations, a deficit began about June 2 and quickly became significant. The deficit continued throughout the remainder of the season. Available water was depleted from July 17 to July 24 and again around August 3. Total water applied (irrigation plus rain) for the three growth periods was 20.3 inches. Total crop water demand (ET_c) was 28.0 inches. Ending water balance, at the third cutting, was – 3.3 inches (88% of AWC depleted).

<u>Watermark sensor readings:</u> Figures 16 and 17 show the Watermark readings, irrigation and rain amounts for Field No. 12 in 1997 and 1998, respectively.

1997 season: Watermark readings were relatively low (below MAD) in May and June but went up sharply in July for the same reasons explained above under "water balance." The readings at 1.0, 2.5, and 4.0 ft. reached MAD around July 10 and WP in mid to late July. The monsoonal rains in late July to early August brought the reading at 1.0 ft. from 174 kPa on August 1 down to 5 kPa on August 5. It was not until after the irrigation on August 22 that the reading at 2.5 ft. also dropped sharply. The readings at 4.0 ft. fluctuated somewhat but remained at or above WP throughout most of the third growth period.

1998 season: The field did not appear to start the season at field capacity (FC), and although the first irrigation brought the 1.0 and 2.5 ft. deep sensors to FC, water was apparently not able to reach the sensor at 4.0 ft. The soil profile appeared to rapidly dry out and although the next irrigation on June 26 was able to bring the 1.0 ft. sensor to near FC, the two deeper sensors remained at wilting point (WP). The next irrigation on July 6 appeared to bring the two shallower sensors to FC while the 4.0 ft. deep sensor remained at WP. The soil profile began another drying cycle, the following rains were of little help, and all three sensors appeared to be at WP by August 7. The next irrigation on August 18 seemed to bring the two shallower sensors back to FC, and with the following irrigation on August 25, all three sensors were at FC. With subsequent irrigations and rains, the sensors at 1.0 and 2.5 ft. stayed near FC, but the sensor at 4.0 ft. began drying out for the remainder of the season.

<u>Discussion and recommendations:</u> Both the water balance calculations and Watermark sensor readings indicate inadequate water management in Field No. 12 in 1997 and 1998. Water availability was adequate in May and June of 1997 but lagged behind crop ET in July through September. More water could have been applied on June 25, July 11, and July 18. The sprinkler nozzles (5/32 inch) used during the first and second growth periods only deliver about 4.5 gpm, which is below the water allotment (5.8 gpm) for the Full Service Irrigators. Had a larger nozzle, e.g. 11/64 inch, been used earlier, three to four inches of additional water would have been applied. Another 2.5 to 2.6 inches could have been added before the third cutting in one application, which would have kept the water deficit from becoming large.

A total of 8.4 inches and 6.6 inches of allocated water was not utilized in 1997 and 1998, respectively. The water deficit was more severe in 1998 than in 1997 because of lower rainfall (4.3 inches vs. 10.4 inches) in 1998. Two irrigations could have been added in 1998, one before the first cutting and one before the second cutting. These additional irrigations would have kept the water balance at a more manageable level. For unknown reasons, the water balance calculations (negative values) and the Watermark sensor readings (below MAD, which are equivalent to positive water balance values) did not agree for the third growth period in 1998. Furthermore, alfalfa yield estimates appear to be too high in 1998, particularly for the first cutting.

Table 4. 1997 water balance for alfalfa Field No. 1.

	Water balance (all units are inches)							MAD: 4.85"		
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/13*	28	0.60		5.14	0.69	3.55	2.95	1.90		
5/15	30			0.50	0.96	0.48	3.43	1.42		
5/19	34	0.10	2.93	1.20	0.98	1.18	2.02	2.83	14.0	irrigation on 5/17
5/21	36	0.21		0.30	1.00	0.30	2.11	2.74		
5/23	38	0.56		0.15	1.00	0.15	1.70	3.15	17.0	budding
5/27	42	0.52		0.65	1.00	0.65	1.83	3.02	20.0	
5/29	44			0.50	1.00	0.50	2.33	2.52		
6/2	47			1.50	1.00	1.50	3.83	1.02	22.0	
6/4	49			0.55	1.00	0.55	4.38	0.47	24.0	
6/6	51			0.75	1.00	0.75	5.13	-0.28		
6/9	54	0.15		0.30	1.00	0.30	5.28	-0.43	25.0	some bloom
6/11	56	0.05		0.35	1.00	0.35	5.58	-0.73	25.0	0-10% bloom
6/13	58			0.60	1.00	0.60	6.18	-1.33		
6/16	61			0.87	1.00	0.87	7.05	-2.20	28.0	10% bloom
6/18	63			0.35	1.00	0.35	7.40	-2.55	31.0	10-20% bloom
Subtotal		2.19	2.93	13.71		12.07				field and plots cut on 6/18
6/23	5			0.35	0.30	0.11	7.50	-2.65		
6/25	7			0.65	0.34	0.22	7.62	-2.77		
6/27	9			0.85	0.42	0.36	7.97	-3.12		
7/1	13		2.38	1.55	0.53	0.82	6.77	-1.92	5.0	
7/3	15			0.70	0.64	0.45	7.22	-2.37		
7/7	19			1.70	0.76	1.29	8.51	-3.66	12.0	
7/9	21		2.69	0.60	0.79	0.47	6.70	-1.85	13.0	
7/11	23			0.70	0.94	0.66	7.36	-2.51	15.0	
7/15	27			1.45	1.00	1.45	8.81	-3.96		
7/18	30			1.20	1.00	1.20	**9.70**	**-4.85**		
7/22	34	0.15	2.64	1.10	1.00	1.10	8.41	-3.56	27.0	30% bloom
7/25	37	0.05		1.05	1.00	1.05	9.41	-4.56		40% bloom
7/29	41	0.85		0.70	1.00	0.70	9.26	-4.41	28.0	50% bloom, lodging
8/1	43	0.50		0.30	1.00	0.30	9.06	-4.21	30.0	lodging
8/5	47	1.10		0.85	1.00	0.85	8.81	-3.96		80% bloom
8/7	49			0.30	1.00	0.30	9.11	-4.26		
8/11	53	0.70		0.70	1.00	0.70	9.11	-4.26		
8/13	55			0.50	1.00	0.50	9.61	-4.76		hay samples cut on 8/13
Subtotal		3.35	7.71	15.25		12.53				
8/18	5			0.30	0.32	0.10	**9.70**	**-4.85**	7.0	irrigation amount estimated
8/26	13	0.10	2.67	2.36	0.45	1.06	8.39	-3.54		bales still on field (8/22)
9/2	19	0.73		1.60	0.77	1.23	8.90	-4.05	11.0	irrigation on 8/26
9/4	21			0.50	0.94	0.47	9.37	-4.52		
9/8	25	0.20	4.20	0.90	1.00	0.90	6.50	-1.65	15.0	
9/10	27			0.55	1.00	0.55	7.05	-2.20	17.0	
9/17	34	1.00		1.30	1.00	1.30	7.35	-2.50	21.0	10% bloom
9/22	39	0.50		0.85	1.00	0.85	7.70	-2.85		
9/24	41			0.33	1.00	0.33	8.03	-3.18	23.0	
9/29	46			0.76	1.00	0.76	8.79	-3.94		missed plots
Subtotal		2.53	6.87	9.45		7.55				
Total		**8.07**	**17.51**	**38.41**		**32.15**				

*Cumulative rain and ETr amounts up to May 13 are from the CoAgmet weather station at Yellow Jacket.

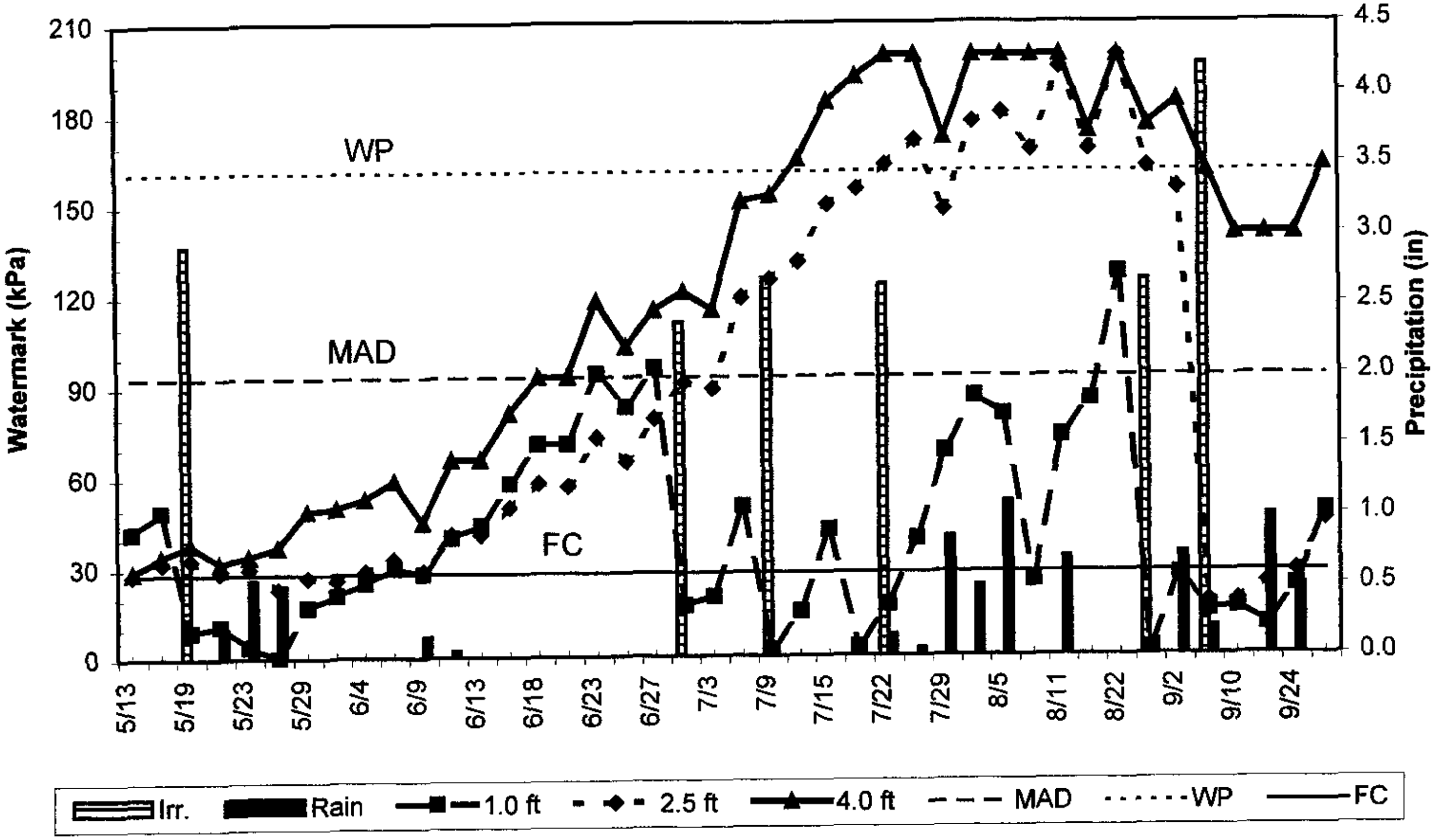

Figure 1. 1997 Watermark sensor readings and precipitation amounts for alfalfa Field No. 1.

Table 5. 1998 water balance for alfalfa Field No. 1.

	Water balance (all units are inches)						MAD: 4.85"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/11*	21	0.68		4.40	0.63	2.77	2.09	2.76	9.0	ETgage installed
5/14	24			0.50	0.90	0.45	2.54	2.31	10.0	soil surface very dry
5/20	30		2.00	1.50	0.96	1.44	2.28	2.57	13.0	irrigation started on 5/18
5/28	38		1.61	2.00	1.00	2.00	2.91	1.94	17.0	bud stage
6/1	42		2.29	1.10	1.00	1.10	2.07	2.78	19.0	
6/4	45			0.80	1.00	0.80	2.87	1.98	21.0	
6/8	49			0.80	1.00	0.80	3.67	1.18	21.0	bud stage
6/11	52			0.50	1.00	0.50	4.17	0.68	21.0	cut hay sample
6/15	56			1.00	1.00	1.00	5.17	-0.32	24.0	partial bloom, lodging
6/18	59	0.05		0.70	1.00	0.70	5.82	-0.97	26.0	3% bloom, field still not cut
Subtotal		0.73	5.90	13.30		11.56				
6/26	8			1.36	0.36	0.49	6.31	-1.46		re-installed gages
6/29	11		2.87	1.00	0.47	0.47	4.34	0.51	3.0	regrowth
7/1	13			0.80	0.57	0.46	4.79	0.06	3.0	
7/6	18	0.05		1.40	0.70	0.98	5.72	-0.87	9.0	
7/9	21	0.10	3.05	0.50	0.85	0.43	3.46	1.39	12.0	full cover
7/13	25			0.90	0.97	0.87	4.33	0.52	15.0	
7/16	28			0.90	1.00	0.90	5.23	-0.38	17.0	bud stage
7/20	32		2.29	1.00	1.00	1.00	4.28	0.57	20.5	1% bloom
7/23	35	0.10		0.70	1.00	0.70	4.88	-0.03	24.0	
7/27	39	0.40		0.60	1.00	0.60	5.08	-0.23	25.0	2% bloom, lodging
7/30	42	0.20		0.40	1.00	0.40	5.28	-0.43	29.0	3% bloom, lodging
8/3	46		2.44	1.00	1.00	1.00	4.21	0.64		cut hay sample
8/6	49			0.60	1.00	0.60	4.81	0.04		
Subtotal		0.85	10.65	11.16		8.89				
8/13	7		2.25	0.50	0.32	0.16	3.06	1.79	3.5	green up
8/17	11			0.70	0.45	0.32	3.37	1.48	5.5	
8/20	14			0.60	0.59	0.35	3.72	1.13	7.0	
8/24	18		2.43	0.70	0.72	0.50	2.16	2.69	10.0	full cover
8/27	21	0.10		0.50	0.85	0.43	2.49	2.36	13.0	full cover
8/31	25			0.80	0.97	0.78	3.26	1.59		
9/3	28		3.04	0.40	1.00	0.40	1.08	3.77	18.0	bud stage
9/8	33			0.80	1.00	0.80	1.88	2.97	20.0	
9/10	35			0.40	1.00	0.40	2.28	2.57	20.0	1% bloom
9/11	36			0.14	1.00	0.14	2.42	2.43		cut hay sample
Subtotal		0.10	7.72	5.54		4.27				
Total		**1.68**	**24.27**	**30.00**		**24.73**				

*Cumulative rain and ETr amounts up to May 11 are from the CoAgmet weather station at Yellow Jacket.

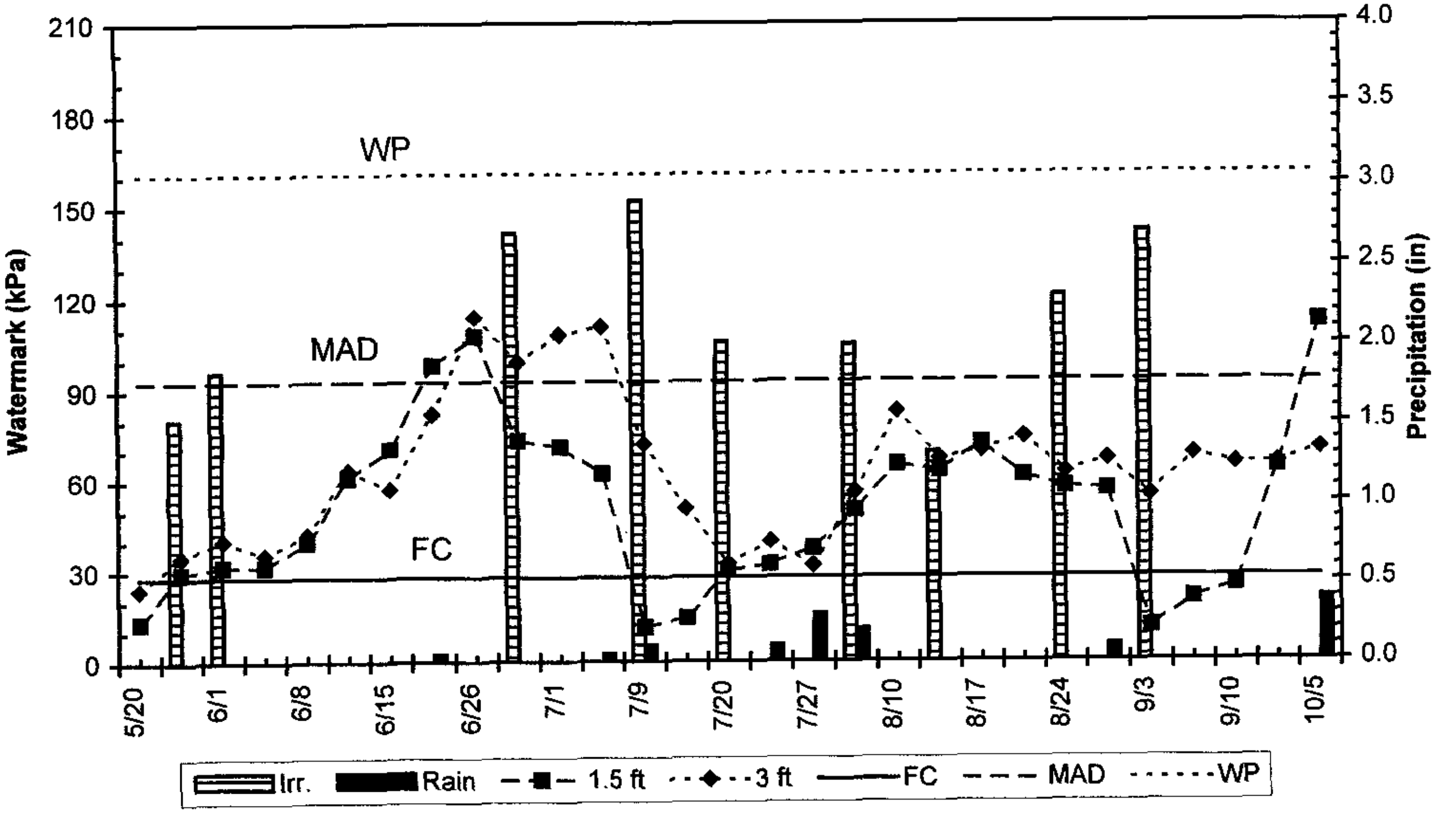

Figure 2. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 1.

Table 6. 1998 water balance for alfalfa Field No. 2.

	Water balance (all units are inches)						MAD: 4.85"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/19*	29	0.68	3.00	6.46	0.76	4.91	1.68	3.17	12.0	irrigation amount estimated started on 5/12
5/28	38		3.70	2.00	1.00	2.00	0.53	4.32	17.0	bud stage
6/1	42			1.10	1.00	1.10	1.63	3.22	18.0	
6/4	45			0.80	1.00	0.80	2.43	2.42	20.0	bud stage
6/5	46			0.25	1.00	0.25	2.68	2.17	21.0	cut hay
Subtotal		0.68	6.70	10.61		9.06				
6/10	5			0.25	0.30	0.08	2.76	2.09		made small bales
6/16	11		3.00	1.48	0.57	0.84	1.05	3.80	5.5	
6/18	13			0.45	0.70	0.32	1.37	3.48	5.7	regrowth
6/25	20			2.40	0.83	1.99	3.36	1.49	7.7	
6/29	24		2.58	1.30	0.94	1.22	2.39	2.46	10.5	
7/1	26			0.80	0.99	0.79	3.18	1.67	11.2	full cover
7/6	31	0.05		1.40	1.00	1.40	4.53	0.32	17.0	
7/9	34	0.10	3.08	0.50	1.00	0.50	2.31	2.54	19.2	
7/13	38			0.90	1.00	0.90	3.21	1.64	22.3	bud stage
7/16	41			0.90	1.00	0.90	4.11	0.74	25.3	2% bloom
7/18	43			0.50	1.00	0.50	4.61	0.24		cut hay
Subtotal		0.15	8.66	10.88		9.44				
7/23	5	0.10	3.38	0.23	0.30	0.07	1.71	3.14	3.3	green up
7/27	9	0.40		0.60	0.51	0.31	1.62	3.23	4.2	
7/30	12	0.20		0.40	0.64	0.26	1.67	3.18	5.3	
8/3	16			1.00	0.77	0.77	2.44	2.41	9.3	
8/6	19			0.60	0.91	0.55	2.99	1.86	11.7	
8/10	23		1.85	1.00	1.00	1.00	2.41	2.44	13.0	full cover
8/13	26		0.14	0.50	1.00	0.50	2.80	2.05	16.0	
8/17	30	0.05		0.70	1.00	0.70	3.45	1.40	18.3	bud stage
8/20	33			0.60	1.00	0.60	4.05	0.80		
8/24	37		2.05	0.70	1.00	0.70	3.00	1.85	21.7	
8/27	40	0.10		0.50	1.00	0.50	3.40	1.45	22.3	early bloom
8/31	44			0.80	1.00	0.80	4.20	0.65	25.7	
9/1	45			0.13	1.00	0.13	4.33	0.52		cut hay
Subtotal		0.85	7.42	7.76		6.88				
Total		**1.68**	**22.78**	**29.25**		**25.38**				

*Cumulative rain and ETr amounts up to May 19 are from the CoAgmet weather station at Yellow Jacket.

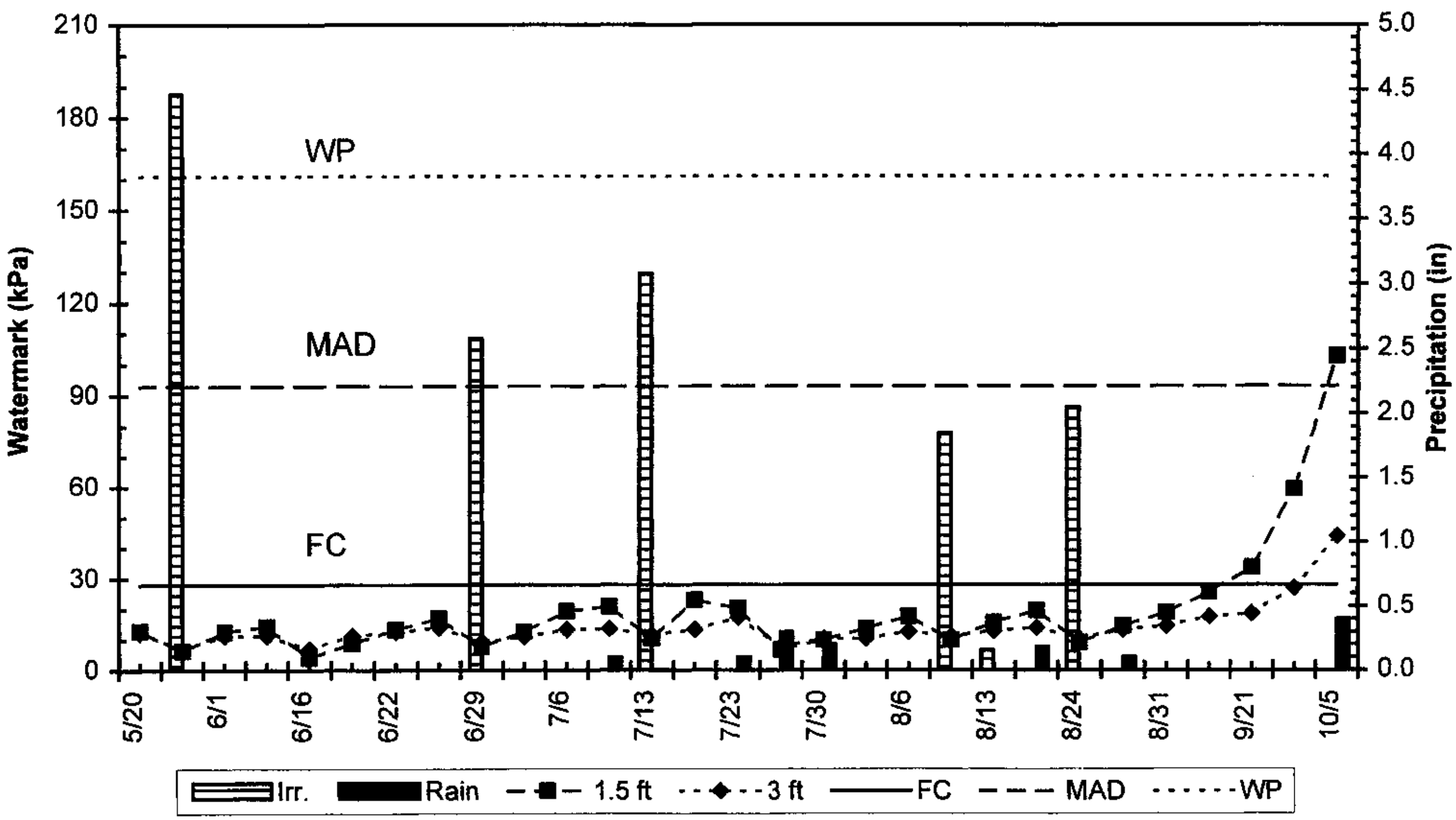

Figure 3. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 2.

Table 7. 1997 water balance for alfalfa Field No. 3.

	Water balance (all units are inches)						MAD: 4.60"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/15*	30	0.66		5.67	0.71	3.30	2.70	1.90	9.0	
5/19	34		0.60	1.30	0.98	1.27	3.46	1.14	14.0	
5/21	36	0.30	0.35	0.12	1.00	0.12	2.99	1.61	19.0	some budding
5/23	38	0.30	0.65	0.20	1.00	0.20	2.33	2.27		
5/27	42	0.60	1.10	0.68	1.00	0.68	1.48	3.12		
5/29	44			0.50	1.00	0.50	1.98	2.62		
6/2	47		1.60	1.45	1.00	1.45	2.07	2.53	24.0	
6/4	49		0.65	0.60	1.00	0.60	2.12	2.48		
6/6	51			0.65	1.00	0.65	2.77	1.83		
6/9	54	0.05		0.30	1.00	0.30	3.02	1.58		
6/11	56	0.10		0.35	1.00	0.35	3.27	1.33		lodging
6/13	58			0.60	1.00	0.60	3.87	0.73		
6/16	61			0.75	1.00	0.75	4.62	-0.02	29.0	0-10% bloom
6/18	63			0.35	1.00	0.35	4.97	-0.37	32.0	plots cut on 6/16
Subtotal		2.01	4.95	13.52		11.12				
6/25	7			0.75	0.30	0.23	5.19	-0.59		baling in progress
6/27	9			0.90	0.38	0.34	5.53	-0.93		
7/1	13			1.85	0.45	0.83	6.37	-1.77		
7/3	15			0.75	0.57	0.43	6.79	-2.19	5.0	
7/7	19		0.64	1.52	0.68	1.03	7.28	-2.68	8.0	
7/9	21			0.75	0.79	0.59	7.88	-3.28	9.0	
7/11	23		0.95	0.75	0.91	0.68	7.75	-3.15	11.0	
7/15	27		1.75	1.50	1.00	1.50	7.76	-3.16		
7/18	30		0.88	1.20	1.00	1.20	8.22	-3.62	18.0	
7/22	34	0.52		1.05	1.00	1.05	8.75	-4.15	21.0	0-10% bloom
7/26	38	0.15		0.90	1.00	0.90	9.10	-4.50	25.0	10% bloom
7/29	41	0.85		0.75	1.00	0.75	9.00	-4.40		plots cut on 7/28
8/1	43	0.50		0.30	1.00	0.30	8.80	-4.20	26.0	60% bloom
8/5	47	1.40		0.90	0.60	0.54	7.94	-3.34		lodging on uncut
8/7	49			0.30	0.50	0.15	8.09	-3.49		field 60% cut on 8/5
8/11	53	0.35		0.85	0.30	0.26	8.00	-3.40		2nd cut complete
Subtotal		3.77	4.22	15.02		10.78				
8/14										hay still on the ground
8/22	11			1.85	0.55	1.02	9.01	-4.41		irrigation in progress
8/26	15		1.21	1.00	0.65	0.65	8.63	-4.03	9.0	
9/2	21	0.35	2.45	1.35	0.95	1.28	7.48	-2.88	13.0	
9/4	23		1.11	0.50	0.98	0.49	7.03	-2.43	14.0	
9/8	27		0.89	0.80	1.00	0.80	7.07	-2.47	17.0	
9/10	29			0.40	0.85	0.34	7.41	-2.81	21.0	outer 2 circles
9/17	36	1.35		1.15	0.75	0.86	6.93	-2.33	23.0	outer 4 circles cut
9/22	41	0.30		0.60	0.50	0.30	6.93	-2.33		
9/24	43	0.05		0.35	0.40	0.14	7.02	-2.42	24.0	some lodging on uncut
9/29	48			1.07	0.30	1.07	8.09	-3.49		third cut completed
Subtotal		2.05	5.66	9.07		6.95				
Total		**7.83**	**14.83**	**37.61**		**28.86**				

*Cumulative rain and ETr amounts up to May 15 are from the CoAgmet weather station at Yellow Jacket.

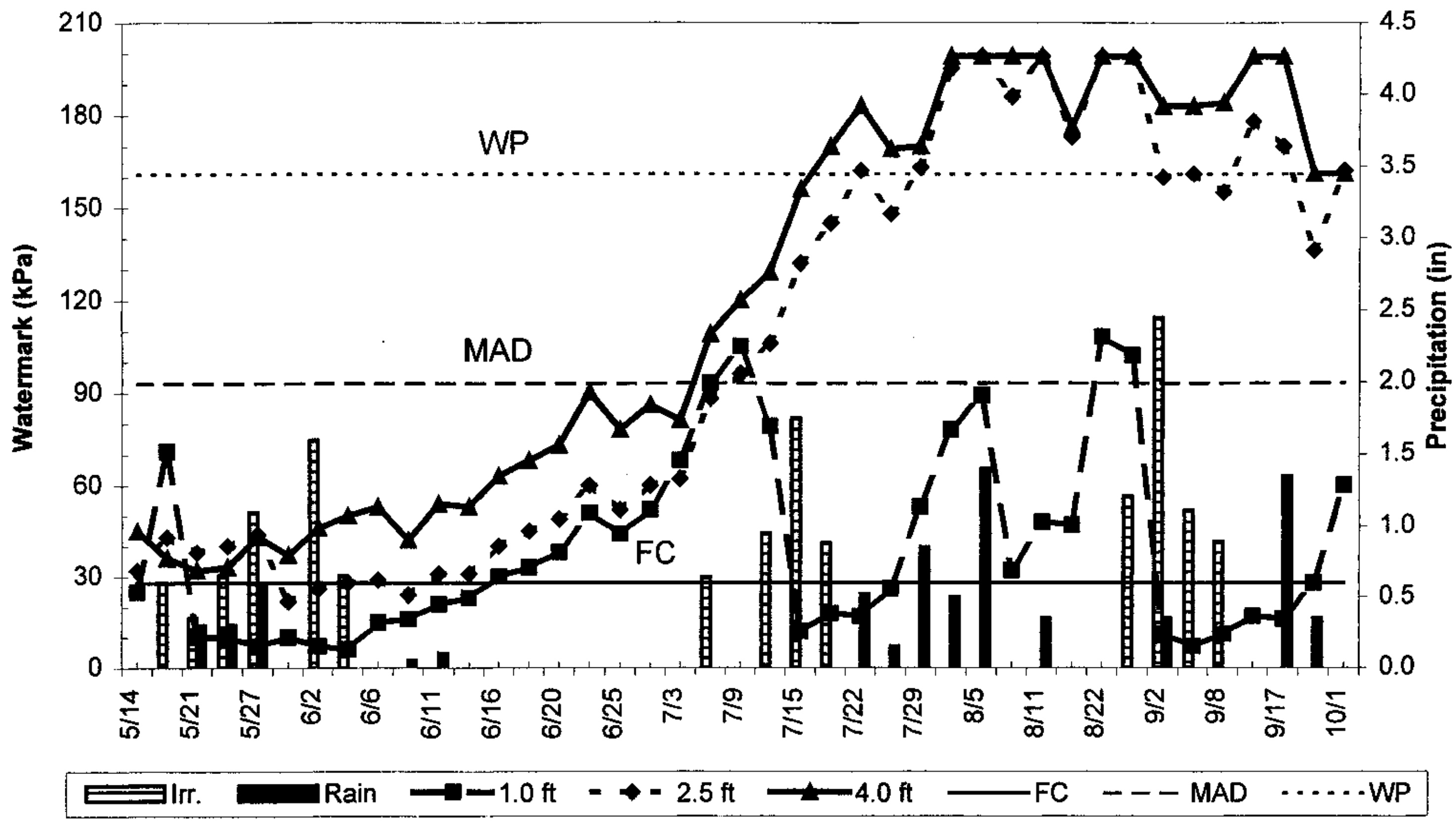

Figure 4. 1997 Watermark sensor readings and precipitation amounts for alfalfa Field No. 3.

Table 8. 1998 water balance for alfalfa Field No. 3.

	Water balance (all units are inches)						MAD: 4.60"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/14*	24	0.68	1.20	5.10	0.65	3.32	1.62	2.99	8.0	
5/28	38		2.91	3.10	0.97	3.01	2.15	2.45	17.0	three irrigations, bud stage
6/1	42		0.70	1.10	1.00	1.10	2.65	1.95	20.0	
6/4	45		0.74	1.00	1.00	1.00	3.02	1.58	20.0	
6/8	49		0.86	1.00	1.00	1.00	3.29	1.31	21.0	
6/11	52		0.86	0.70	1.00	0.70	3.26	1.34	21.5	cut hay sample (6/12)
6/15	56			1.12	1.00	1.12	4.38	0.22		field cut
Subtotal		0.68	7.27	13.12		11.24				
6/25	10			1.66	0.43	0.71	5.10	-0.50		
6/29	14		0.66	1.70	0.57	0.97	5.50	-0.90	4.0	regrowth
7/1	16		0.76	1.00	0.68	0.68	5.54	-0.94	5.0	
7/6	21		1.48	1.80	0.81	1.46	5.74	-1.14	9.0	two irrigations, pivot stuck
7/9	24	0.20	0.74	0.60	0.96	0.58	5.49	-0.89	12.0	full cover
7/13	28	0.10	0.82	1.00	1.00	1.00	5.69	-1.09	15.0	
7/16	31		0.78	1.20	1.00	1.20	6.23	-1.63	20.5	bud stage
7/20	35		0.91	1.30	1.00	1.30	6.75	-2.15	21.5	
7/22	37	0.10		0.48	1.00	0.48	7.13	-2.53		cut hay sample
Subtotal		0.40	6.15	10.74		8.38				(2nd cutting date unknown)
8/10	9			2.90	0.30	0.87	8.00	-3.40		baling in progress
8/13	12			0.70	0.36	0.25	8.25	-3.65		
8/17	16	0.95	0.90	1.10	0.45	0.50	7.03	-2.43	3.0	pivot stuck on 8/16 & 8/18
8/20	19			0.90	0.51	0.46	7.49	-2.89	4.0	green up, pivot stuck once
8/24	23		2.00	0.80	0.76	0.61	6.40	-1.80	6.0	two irrigations
8/27	26		1.15	0.70	0.89	0.62	6.05	-1.45	9.0	
8/31	30		0.91	1.10	0.96	1.06	6.33	-1.73	11.0	
9/3	33		1.04	0.50	1.00	0.50	5.94	-1.34	13.0	full cover
9/8	38			1.20	1.00	1.20	7.14	-2.54	14.0	bud stage
9/10	40			0.40	1.00	0.40	7.54	-2.94	15.5	1% bloom
9/11	41			0.18	1.00	0.18	7.72	-3.12		cut hay sample
Subtotal		0.95	6.00	10.48		6.64				
Total		**2.03**	**19.42**	**34.34**		**26.26**				

*Cumulative rain and ETr amounts up to May 14 are from the CoAgmet weather station at Yellow Jacket.

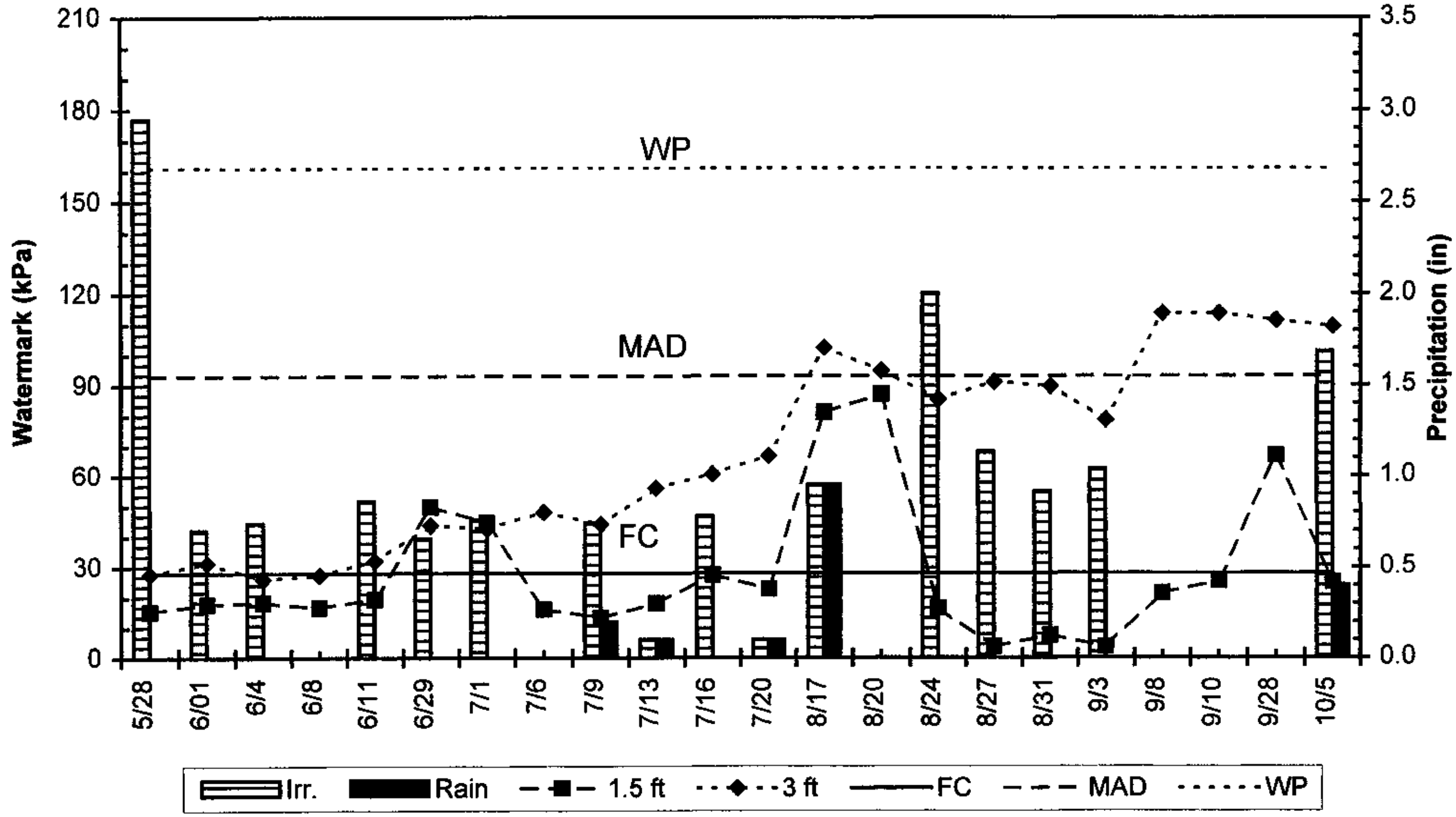

Figure 5. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 3.

Table 9. 1998 water balance for alfalfa Field No. 4.

Water balance (all units are inches)							MAD: 4.85"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/14*	24	0.68	1.00	5.10	0.65	3.32	1.79	3.07		
5/28	38		2.72	3.10	1.00	3.10	2.57	2.28	17.0	three irigations
6/1	42		0.92	1.10	1.00	1.10	2.89	1.96	19.0	bud stage
6/4	45		1.06	1.00	1.00	1.00	2.99	1.86	20.0	
6/8	49			1.00	1.00	1.00	3.99	0.86	21.0	
6/11	52			0.70	1.00	0.70	4.69	0.16		field cut
Subtotal		0.68	5.70	12.00		10.22				(hay sample on 6/10)
6/16	5									baling in progress
6/22	11			3.10	0.40	1.24	5.93	-1.08	3.5	bale removal
6/25	14			1.10	0.59	0.65	6.58	-1.73		
6/29	18		0.66	1.70	0.72	1.22	7.24	-2.39	6.0	
7/1	20		0.83	1.00	0.83	0.83	7.37	-2.52	8.0	
7/6	25	0.05	1.58	1.80	0.96	1.73	7.70	-2.85	13.0	two irrigations
7/9	28	0.20		0.60	1.00	0.60	8.10	-3.25	15.0	
7/13	32	0.10	1.69	1.00	1.00	1.00	7.57	-2.72	21.0	two irrigations
7/16	35			1.20	1.00	1.20	8.77	-3.92	23.0	bud/early bloom
7/17	36			0.33	1.00	0.33	9.10	-4.25		cut hay sample
Subtotal		0.35	4.76	11.5		8.47				(2nd cutting date unknown)
7/22	5			0.24	0.30	0.07	9.17	-4.32		
8/6	20	1.05		3.62	0.60	2.17	**9.70**	**-4.85**	5.3	green up
8/10	24		0.73	1.40	0.72	1.01	**9.70**	**-4.85**		
8/13	27		0.93	0.70	0.81	0.57	9.48	-4.63	6.7	
8/17	31		0.77	1.10	0.94	1.03	**9.70**	**-4.85**	11.0	
8/20	34		0.78	0.90	0.97	0.87	**9.70**	**-4.85**	12.0	full cover
8/24	38	0.05	1.68	0.80	1.00	0.80	9.02	-4.17	14.0	two irrigations
8/27	41		0.90	0.70	1.00	0.70	8.96	-4.11	16.0	bud stage
8/31	45			1.10	1.00	1.10	**9.70**	**-4.85**	22.0	bud/early bloom
9/3	48			0.50	1.00	0.50	**9.70**	**-4.85**		cut hay sample (9/2)
Subtotal		1.10	5.79	11.06		8.83				(3rd cutting date unknown)
Total		**2.13**	**16.25**	**34.56**		**27.51**				

*Cumulative rain and ETr amounts up to May 14 are from the CoAgmet weather station at Yellow Jacket.

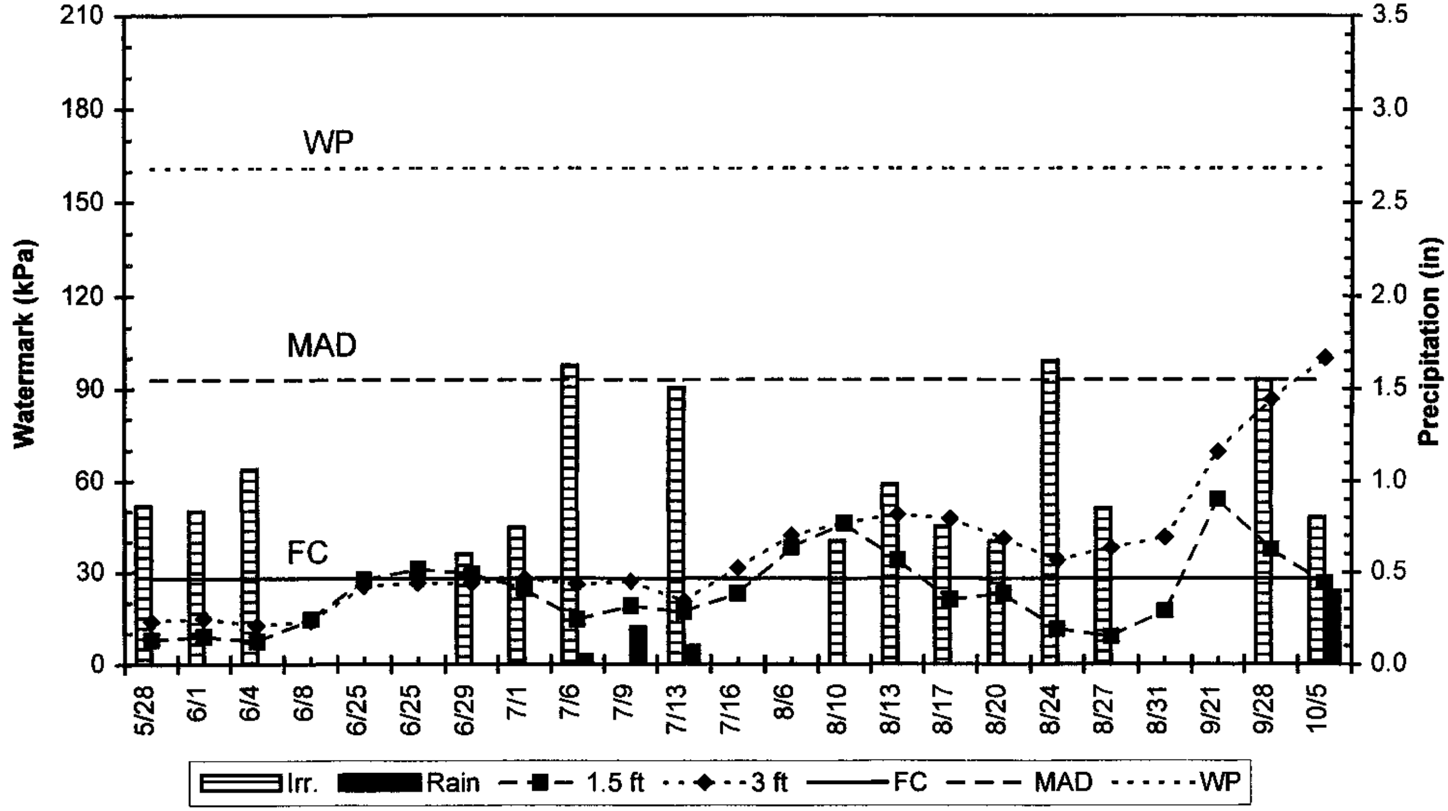

Figure 6a. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 4. Average of three stations.

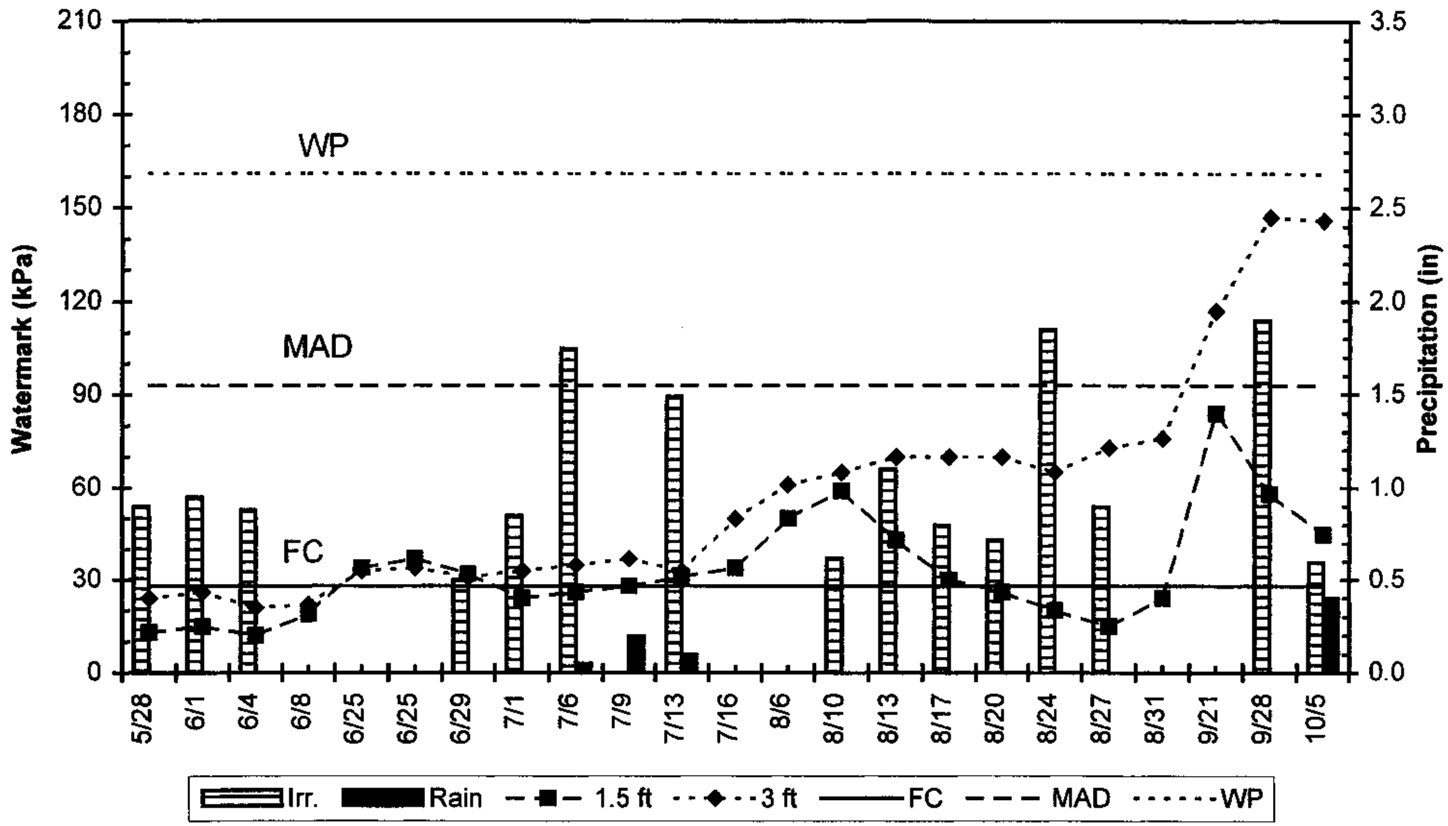

Figure 6b. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 4. Station No. 1.

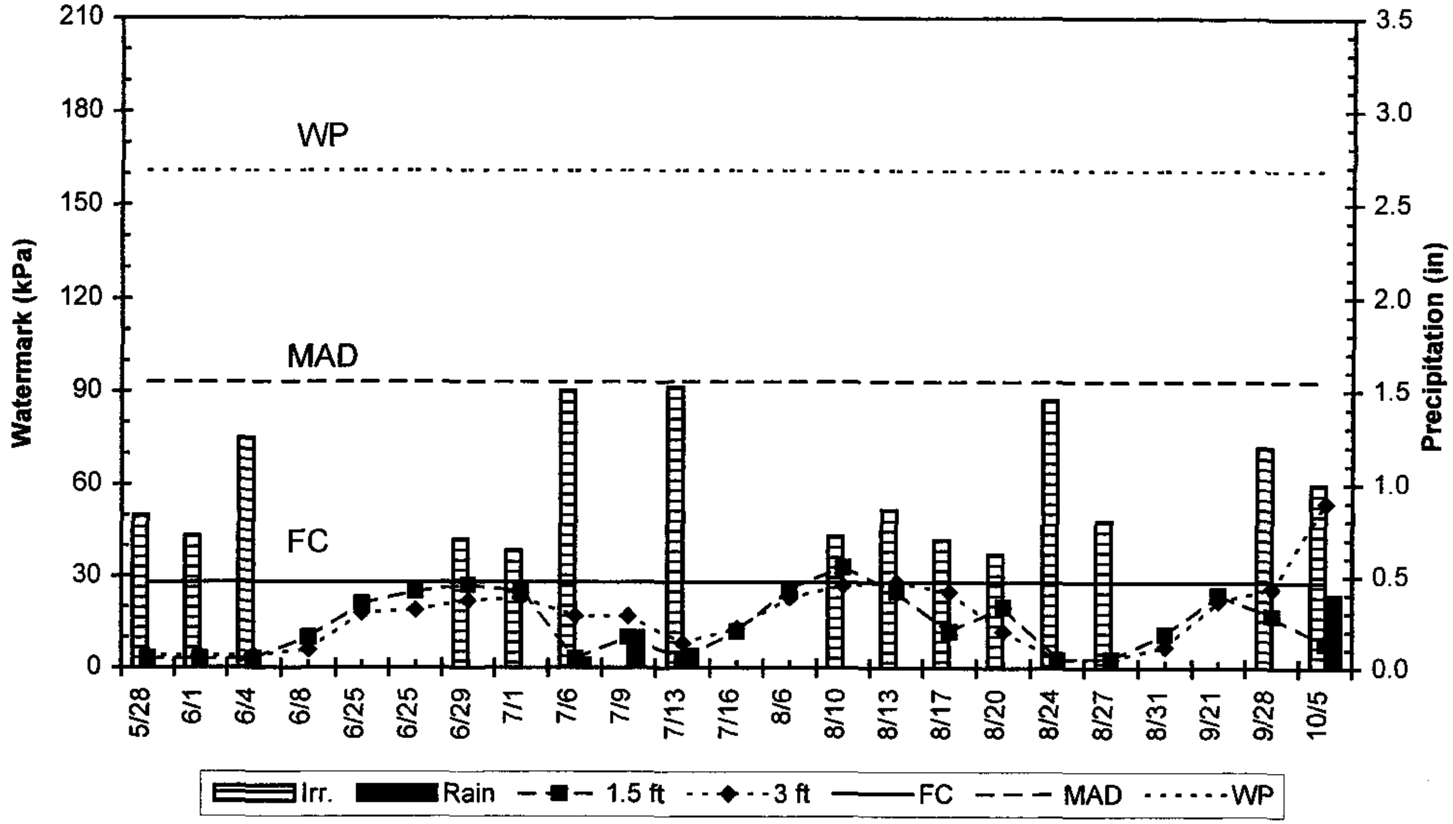

Figure 6c. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 4. Station No. 2.

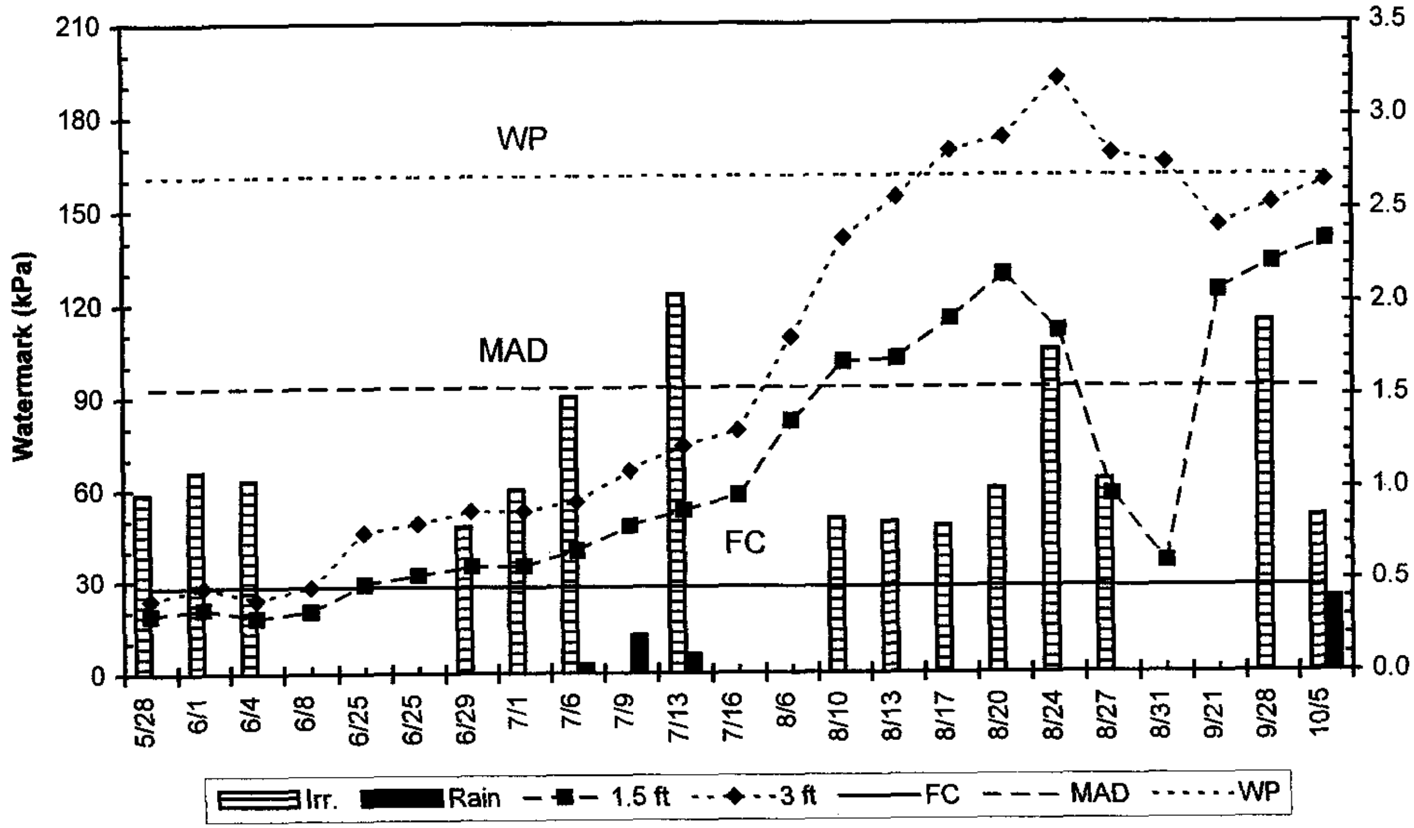

Figure 6d. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 4. Station No. 3.

Table 10. 1998 water balance for alfalfa Field No. 5.

	Water balance (all units are inches)							MAD: 4.85"		
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/12*	22	0.68		4.67	0.61	2.85	2.17	2.68		ETgage installed today
5/15	25			0.38	0.88	0.33	2.50	2.35		
5/26	36		1.68	2.93	0.96	2.81	3.88	0.97	16.0	
5/29	39		0.49	1.00	1.00	1.00	4.46	0.39	16.0	bud stage
6/2	43		0.99	1.30	1.00	1.30	4.92	-0.07	17.5	
6/5	46		0.45	1.00	1.00	1.00	5.54	-0.69	18.7	
6/9	50		0.86	1.10	1.00	1.10	5.91	-1.06	18.3	bud stage
6/11	52			0.60	1.00	0.60	6.51	-1.66		cut hay
Subtotal		0.68	4.47	12.97		10.99				
6/19	8			0.85	0.30	0.26	6.16	-1.31		
6/23	12			1.60	0.40	0.64	6.80	-1.95	3.3	regrowth
6/26	15		1.70	1.30	0.49	0.64	5.99	-1.14		
6/30	19		0.62	1.50	0.60	0.90	6.37	-1.52		
7/2	21		0.55	0.90	0.76	0.68	6.58	-1.73	5.8	
7/7	26		1.92	1.50	0.87	1.31	6.26	-1.41	10.0	
7/10	29	1.00	0.63	0.50	0.98	0.49	5.21	-0.36	11.3	full cover
7/14	33		1.25	1.10	1.00	1.10	5.25	-0.40	15.2	bud stage
7/17	36		0.52	0.90	1.00	0.90	5.71	-0.86	19.0	
7/20	39			1.30	1.00	1.30	7.01	-2.16		cut hay
Subtotal		1.00	7.19	11.45		8.21				
7/28	8	0.90		0.50	0.32	0.16	6.27	-1.42		
7/31	11			0.80	0.40	0.32	6.59	-1.74		
8/4	15			0.90	0.47	0.42	7.01	-2.16	3.8	regrowth
8/7	18			0.80	0.60	0.48	7.49	-2.64	6.3	green up
8/11	22		1.67	1.00	0.74	0.74	6.81	-1.96	7.0	
8/14	25	0.10	0.65	0.60	0.83	0.50	6.66	-1.81	6.7	
8/18	29		1.33	1.00	0.91	0.91	6.44	-1.59	8.8	
8/21	32	0.10	0.64	0.60	0.98	0.59	6.38	-1.53	10.0	full cover
8/25	36	0.10	0.73	0.80	1.00	0.80	6.46	-1.61	13.3	
8/28	39		1.53	0.60	1.00	0.60	5.76	-0.91	15.0	
9/1	43		0.70	1.10	1.00	1.10	6.26	-1.41	15.3	
9/4	46			0.50	1.00	0.50	6.76	-1.91	20.3	bud stage
9/7	49			0.80	1.00	0.80	7.56	-2.71		cut hay
Subtotal		1.20	7.25	10.00		7.92				four-inch height on 9/22
Total		**2.88**	**18.91**	**34.42**		**27.12**				

*Cumulative rain and ETr amounts up to May 12 are from the CoAgmet weather station at Yellow Jacket.

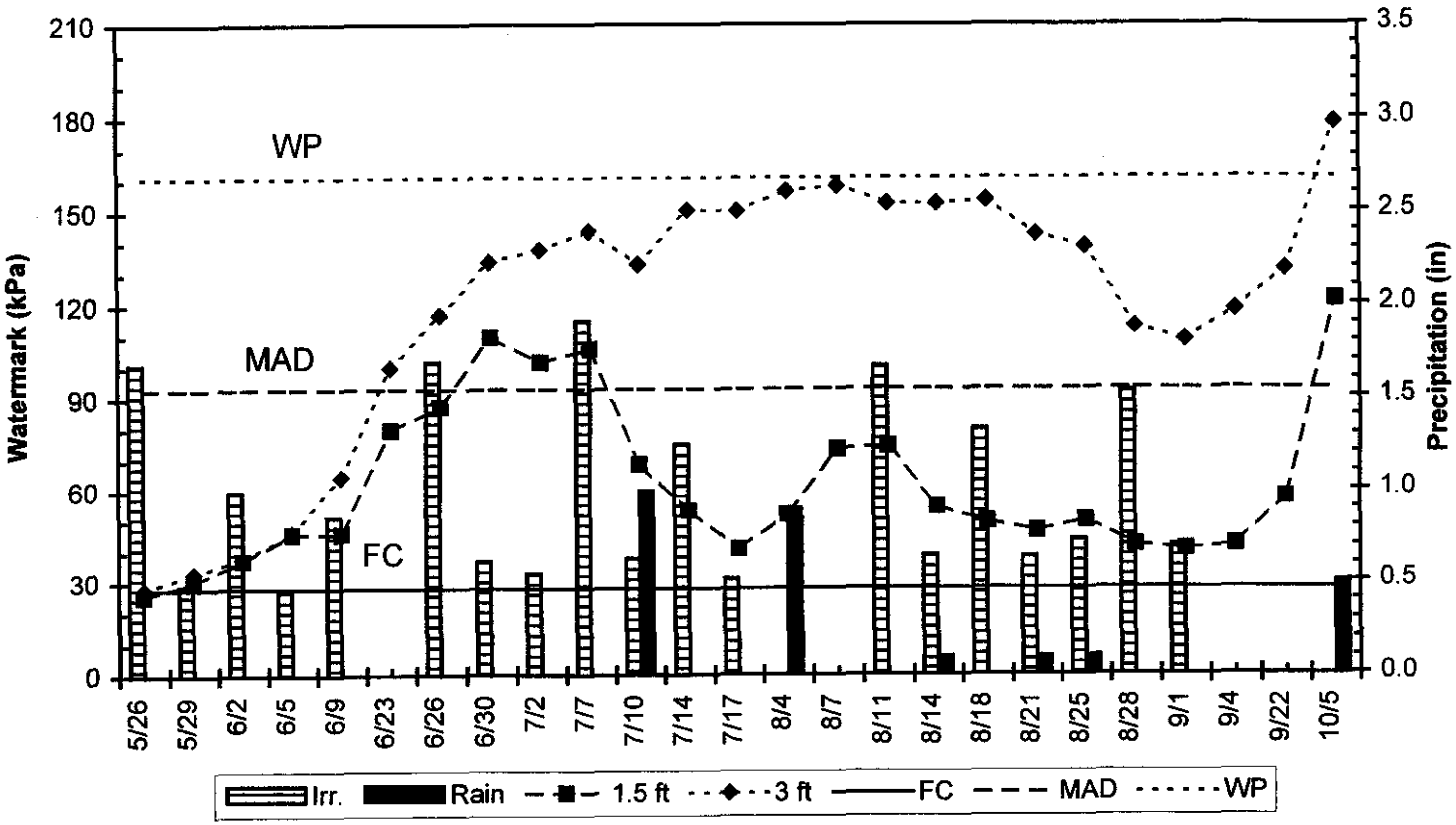

Figure 7. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 5.

Table 11. 1998 water balance for alfalfa Field No. 6.

	Water balance (all units are inches)						MAD: 4.85"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/11*	21	0.68		4.40	0.60	2.64	1.96	2.89		ETgage installed today
5/15	25			0.38	0.87	0.33	2.28	2.57		
5/26	36		1.74	2.93	0.96	2.81	3.61	1.24	13.0	frost damage
5/29	39		0.77	1.00	1.00	1.00	3.96	0.89	15.5	bud stage
6/2	43		0.63	1.30	1.00	1.30	4.72	0.13	16.5	
6/5	46			1.00	1.00	1.00	5.72	-0.87	18.2	cut hay (bud stage)
Subtotal		0.68	3.14	11.00		9.07				
6/16	11		1.22	1.80	0.40	0.72	5.41	-0.56	5.3	
6/19	14		0.87	0.60	0.59	0.35	5.02	-0.17	5.7	
6/23	18		0.81	1.60	0.72	1.15	5.48	-0.63	6.0	
6/26	21		0.97	1.30	0.80	1.04	5.70	-0.85	6.5	
6/30	25		1.40	1.50	0.91	1.37	5.87	-1.02	10.8	
7/2	27			0.90	0.98	0.88	6.76	-1.91	11.2	full cover
7/7	32	0.80	0.68	1.50	1.00	1.50	6.88	-2.03	16.3	irrigation amount from farmer
7/10	35	0.20	0.50	0.50	1.00	0.50	6.75	-1.90	19.7	bud stage
7/14	39			1.10	1.00	1.10	7.85	-3.00		cut hay
Subtotal		1.00	6.45	10.80		8.61				
7/21	7			0.67	0.32	0.21	8.07	-3.22	3.0	green up
7/24	10	0.60		0.70	0.43	0.30	7.77	-2.92	4.0	
7/28	14	0.30	0.43	0.50	0.57	0.29	7.39	-2.54	7.0	
7/31	17			0.80	0.70	0.56	7.95	-3.10	8.7	
8/4	21		0.77	0.90	0.83	0.75	8.04	-3.19	11.7	full cover
8/7	24		1.23	0.80	0.96	0.77	7.76	-2.91	13.0	
8/11	28		0.71	1.00	1.00	1.00	8.16	-3.31	17.7	
8/14	31	0.10	0.74	0.60	1.00	0.60	8.03	-3.18	18.0	bud stage
8/18	35		0.59	1.00	1.00	1.00	8.53	-3.68	20.0	early bloom
8/21	38	0.10		0.60	1.00	0.60	9.03	-4.18	21.3	
8/22	39			0.30	1.00	0.30	9.33	-4.48		
Subtotal		1.10	4.47	7.87		6.38				
8/28	6	0.10		0.28	0.35	0.10	9.33	-4.48	3.0	
9/1	10		1.05	1.10	0.43	0.47	8.91	-4.06	4.0	green up
9/4	13			0.50	0.49	0.25	9.15	-4.30	4.0	
9/9	18		1.15	1.00	0.59	0.59	8.77	-3.92	7.7	
9/11	20		0.64	0.40	0.63	0.25	8.47	-3.62	7.3	
9/15	24	0.28	0.40	0.55	0.71	0.39	8.24	-3.39	9.3	
9/18	27			0.55	0.77	0.42	8.67	-3.82	9.3	full cover
9/22	31			0.80	0.85	0.68	9.35	-4.50	11.0	bud stage
9/28	37			1.20	0.97	1.16	**9.70**	**-4.85**		
Subtotal		0.38	3.24	6.38		4.32				
Total		**3.16**	**17.30**	**36.05**		**28.38**				

*Cumulative rain and ETr amounts up to May 11 are from the CoAgmet weather station at Yellow Jacket.

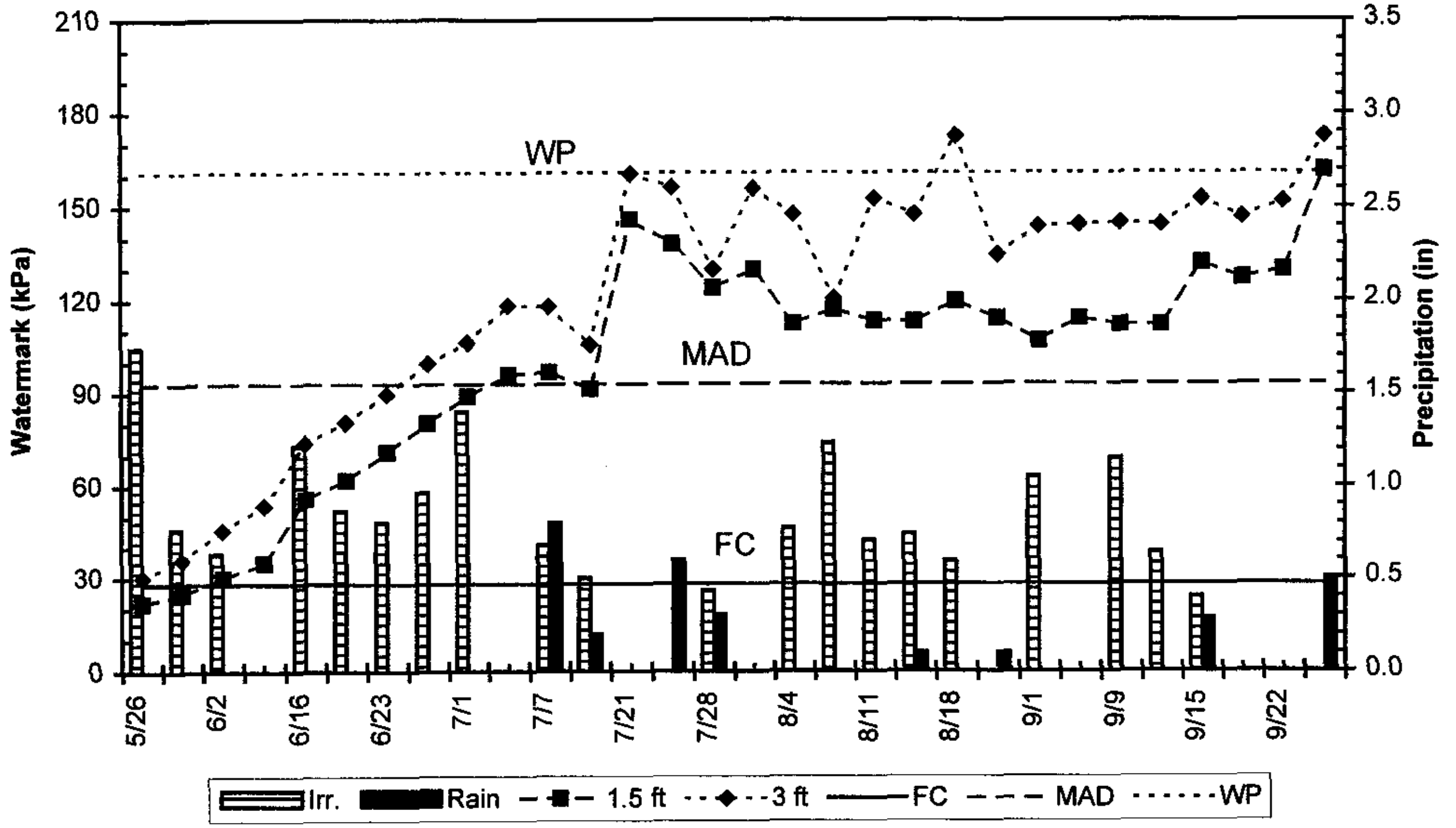

Figure 8. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 6.

Table 12. 1997 water balance for alfalfa Field No. 7.

	Water balance (all units are inches)						MAD: 5.40"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/12*	27	0.60		4.90	0.69	2.20	1.60	3.80	8.0	
5/15	30			0.82	0.95	0.78	2.38	3.02	13.0	
5/19	34			0.98	0.98	0.96	3.34	2.06	16.0	
5/21	36	0.17		0.15	1.00	0.15	3.32	2.08	16.0	
5/23	38	0.40	1.33	0.17	1.00	0.17	1.96	3.44		
5/27	42	0.67	1.00	0.46	1.00	0.46	0.90	4.50	21.0	
6/2	47		0.95	1.15	1.00	1.15	1.24	4.16	27.0	
6/4	49			0.55	1.00	0.55	1.79	3.61	28.0	
6/5	50			0.20	1.00	0.20	1.99	3.41		
6/6	51			0.40	1.00	0.40	2.39	3.01		
6/9	54	0.10		0.20	1.00	0.20	2.49	2.91		some lodging
6/11	56	0.15		0.35	1.00	0.35	2.69	2.71		lodging, 0% bloom
6/13	58			0.50	1.00	0.50	3.19	2.21		
6/16	61			0.78	1.00	0.78	3.97	1.43		cut today
Subtotal		2.09	3.28	11.61		8.85				
6/23	7			0.80	0.32	0.26	4.29	1.11		hay partially baled
6/25	9			0.40	0.40	0.16	4.69	0.71		
6/27	11			0.75	0.47	0.35	5.16	0.24		
7/1	15			1.40	0.60	0.84	5.76	-0.36		
7/3	17			0.80	0.70	0.56	6.46	-1.06	5.0	
7/9	23		1.10	0.75	0.83	0.62	6.36	-0.96	11.0	
7/15	29		0.95	1.95	0.93	1.81	6.48	-1.08	15.0	
7/18	32		0.89	1.00	0.99	0.99	6.71	-1.31		
7/22	36	0.15		1.05	1.00	1.05	7.56	-2.16	21.0	0-10% bloom
7/26	40	0.15		1.05	1.00	1.05	8.41	-3.01	25.0	10% bloom
7/29	43	0.55		0.40	1.00	0.40	8.86	-3.46	28.0	lodging, 10% bloom
8/1	45	1.20		0.40	1.00	0.40	8.66	-3.26	29.0	lodging
8/5	49	0.85		0.80	1.00	0.80	8.81	-3.41		
8/7	51			0.35	1.00	0.35	9.81	-4.41		
8/11	55	0.35		0.80	1.00	0.80	10.46	-5.06		
8/14	58			0.65	1.00	0.65	**10.80**	**-5.40**		plots cut on 8/13
Subtotal		3.25	2.94	13.35		11.09				field cut after 8/14
8/22	8			0.84	0.40	0.34	**10.80**	**-5.40**		baling in progress
8/26	12	0.10	1.78	1.00	0.60	0.60	9.79	-4.39		
9/2	18	0.70	0.95	1.40	1.00	1.40	9.68	-4.28	14.0	
9/4	20			0.40	1.00	0.40	10.08	-4.68	15.0	
9/8	24		1.10	0.90	1.00	0.90	10.04	-4.64	18.0	0% bloom
9/12	28	0.75	1.10	0.80	1.00	0.80	9.16	-3.76	20.0	
9/17	33	0.80		0.70	1.00	0.70	9.06	-3.66	22.0	0-10% bloom
9/22	38	0.55		0.50	1.00	0.50	9.01	-3.61		
9/24	40			0.35	1.00	0.35	9.36	-3.96	23.0	lodging, 0-10% bloom
9/30	46			0.92	1.00	0.92	10.28	-4.88		plots cut on 9/30
Subtotal		2.90	4.93	7.81		6.91				field cut on 10/01
Total		**8.24**	**11.15**	**32.77**		**26.85**				

*Cumulative rain and ETr amounts up to May 12 are from the CoAgmet weather station at Yellow Jacket.

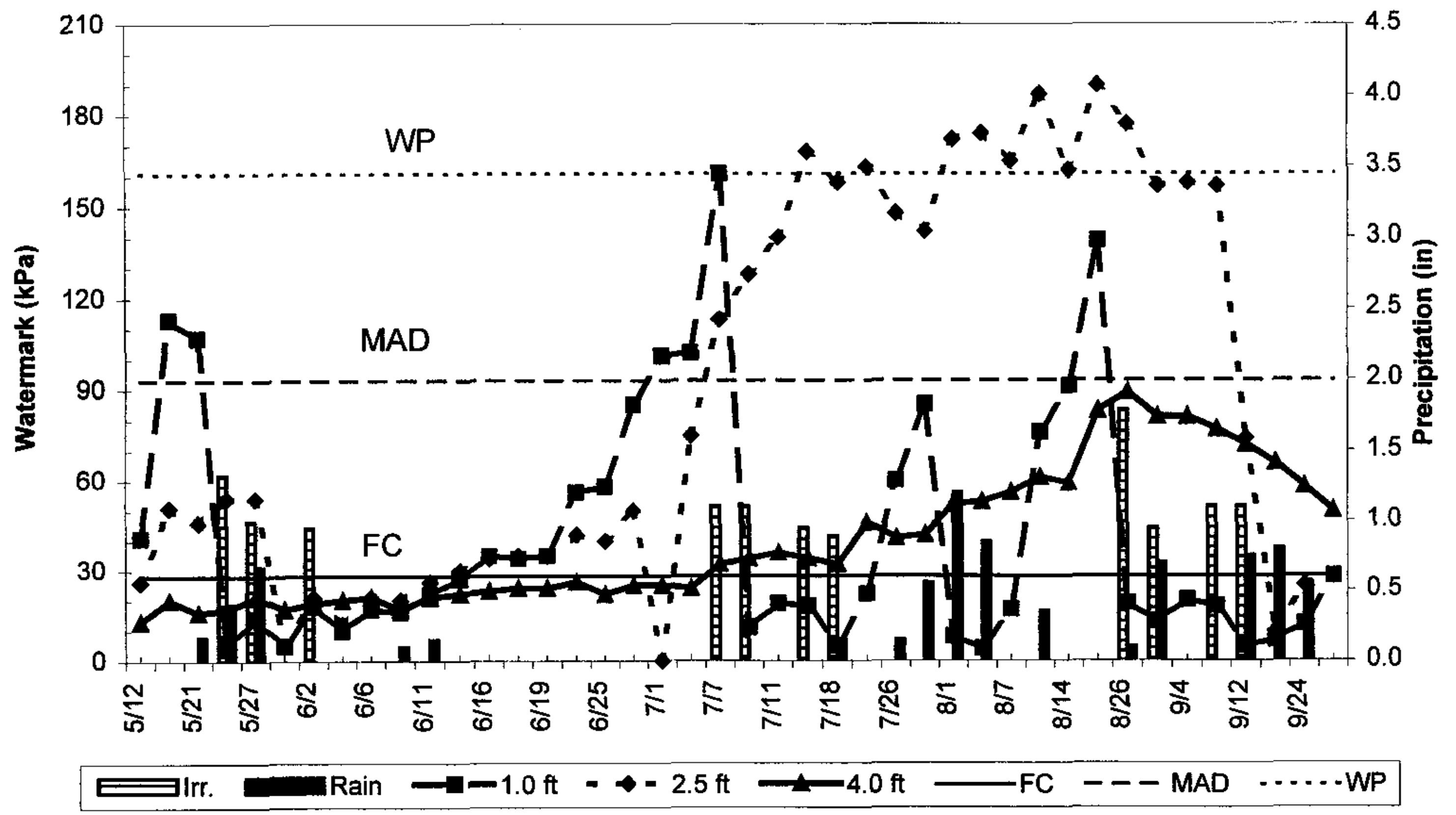

Figure 9. 1997 Watermark sensor readings and precipitation amounts for alfalfa Field No. 7.

Table 13. 1998 water balance for alfalfa Field No. 7.

Water balance (all units are inches)							MAD: 5.40"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/11*	21	0.68		4.40	0.65	2.86	2.18	3.22	7	
5/26	36		3.00	2.00	0.97	1.94	1.57	3.83	15	two irrigations (5/17 & 5/22)
5/29	39		1.75	0.90	1.00	0.90	0.98	4.42	17	bud stage
6/2	43			1.10	1.00	1.10	2.08	3.32	20.5	
6/5	46			0.80	1.00	0.80	2.88	2.52		bud stage
6/8	49			0.75	1.00	0.75	3.63	1.77		cut hay
Subtotal		0.68	4.75	9.95		8.35				
6/19	11			1.50	0.38	0.57	4.20	1.20	4	hay removed 6/18
6/23	15		2.00	1.30	0.57	0.74	3.24	2.16		
6/26	18			1.20	0.70	0.84	4.08	1.32	5	
6/30	22		1.20	1.50	0.83	1.25	4.31	1.09	9	
7/2	24			0.90	0.94	0.85	5.15	0.25	10	
7/7	29	0.48	1.25	1.40	1.00	1.40	5.01	0.39	15.5	full cover
7/10	32	0.10		0.40	1.00	0.40	5.31	0.09	18	bud stage
7/14	36	0.20	1.55	1.30	1.00	1.30	5.09	0.31	23	
7/17	39			1.20	1.00	1.20	6.29	-0.89	25	
7/21	43			1.30	1.00	1.30	7.59	-2.19	26	cut hay (early bloom)
Subtotal		0.78	6.00	12.00		9.84				
7/27	6	1.45		0.20	0.30	0.06	6.20	-0.80		7/22-7/27 rainfall
7/31	10			0.70	0.30	0.21	6.41	-1.01		
8/7	17			2.30	0.30	0.69	7.10	-1.70		
8/11	21			1.20	0.40	0.48	7.58	-2.18	3	green up
8/14	24	0.05	1.27	0.70	0.60	0.42	6.87	-1.47	4	green up
8/18	28			1.20	0.80	0.96	7.83	-2.43	6	
8/21	31	0.30	1.70	0.50	0.90	0.45	6.54	-1.14	9	
8/25	35	0.14		0.90	1.00	0.90	7.30	-1.90	14	full cover
8/28	38		1.30	0.70	1.00	0.70	6.89	-1.49	16	bud stage
9/1	42		1.65	1.10	1.00	1.10	6.59	-1.19	17	
9/4	45			0.70	1.00	0.70	7.29	-1.89	18	
9/9	50			1.00	1.00	1.00	8.29	-2.89	22	1% bloom
9/11	52	0.05		0.40	1.00	0.40	8.64	-3.24	23	2% bloom
9/14	55	0.33		0.40	1.00	0.40	8.71	-3.31		cut hay (5% bloom)
Subtotal		2.32	5.92	12.00		8.47				
Total		**3.78**	**16.67**	**33.95**		**26.66**				

*Cumulative rain and ETr amounts up to May 11 are from the CoAgmet weather station at Yellow Jacket.

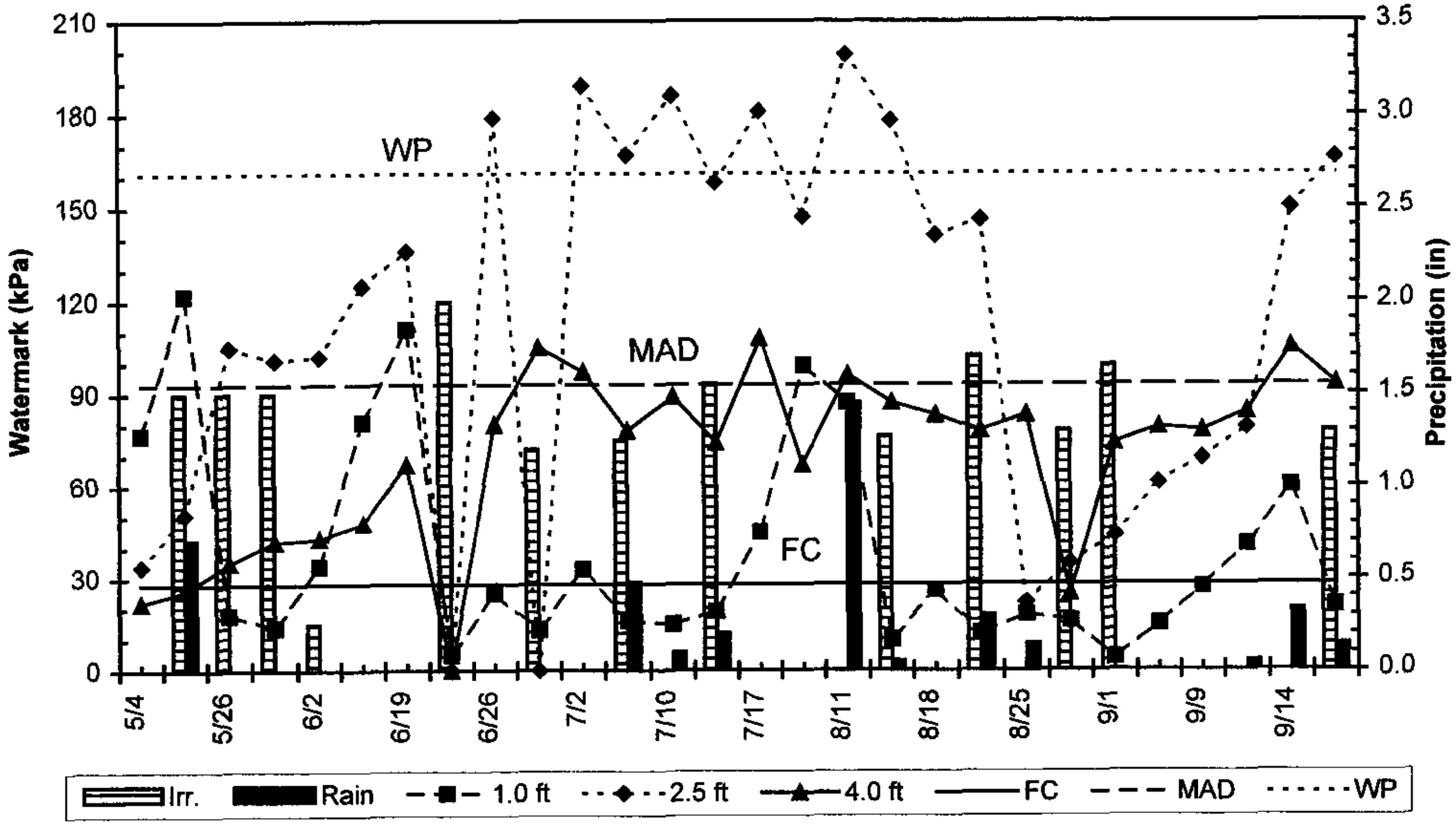

Figure 10. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 7.

Table 14. 1997 water balance for alfalfa Field No. 8.

Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
	Water balance (all units are inches)						MAD: 4.60"			
5/12*	27	0.60		4.90	0.69	2.20	1.60	3.00	7.0	ETgage installed
5/15	30			0.82	0.95	0.78	2.38	2.22	10.0	
5/19	34			0.98	0.98	0.96	3.34	1.26	14.0	
5/21	36	0.17		0.15	1.00	0.15	3.32	1.28		
5/23	38	0.40	3.46	0.17	1.00	0.17	0.15	4.45	17.0	
5/27	42	0.75		0.46	1.00	0.46	0.00	4.60	17.0	
5/29	44			0.42	1.00	0.42	0.42	4.18	19.0	
6/2	47			1.15	1.00	1.15	1.57	3.03	26.0	
6/4	49			0.55	1.00	0.55	2.12	2.48	28.0	
6/5	50			0.20	1.00	0.20	2.32	2.28		
6/6	51			0.40	1.00	0.40	2.72	1.88		
6/9	54	0.10		0.20	1.00	0.20	2.82	1.78		some lodging
6/11	56	0.05		0.35	1.00	0.35	3.12	1.48		0-10% bloom
6/13	58			0.50	1.00	0.50	3.62	0.98		10% bloom
6/16	61			0.78	1.00	0.78	4.40	0.20		10-20% bloom
Subtotal		2.07	3.46	12.03		9.27				field cut on 6/17
6/23	7			2.00	0.32	0.26	4.66	-0.06		
6/25	9			0.40	0.40	0.16	4.82	-0.22		
6/27	11			0.75	0.47	0.35	5.17	-0.57		bales still on field
7/1	15			1.40	0.60	0.84	6.01	-1.41		irrigation started on 6/30
7/3	17		3.69	0.80	0.70	0.56	3.43	1.17	6.0	
7/7	21			1.40	0.80	1.12	4.55	0.05	9.0	
7/9	23			0.75	0.90	0.68	5.23	-0.63	12.0	
7/15	29		2.64	1.95	1.00	1.95	4.93	-0.33	17.0	some budding
7/18	32			1.00	1.00	1.00	5.93	-1.33	21.0	
7/22	36	0.14		1.05	1.00	1.05	6.84	-2.24	26.0	10% bloom
7/25	39	0.15		0.80	1.00	0.80	7.49	-2.89		yield plots cut
Subtotal		0.29	6.33	12.30		8.76				field cut on 7/26
7/29	3	0.55								
8/1	5	1.20		0.40	0.30	0.12	5.86	-1.26		
8/5	9	0.85		0.80	0.40	0.32	5.33	-0.73	4.0	
8/7	11			0.35	0.50	0.18	5.51	-0.91	7.0	
8/11	15	0.35		0.80	0.60	0.48	5.64	-1.04	7.0	
8/14	18			0.65	0.75	0.49	6.13	-1.53	9.0	
8/22	26		2.64	2.25	0.85	1.91	5.79	-1.19		irrigation amount estimated
8/26	30	0.10		1.00	0.95	0.95	6.64	-2.04		
9/2	36	0.70	2.42	1.40	1.00	1.40	5.29	-0.69	16.0	
9/4	38			0.40	1.00	0.40	5.69	-1.09	18.0	
9/8	42			0.90	1.00	0.90	6.59	-1.99	20.0	0-10% bloom
9/12	46	0.73		0.80	1.00	0.80	6.66	-2.06	21.0	
9/17	51	0.80		0.70	1.00	0.70	6.56	-1.96		20% bloom
9/22	56			0.50	1.00	0.50	7.06	-2.46		
9/24	58	0.55		0.35	1.00	0.35	6.86	-2.26	23.0	30% bloom, lodging
9/30	64			1.00	1.00	1.00	7.86	-3.26		yield plots cut on 9/27
Subtotal		5.83	5.06	12.30		10.50				field cut on 10/1
Total		**8.19**	**14.85**	**36.63**		**28.53**				

*Cumulative rain and ETr amounts up to May 12 are from the CoAgmet weather station at Yellow Jacket.

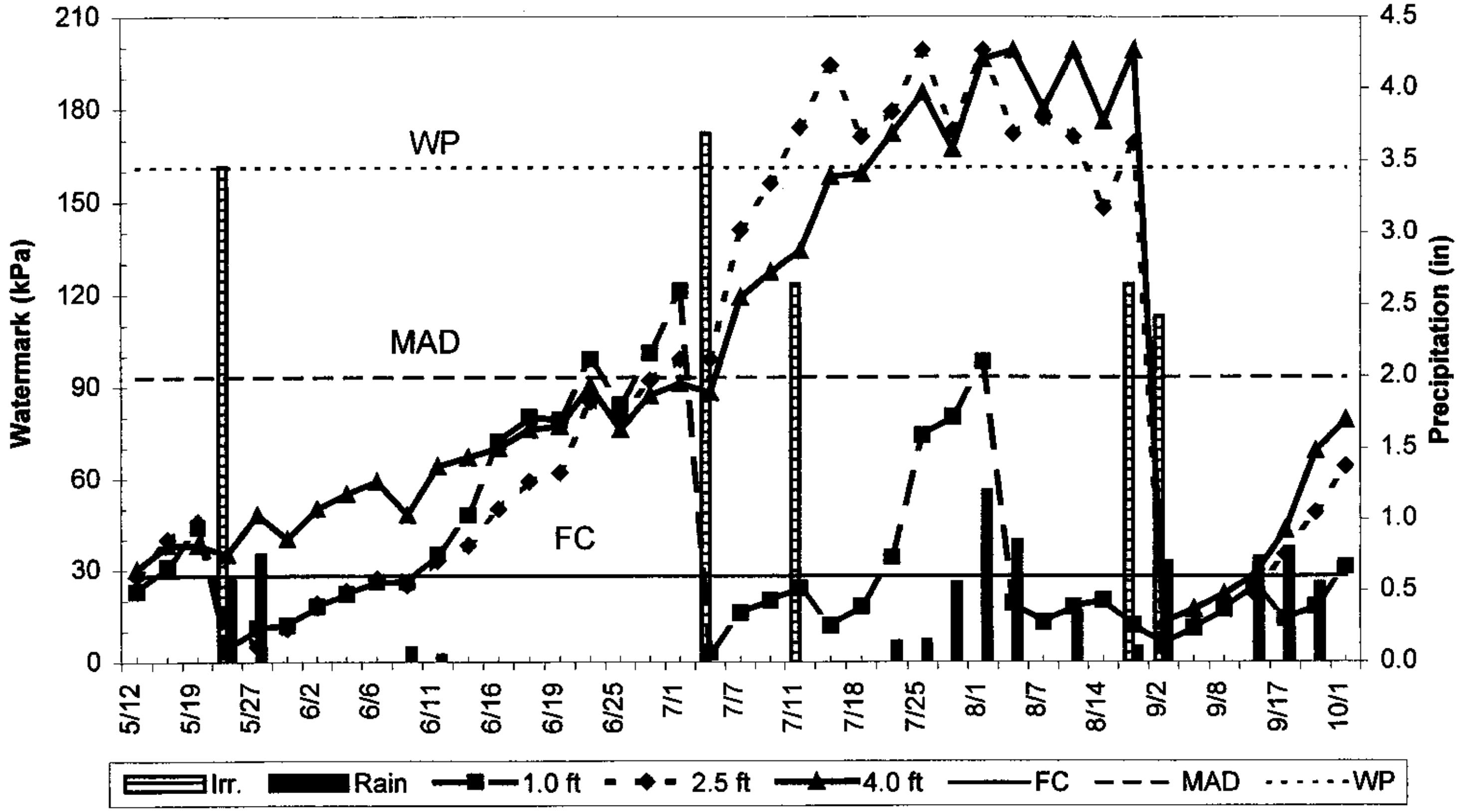

Figure 11. 1997 Watermark sensor readings and precipitation amounts for alfalfa Field No. 8.

Table 15. 1998 water balance for alfalfa Field No. 8.

Water balance (all units are inches)							MAD: 4.60"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/11*	21	0.68		4.40	0.62	2.73	2.05	2.55	5.0	
5/26	36		2.00	2.00	0.95	1.90	2.25	2.35	12.0	
5/29	39			0.90	1.00	0.90	3.15	1.45	16.0	bud stage
6/2	43			1.10	1.00	1.10	4.25	0.35	19.0	
6/5	46			0.80	1.00	0.80	5.05	-0.45		bud stage
6/9	50			1.00	1.00	1.00	6.05	-1.45		cut hay
Subtotal		0.68	2.00	10.20		8.43				
6/19	10			1.25	0.38	0.48	6.52	-1.92	3.5	regrowth
6/23	14			1.30	0.57	0.74	7.26	-2.66		
6/26	17		2.00	1.20	0.70	0.84	6.40	-1.80	5.0	
6/30	21			1.50	0.83	1.25	7.65	-3.05	6.0	
7/2	23			0.90	0.94	0.85	8.49	-3.89	8.0	
7/7	28	0.48	2.60	1.40	1.00	1.40	7.20	-2.60	11.0	full cover
7/10	31	0.10		0.40	1.00	0.40	7.50	-2.90	13.0	
7/14	35	0.20		1.30	1.00	1.30	8.60	-4.00	17.0	bud stage
7/17	38		2.85	1.20	1.00	1.20	7.38	-2.78	19.0	bud/early bloom
7/21	42			1.30	1.00	1.30	8.68	-4.08	23.0	cut hay (2% bloom)
Subtotal		0.78	7.45	11.75		9.75				
7/27	6	0.70		0.20	0.30	0.06	8.04	-3.44		
7/31	10	0.75		0.70	0.42	0.29	7.58	-2.98		
8/7	17			2.30	0.62	1.43	9.01	-4.41	9.0	green up
8/11	21			1.20	0.83	1.00	**9.20**	**-4.60**	10.0	
8/14	24	0.05	2.20	0.70	0.96	0.67	7.95	-3.35	12.0	full cover
8/18	28			1.20	1.00	1.20	9.15	-4.55		pre-bud
8/21	31	0.30	1.15	0.50	1.00	0.50	8.37	-3.77		
8/25	35	0.14		0.90	1.00	0.90	9.13	-4.53	18.0	bud stage
8/28	38		2.30	0.70	1.00	0.70	7.88	-3.28	21.0	
9/1	42			1.10	1.00	1.10	8.98	-4.38	22.0	1% bloom
9/4	45			0.70	1.00	0.70	**9.20**	**-4.60**	20.0	3% bloom
9/9	50			1.00	1.00	1.00	**9.20**	**-4.60**	23.0	
9/11	52	0.05		0.40	1.00	0.40	**9.20**	**-4.60**		cut hay (70% bloom)
Subtotal		1.99	5.65	11.60		9.95				
Total		**3.45**	**15.10**	**33.55**		**28.12**				

*Cumulative rain and ETr amounts up to May 11 are from the CoAgmet weather station at Yellow Jacket.

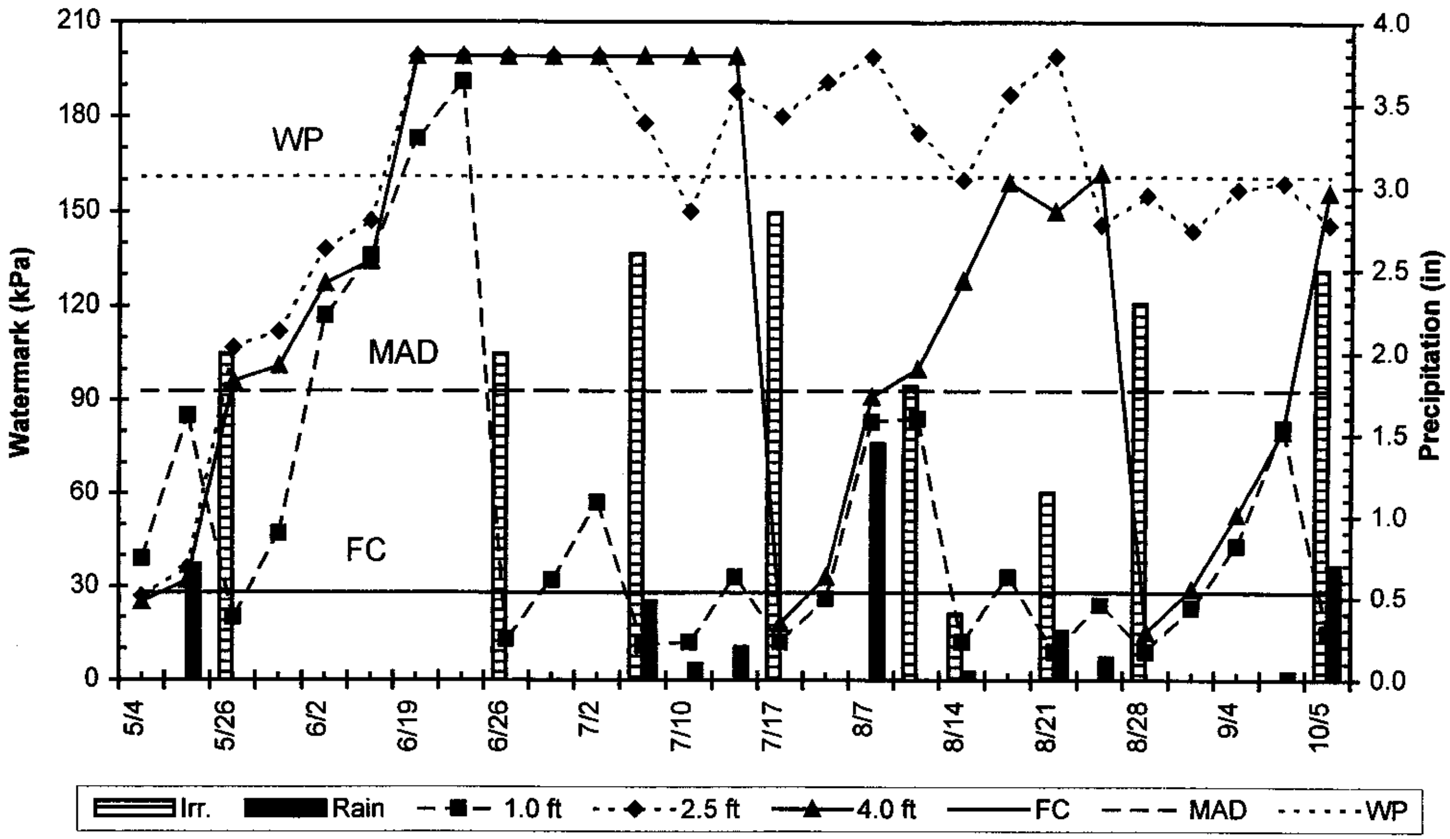

Figure 12. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 8.

Table 16. 1997 water balance for alfalfa Field No. 9.

	Water balance (all units are inches)						MAD: 4.35"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/12*	27	0.60		4.90	0.69	3.38	2.78	1.57		
5/15	30			0.55	0.95	0.52	3.30	1.05	8.0	
5/19	34		2.46	1.15	0.98	1.13	2.34	2.01	13.0	
5/21	36	0.38		0.30	1.00	0.30	2.26	2.09	15.0	
5/23	38	0.37		0.15	1.00	0.15	2.04	2.31		some budding
5/27	42	0.60		0.60	1.00	0.60	2.04	2.31	20.0	
5/29	44			0.30	1.00	0.30	2.34	2.01		
6/2	47			1.45	1.00	1.45	3.79	0.56		field and yield plots cut
Subtotal		1.95	2.46	9.40		7.83				
6/13	11	0.30		0.65	0.40	0.26	3.75	0.60		hay baled
6/17	15			0.70	0.50	0.35	4.10	0.25		
6/18	16			0.32	0.60	0.19	4.29	0.06		
6/23	21		2.70	1.70	0.70	1.19	3.19	1.16	6.0	
6/25	23			0.90	0.75	0.68	3.86	0.49	7.0	
6/27	25			0.85	0.80	0.68	4.54	-0.19	8.0	
7/1	29			1.45	0.90	1.31	5.85	-1.50	11.0	
7/3	31			0.65	1.00	0.65	6.50	-2.15	12.0	
7/7	35		3.02	1.28	1.00	1.28	5.21	-0.86	18.0	
7/9	37			1.12	1.00	1.12	6.33	-1.98		
7/11	39			0.65	1.00	0.65	6.98	-2.63	19.0	
7/15	43			1.40	1.00	1.40	8.38	-4.03		0-10% bloom
7/18	46		3.43	1.15	1.00	1.15	6.61	-2.26	24.0	
7/22	50	0.70		0.90	1.00	0.90	6.81	-2.46	24.0	60% bloom
7/25	53	0.20		1.00	1.00	1.00	7.61	-3.26		80% bloom
7/27	55			0.40	1.00	0.40	8.01	-3.66		field and yield plots cut
Subtotal		1.20	9.15	15.12		13.20				
8/1	4	0.80								
8/5	8	1.00		0.85	0.45	0.38	6.60	-2.25	5.0	bales still on the field
8/7	10			0.45	0.50	0.23	6.82	-2.47		
8/11	14	0.50		0.60	0.85	0.51	6.83	-2.48	10.0	
8/14	17			0.70	0.95	0.67	7.50	-3.15	12.0	
8/22	25		2.50	2.30	1.00	2.30	7.67	-3.32		
8/26	29	0.05		1.15	1.00	1.15	**8.70**	**-4.35**		
9/2	35	0.45	2.30	1.40	1.00	1.40	7.70	-3.35	16.0	
9/4	37			0.50	1.00	0.50	8.20	-3.85	17.0	field cut
Subtotal		2.80	4.80	7.95		7.13				missed yield plots
Total		**5.95**	**16.41**	**32.47**		**28.17**				

*Cumulative rain and ETr amounts up to May 12 are from the CoAgmet weather station at Yellow Jacket.

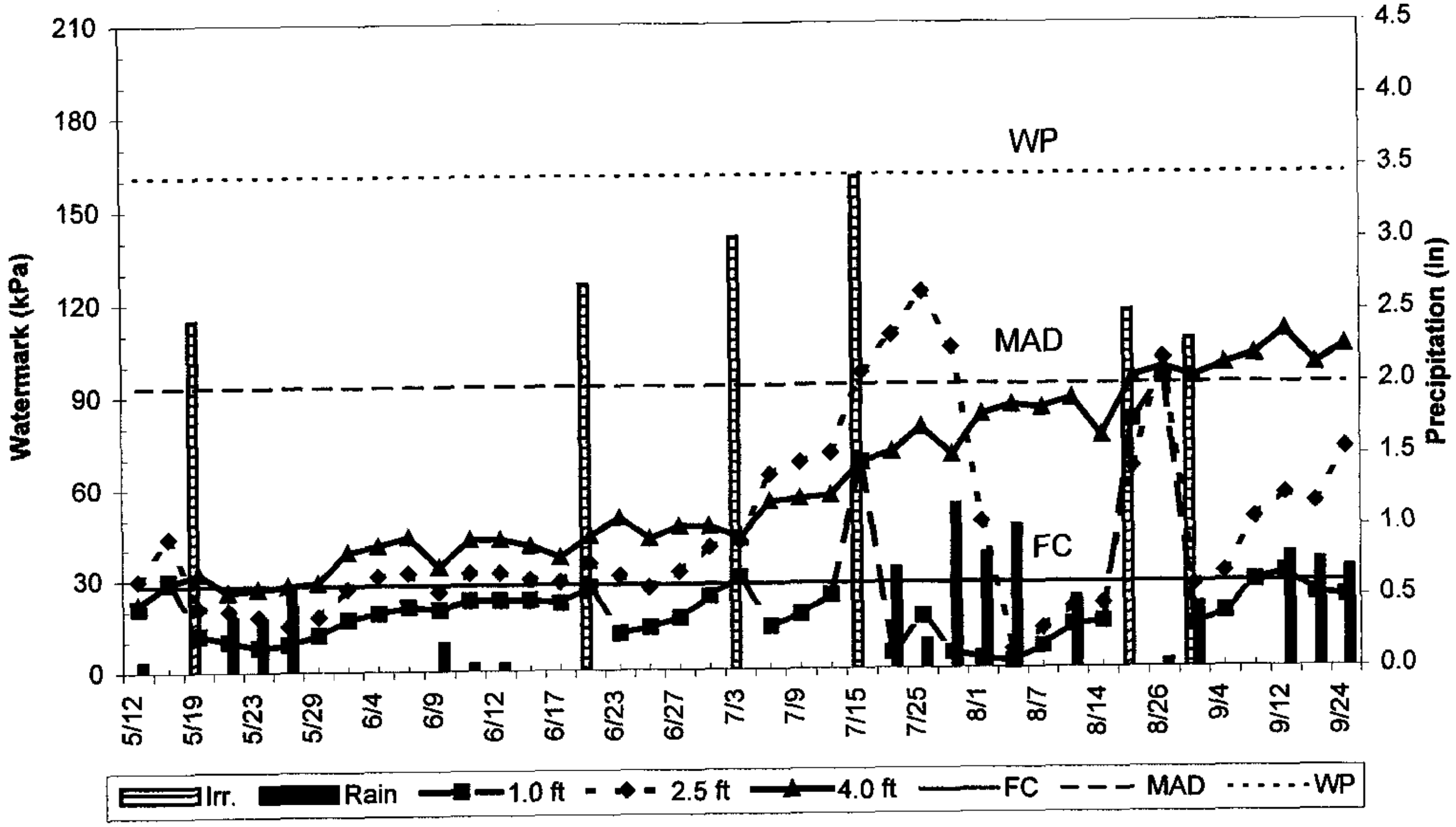

Figure 13. 1997 Watermark sensor readings and precipitation amounts for alfalfa Field No. 9.

Table 17. 1998 water balance for alfalfa Field No. 10.

Water balance (all units are inches)							MAD: 4.35"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/12*	22	0.68		4.67	0.64	2.99	2.31	2.04		ETgage installed
5/15	25			0.38	0.89	0.34	2.65	1.70		
5/26	36		1.78	2.40	0.97	2.33	3.46	0.89	14.0	irrigation started on 5/21
5/29	39			0.80	1.00	0.80	4.26	0.09	16.0	bud stage
6/2	43			1.30	1.00	1.30	5.56	-1.21	19.0	bud stage
6/3	44			0.30	1.00	0.30	5.86	-1.51		cut hay sample
Subtotal		0.68	1.78	9.85		8.06				
6/9	6			0.25	0.30	0.08	5.94	-1.59		
6/16	13			1.90	0.47	0.89	6.83	-2.48	4.3	regrowth
6/19	16			0.80	0.60	0.48	7.31	-2.96	5.0	
6/23	20		2.63	1.30	0.70	0.91	5.98	-1.63	5.5	
6/26	23			1.30	0.80	1.04	7.02	-2.67	6.5	
6/30	27			1.50	0.93	1.40	8.42	-4.07	7.5	
7/2	29		3.38	0.70	0.96	0.67	6.22	-1.87	10.0	full cover
7/7	34	0.70		1.50	1.00	1.50	7.02	-2.67	14.0	
7/10	37	0.20		0.30	1.00	0.30	7.12	-2.77	17.5	bud stage
7/14	41			1.20	1.00	1.20	8.32	-3.97	20.0	
7/17	44			1.10	1.00	1.10	**8.70**	**-4.35**	24.0	1% bloom
Subtotal		0.90	6.01	11.85		9.57				
7/28	11	1.81		0.60	0.40	0.24	7.13	-2.78		
7/31	14	0.15		0.70	0.50	0.35	7.33	-2.98	4.0	
8/7	21			1.80	0.70	1.26	8.59	-4.24	6.0	green up
8/11	25			1.30	0.77	1.00	**8.70**	**-4.35**	7.0	
8/14	28		2.75	0.70	0.85	0.60	6.96	-2.61	7.5	
8/18	32			1.00	0.91	0.91	7.87	-3.52	9.0	
8/21	35	0.20		0.70	0.97	0.68	8.35	-4.00	10.0	full cover
8/25	39	0.21		0.90	1.00	0.90	**8.70**	**-4.35**	12.0	
8/28	42		2.78	0.60	1.00	0.60	6.94	-2.59	14.0	bud stage
9/1	46			1.00	1.00	1.00	7.94	-3.59	17.0	bud stage
9/4	49			0.60	1.00	0.60	8.54	-4.19	18.0	1% bloom
9/9	54			0.80	1.00	0.80	**8.70**	**-4.35**		
9/11	56	0.05	3.35	0.30	1.00	0.30	6.10	-1.75	20.0	10% bloom, lodging
9/15	60	0.31		0.55	1.00	0.55	6.34	-1.99		5 to 20% bloom
9/18	63			0.55	1.00	0.55	6.89	-2.54		20% bloom, lodging
9/22	67			0.50	1.00	0.50	7.39	-3.04	23.0	
Subtotal		2.73	8.88	12.60		10.84				cut hay sample (9/22)
Total		**4.31**	**16.67**	**34.30**		**28.46**				

*Cumulative rain and ETr amounts up to May 12 are from the CoAgmet weather station at Yellow Jacket.

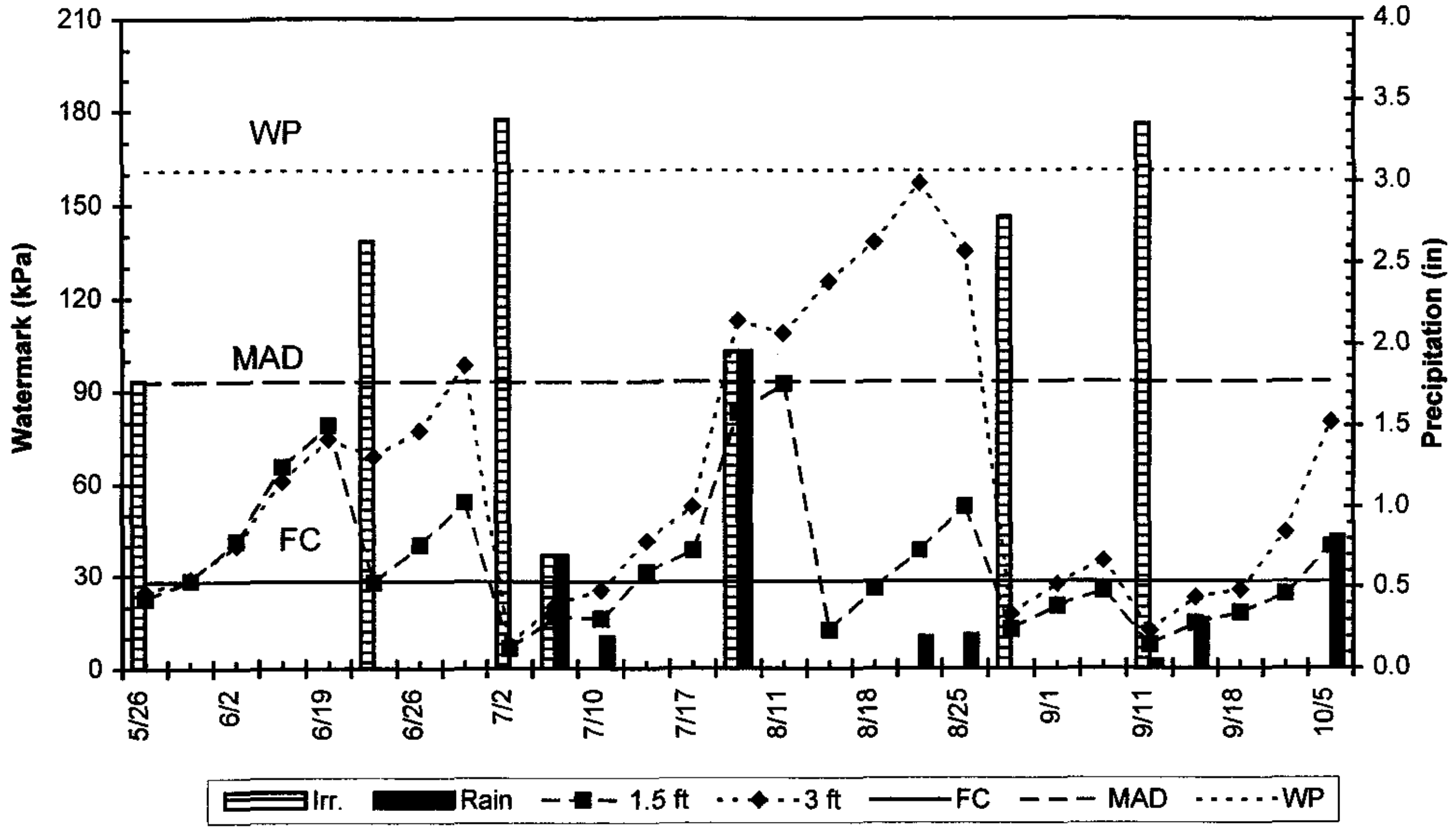

Figure 14. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 10.

Table 18. 1998 water balance for alfalfa Field No. 11.

	Water balance (all units are inches)						MAD: 4.35"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/12*	22	0.68		4.67	0.65	3.04	2.36	1.99		ETgage installed
5/15	25			0.38	0.91	0.34	2.70	1.65		
5/26	36		3.00	2.40	0.98	2.35	2.50	1.85	15.0	irrigation started on 5/20
5/29	39			0.80	1.00	0.80	3.30	1.05		
6/2	43		3.07	1.90	1.00	1.90	2.59	1.76	17.0	bud stage
6/5	46			0.90	1.00	0.90	3.49	0.86	20.0	
6/9	50			0.90	1.00	0.90	4.39	-0.04	18.7	cut hay sample and field
Subtotal		0.68	6.07	11.95		10.23				
6/23	14			2.90	0.38	1.10	5.49	-1.14		
6/26	17			1.30	0.57	0.74	6.23	-1.88	4.0	regrowth
6/30	21			1.50	0.70	1.05	7.28	-2.93	6.0	
7/2	23			0.70	0.83	0.58	7.86	-3.51	8.0	
7/7	28	0.70		1.50	0.94	1.41	8.57	-4.22	9.0	
7/10	31	0.20	3.28	0.30	1.00	0.30	5.89	-1.54	11.5	full cover
7/14	35			1.20	1.00	1.20	7.09	-2.74	13.0	bud stage
7/17	38			1.10	1.00	1.10	8.19	-3.84	16.8	1% bloom
7/21	42			1.10	1.00	1.10	**8.70**	**-4.35**	18.0	4% bloom
7/24	45	0.61	3.22	0.70	1.00	0.70	6.05	-1.70	22.0	4% bloom
7/28	49	1.20		0.60	1.00	0.60	5.45	-1.10	24.0	6% bloom
7/31	52	0.15		0.70	1.00	0.70	6.00	-1.65	25.0	7% bloom
8/2	54			0.52	1.00	0.52	6.52	-2.17		cut hay sample
Subtotal		2.86	6.50	14.12		11.10				
8/7	5			0.26	0.30	0.08	6.60	-2.25		early regrowth
8/11	9			1.30	0.34	0.44	7.04	-2.69		
8/14	12	0.05		0.70	0.45	0.32	7.31	-2.96	3.0	green up
8/18	16			1.00	0.51	0.51	7.82	-3.47		few bales still in the field
8/21	19	0.20	2.60	0.70	0.60	0.42	5.83	-1.48	4.0	
8/25	23	0.21		0.90	0.87	0.78	6.40	-2.05	7.0	
8/28	26			0.60	0.94	0.56	6.97	-2.62	8.0	
9/1	30		3.00	1.00	0.99	0.99	5.41	-1.06	13.0	full cover
9/4	33			0.60	1.00	0.60	6.01	-1.66		
9/9	38			0.80	1.00	0.80	6.81	-2.46	17.0	
9/11	40	0.05		0.30	1.00	0.30	7.06	-2.71	18.0	bud stage
9/15	44	0.30		0.55	1.00	0.55	7.31	-2.96		
9/18	47		2.62	0.55	1.00	0.55	5.63	-1.28		
9/22	51			0.50	1.00	0.50	6.13	-1.78	20.7	cut hay sample
Subtotal		0.81	8.22	9.76		7.40				
Total		**4.35**	**20.79**	**35.83**		**28.73**				

*Cumulative rain and ETr amounts up to May 12 are from the CoAgmet weather station at Yellow Jacket.

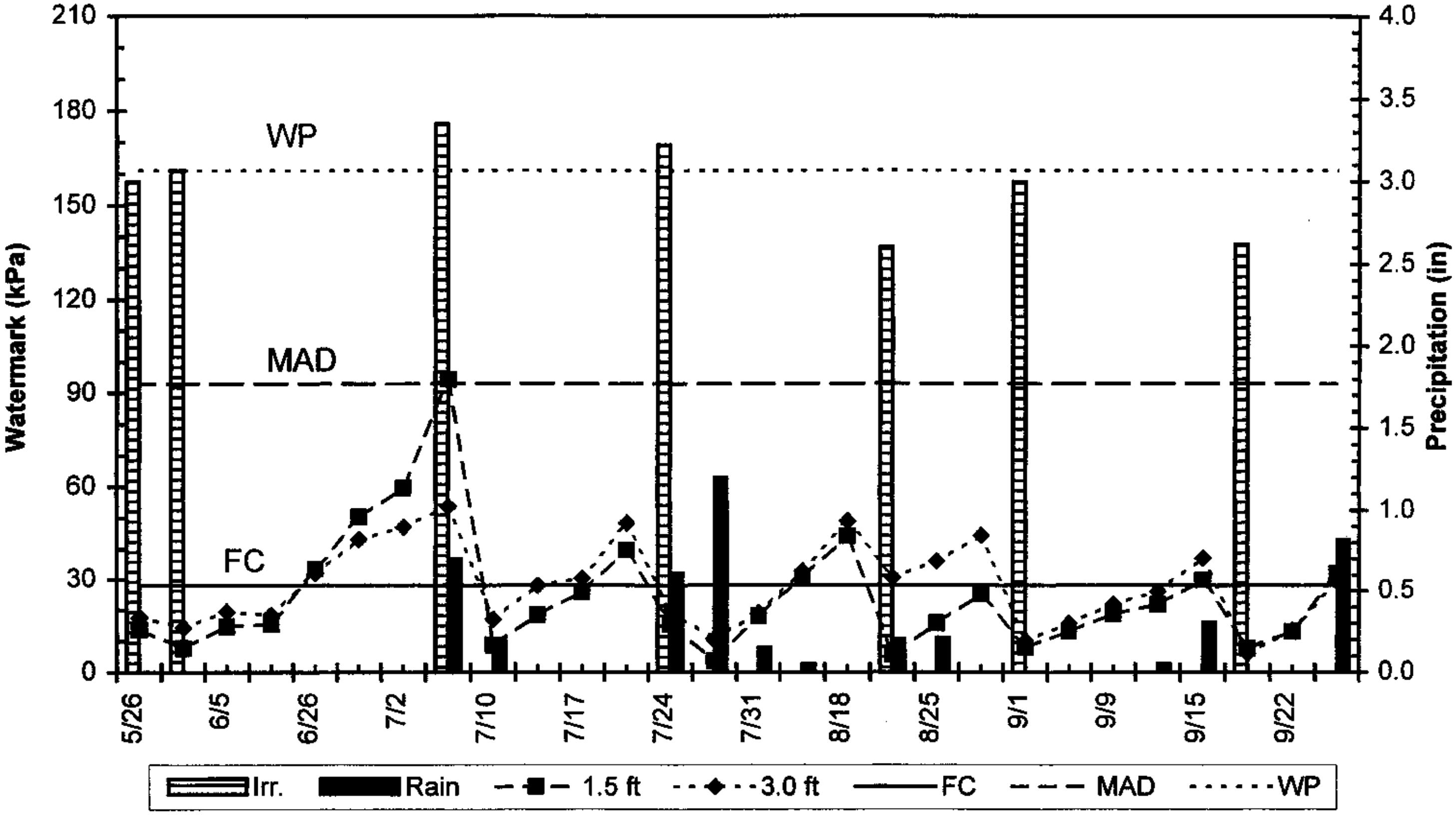

Figure 15. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 11.

Table 19. 1997 water balance for alfalfa Field No. 12.

	Water balance (all units are inches)							MAD: 4.35"		
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/14*	29	0.66		5.40	0.69	3.73	3.29	1.06		
5/15	30			0.55	0.85	0.47	3.76	0.59	8.0	
5/19	34			1.15	0.93	1.07	4.83	-0.48	12.0	
5/21	36	0.26		0.30	0.97	0.29	4.86	-0.51	13.0	
5/23	38	1.58		0.15	1.00	0.15	3.43	0.92		
5/27	42	1.00	4.01	0.60	1.00	0.60	0.00	4.35	17.0	some budding
5/29	44			0.30	1.00	0.30	0.30	4.05		
6/2	47			1.45	1.00	1.45	1.75	2.60		yield plots cut
6/4	49			0.55	1.00	0.55	2.30	2.05	20.0	
Subtotal		3.50	4.01	10.45		8.60				
										field cut (June 5&6)
6/11	5	0.25								hay not raked yet
6/13	7			0.35	0.30	0.11	2.16	2.20		
6/17	11			0.70	0.34	0.24	2.39	1.96		
6/18	12			0.32	0.43	0.14	2.53	1.82		
6/23	17			1.70	0.55	0.94	3.47	0.88	4.0	
6/25	19		1.89	0.90	0.68	0.61	2.47	1.88	5.0	
6/27	21			0.85	0.75	0.64	3.11	1.24	7.0	
7/1	25			1.45	0.87	1.26	4.37	-0.02	8.0	
7/3	27			0.65	0.98	0.64	5.01	-0.66	10.0	
7/7	31			1.28	1.00	1.28	6.29	-1.94	14.0	
7/9	33			1.12	1.00	1.12	7.41	-3.06		
7/11	35		1.47	0.65	1.00	0.65	6.81	-2.46	17.0	
7/15	39			1.40	1.00	1.40	8.21	-3.86		some budding
7/18	42		1.62	1.15	1.00	1.15	7.98	-3.63	23.0	
7/22	46	0.50		0.90	1.00	0.90	8.38	-4.03	27.0	10% bloom
7/25	49	0.26		0.29	1.00	0.29	8.41	-4.06		40% bloom
Subtotal		1.01	4.98	13.71		11.35				field cut
7/29	4	1.15								
8/1	7	0.80		0.30	0.32	0.10	6.56	-2.21		
8/5	11	1.00		0.85	0.45	0.38	5.94	-1.59	4.0	hay not baled yet
8/7	13			0.45	0.57	0.26	6.20	-1.85	6.0	
8/11	17	0.60		0.60	0.68	0.41	6.00	-1.65	9.0	
8/14	20			0.70	0.81	0.57	6.57	-2.22	11.0	
8/22	28		2.63	2.30	0.97	2.23	6.57	-2.22		
8/26	32	0.05		1.15	1.00	1.15	7.67	-3.32		
9/2	38	0.40		1.40	1.00	1.40	8.50	-4.15	16.0	
9/4	40			0.50	1.00	0.50	8.50	-4.15		
9/8	44		2.48	0.80	1.00	0.80	7.19	-2.84	22.0	
9/12	48	0.80		0.85	1.00	0.85	7.24	-2.89	24.0	some lodging
9/17	53	0.70		0.65	1.00	0.65	7.19	-2.84	25.0	20% bloom
9/22	58	0.40		0.65	1.00	0.65	7.44	-3.09		
9/24	60			0.20	1.00	0.20	7.64	-3.29	26.0	20% bloom
9/27	63			0.30	1.00	0.30	7.94	-3.59		yield plots cut
9/28	64			0.15	1.00	0.15	8.09	-3.74		
9/29	65			0.15	1.00	0.15	8.24	-3.89		
9/30	66			0.15	1.00	0.15	8.39	-4.04		field cut on 10/1
Subtotal		5.90	5.11	12.15		10.89				
Total		**10.41**	**14.10**	**36.31**		**30.85**				

*Cumulative rain and ETr amounts up to May 14 are from the CoAgmet weather station at Yellow Jacket.

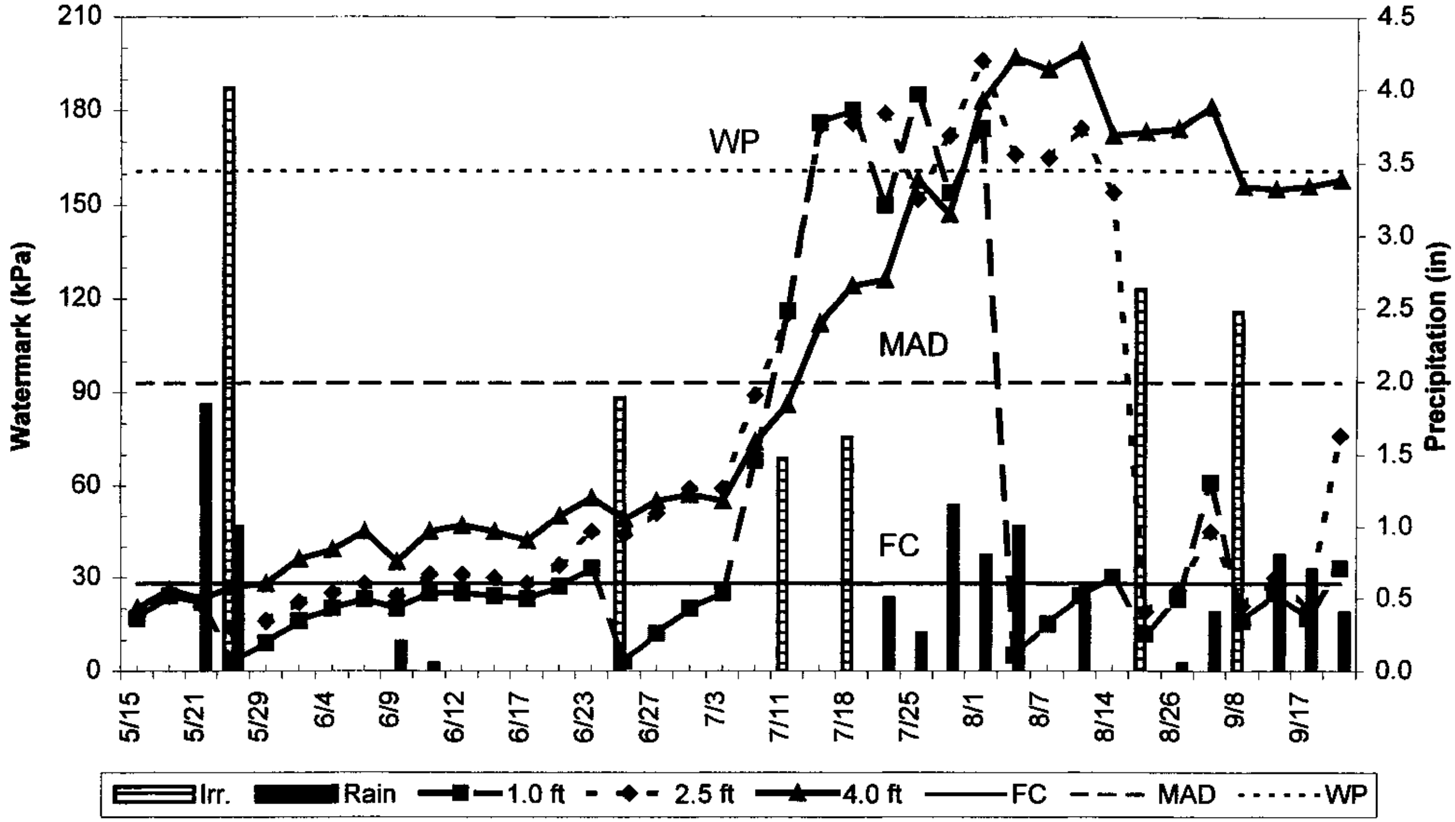

Figure 16. 1997 Watermark sensor readings and precipitation amounts for alfalfa Field No. 12.

Table 20. 1998 water balance for alfalfa Field No. 12.

	Water balance (all units are inches)						MAD: 4.35"			
Date	Days after planting	Rain	Gross irrigation	ETgage ETr	Crop Kc	Crop ETc	Cumul. depletion	Water balance	Crop height	Comments
5/12	22	0.68		4.67	0.67	3.13	2.45	1.90	9.0	Etgage installed
5/15	25			0.38	0.93	0.35	2.80	1.55		
5/26	36		3.05	2.40	0.99	2.38	2.59	1.76	15.0	
5/29	39			0.80	1.00	0.80	3.39	0.96	19.5	bud stage
6/2	43			1.90	1.00	1.90	5.29	-0.94	20.0	
6/5	46			0.90	1.00	0.90	6.19	-1.84	22.0	
6/9	50			0.90	1.00	0.90	7.09	-2.74		bud stage
Subtotal		0.68	3.05	11.95		10.36				plot and field cut on 6/9
6/19	10			1.63	0.30	0.49	7.57	-3.22		
6/23	14			1.30	0.40	0.52	8.09	-3.74	3.0	regrowth
6/26	17		2.65	1.30	0.57	0.74	6.58	-2.23	4.0	
6/30	21			1.50	0.79	1.19	7.77	-3.42	7.0	
7/2	23			0.70	0.91	0.64	8.41	-4.06		
7/7	28	0.70	2.75	1.50	0.99	1.49	6.85	-2.50	10.0	
7/10	31	0.20		0.30	1.00	0.30	6.95	-2.60	12.0	full cover
7/14	35			1.20	1.00	1.20	8.15	-3.80	20.0	bud stage
7/17	38			1.10	1.00	1.10	**8.70**	**-4.35**	23.0	3% bloom
7/21	42			1.10	1.00	1.10	**8.70**	**-4.35**	24.0	4% bloom
7/24	45	0.61		0.70	1.00	0.70	**8.70**	**-4.35**		7% bloom
7/28	49	1.20		0.60	1.00	0.60	8.10	-3.75	25.0	10% bloom, lodging
7/31	52	0.15		0.70	1.00	0.70	8.65	-4.30	27.0	
8/3	55			0.78	1.00	0.78	**8.70**	**-4.35**		cut hay sample
Subtotal		2.86	5.40	14.41		11.54				
8/18	15		2.35	2.38	0.30	0.71	7.42	-3.07	1.0	
8/21	18	0.20		0.70	0.45	0.32	7.53	-3.18	3.0	regrowth
8/25	22	0.21	2.74	0.90	0.59	0.53	5.52	-1.17	5.0	
8/28	25			0.60	0.72	0.43	5.96	-1.61	7.0	
9/1	29			1.00	0.85	0.85	6.81	-2.46	10.0	full cover
9/4	32			0.60	0.98	0.59	7.39	-3.04	15.0	
9/9	37		1.70	0.80	1.00	0.80	6.75	-2.40	17.0	bud stage
9/11	39	0.05	0.70	0.30	1.00	0.30	6.40	-2.05		
9/15	43	0.31		0.55	1.00	0.55	6.64	-2.29	21.0	early bloom
9/18	46	0.02		0.55	1.00	0.55	7.17	-2.82		
9/22	50			0.50	1.00	0.50	7.67	-3.32	22.0	early bloom
Subtotal		0.79	7.49	8.88		6.13				cut hay sample (9/22)
Total		**4.33**	**15.94**	**35.24**		**28.03**				

*Cumulative rain and ETr amounts up to May 12 are from the CoAgmet weather station at Yellow Jacket.

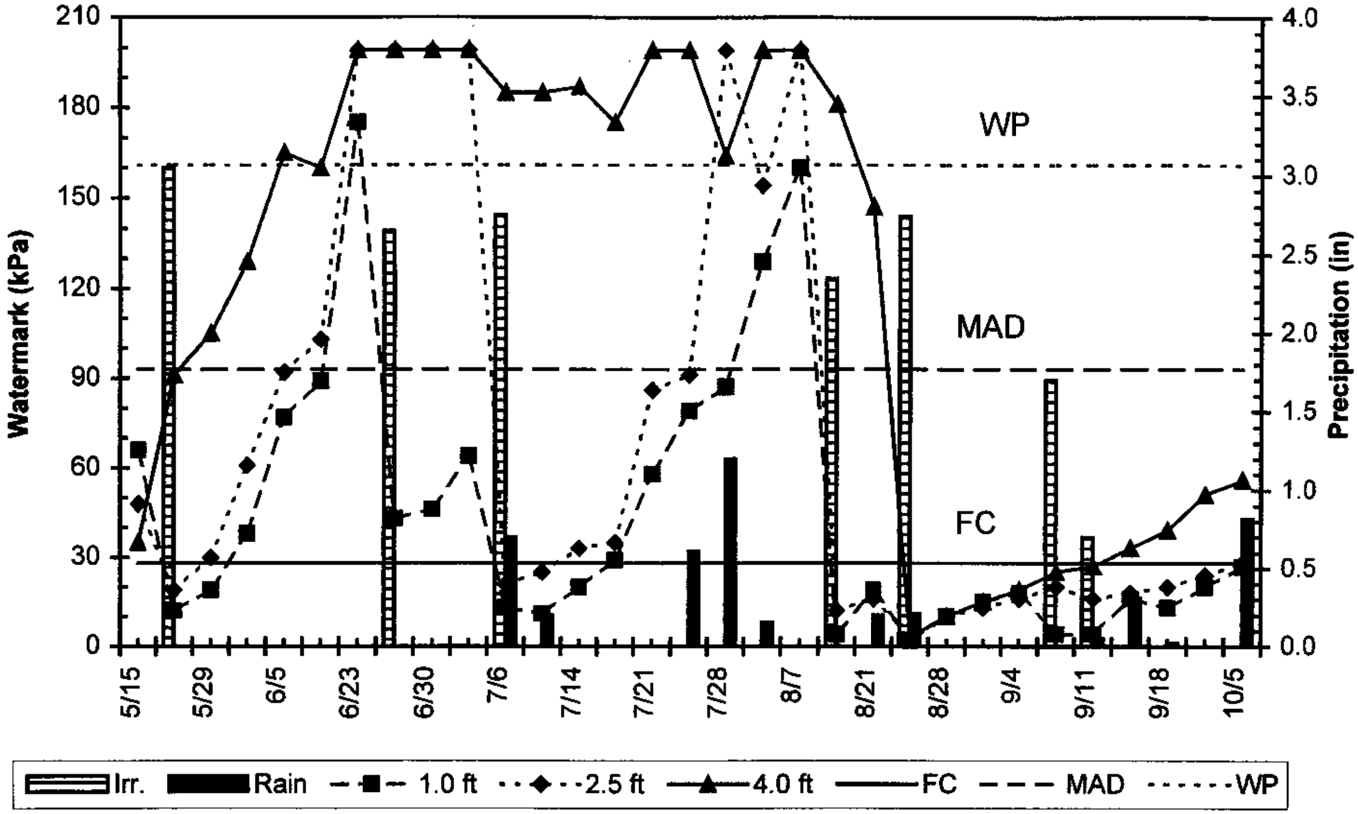

Figure 17. 1998 Watermark sensor readings and precipitation amounts for alfalfa Field No. 12.