Sprinkler system installation and monitoring of plant microclimate
by Douglas John Oellermann

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Agricultural Engineering
Montana State University

Abstract:
A sprinkler irrigation system to irrigate 24 10 m. x 10 m. individual test plots of alfalfa and spring wheat at precise rates was designed and installed. This was accomplished by using quick coupler valves on the corner of each plot in conjunction with quick coupler keys using quarter-circle sprinkler heads. Plots could thus be selectively irrigated for any chosen duration of time. The offseason use of irrigation water was investigated, including late fall irrigation in spring wheat and alfalfa and early spring irrigation on alfalfa, as well as normal seasonal irrigation. Parameters monitored included daily maximum and minimum soil temperatures at 5 and 20 cm., soil moisture levels before and after irrigation during the growing season and monthly during the dormant season, crop yields and weather parameters such as daily maximum and minimum air temperatures, precipitation, solar radiation, wind run, relative humidity and standard pan evaporation. The project investigated the efficiency of storage of water in the off-season, the effects of off-season irrigation on soil temperature regimes and crop yield and possible energy or equipment savings by lengthening of the irrigation season. The relationship between spring wheat yield and total water applied during the 1977 season was evaluated. A second order regression equation with r2 = 0.7804 was determined which indicates that yield increases with increased water to a certain point, then decreases.

Some plots had a gross gain in water over-winter while others had a gross loss. No relationship could be established. The efficiency of irrigation water storage over-winter was calculated for the plots. The spring wheat plots had higher overall efficiencies than the alfalfa since the former were drier prior to fall,irrigation. Positive spring wheat efficiencies ranged from 43-65%. Alfalfa efficiencies were all negative with one exception, 25%. Negative efficiencies indicate more water was lost than was applied by irrigation. Fall irrigation is beneficial if the soil profile is dry prior to fall irrigation and spring precipitation and runoff are not excessive.

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Date August 1, 1978

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Approved:

Thomas L. Hanson
Chairman, Graduate Committee

W. E. Larsen
Head, Major Department

Henry L Parsons
Graduate Dean

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ABSTRACT

A sprinkler irrigation system to irrigate 24 10 m. x 10 m. individual test plots of alfalfa and spring wheat at precise rates was designed and installed. This was accomplished by using quick coupler valves on the corner of each plot in conjunction with quick coupler keys using quarter-circle sprinkler heads. Plots could thus be selectively irrigated for any chosen duration of time. The off-season use of irrigation water was investigated, including late fall irrigation in spring wheat and alfalfa and early spring irrigation on alfalfa, as well as normal seasonal irrigation. Parameters monitored included daily maximum and minimum soil temperatures at 5 and 20 cm., soil moisture levels before and after irrigation during the growing season and monthly during the dormant season, crop yields and weather parameters such as daily maximum and minimum air temperatures, precipitation, solar radiation, wind run, relative humidity and standard pan evaporation. The project investigated the efficiency of storage of water in the off-season, the effects of off-season irrigation on soil temperature regimes and crop yield and possible energy or equipment savings by lengthening of the irrigation season. The relationship between spring wheat yield and total water applied during the 1977 season was evaluated. A second order regression equation with $r^2 = 0.7804$ was determined which indicates that yield increases with increased water to a certain point, then decreases. Some plots had a gross gain in water over-winter while others had a gross loss. No relationship could be established. The efficiency of irrigation water storage over-winter was calculated for the plots. The spring wheat plots had higher overall efficiencies than the alfalfa since the former were drier prior to fall irrigation. Positive spring wheat efficiencies ranged from 43-65%. Alfalfa efficiencies were all negative with one exception, 25%. Negative efficiencies indicate more water was lost than was applied by irrigation. Fall irrigation is beneficial if the soil profile is dry prior to fall irrigation and spring precipitation and runoff are not excessive.

Chapter 1

BASIS OF INVESTIGATION

As water becomes more and more valuable in man's daily life, every drop must be utilized to its maximum. Agriculture is in increasing competition with industry, recreation, wildlife, municipalities and many other interests for the use of a renewable, but annually finite resource. Even in the West, where irrigators have enjoyed almost exclusive use of the waters, industries, especially energy-related companies, are demanding and receiving rights to the use of these waters. Irrigators are increasingly efficient with their limited rights, due to modern sprinkler systems and better utilization of existing systems. By knowing the properties of the soils under irrigation and monitoring the soil moisture levels, they can apply the right amount at the right time.

There is always room for improvement to any system. One such improvement suggested is to utilize waters not normally used for irrigation. These are waters now going down the stream from fall and spring precipitation and early spring snow melt. Can fall and spring applied water be stored in the soil for seasonal use? What efficiencies can be attained? This thesis will address some of these questions.

STATEMENT OF PROBLEM

The problem is to determine the feasibility of off-season irrigation (i.e., late fall and early spring irrigations) on irrigated crops in relation to the disposition of off-season applied water in the soil profile, soil temperatures, climatic variables, system size and power requirements.

Storage of Irrigation Water

Can irrigation water applied during the off-season be stored for seasonal use? If it can be stored, it is important to know how much. Is it efficient? Water which is stored in the soil can be used as a reserve to draw upon during peak demand periods when the irrigation system cannot supply all of the crop's demands. This is analogous to a city water system when both the water reservoir and the pumping station supply the needs at peak use rates.

Effects on Soil Temperatures

Will soil temperatures be adversely affected? All crops have an optimum soil temperature at which they grow the best. Soil temperatures which are significantly lowered could have a harmful effect on the crop, reducing yields and thus adding to the cost of off-season irrigation.

Effects on System Size

Will a savings be realized by using a smaller system over a longer period of time, that is, both in-season and off-season? A smaller system will use less energy per hour, but the duration of use is longer. The same total amount of water for a certain crop still needs to be supplied, be it in-season, or off-season.

Climatological Effects

The variations of climate from one year to the next will certainly have significance on the practicability of off-season irrigation. What are the effects of a dry fall or a wet spring on this practice, or vice-versa? These questions need to be answered.

REVIEW OF SELECTED LITERATURE

In order to understand better what is known on the subject and to identify areas lacking in knowledge, several areas were reviewed. It is of interest to investigate research already done in such areas as the efficiency of storage of fall and spring applied water, the movement of water in the soil profile in all seasons, and the soil moisture requirements of crops and the effects of soil moisture stress on them. Also of interest are the optimum growing temperatures of crops, the effect of irrigation on soil temperatures and the specific effects of these variables on spring wheat and alfalfa, the crops to be grown in this experiment.

Storage Efficiencies

It is of primary interest to know how much water due to an off-season fall or spring (preseason) irrigation is stored in the soil and utilized. It has been found that carryover from fall to spring is affected by the soil moisture content (Timmons, 1968). Moreover, Hobbs (1971) states that the storage efficiency is inversely related to soil moisture content.

Fall irrigation. A variety of storage efficiencies have been found for fall irrigation. In Saskatchewan, Staple (1960) determined an efficiency of 37% on stubble fields while Timmons (1968) estimated that 1/3 of the total dormant season precipitation in Minnesota was stored. A similar 31% efficiency was found in a dry profile by Hobbs (1971). A late fall irrigation in Texas yielded a high 54% efficiency (Musick, 1971). Raney (1960) says that from tests made from 1953-57 in Kansas, he can conclude that fall irrigation is profitable in a dry fall.

It would appear that as much as 1/3-1/2 of water applied to a dry soil profile in the fall can be conserved over-winter. The amount conserved is a function of the soil moisture level at the time of irrigation.

Preseason irrigation. Preseason irrigation efficiencies are similar to those of fall irrigation. In order to increase efficiencies, Musick (1970) suggests cutting off seasonal irrigation at an early date, no later than early grain filling, to dry out the profile. As in fall irrigation, the efficiency was highest when the soil moisture content was lowest. Musick (1971) also states that low evaporative potential at the time of irrigation raised efficiencies. In this test, the efficiencies were believed to be affected by low soil permeability and difficulty of wetting the soil to a considerable depth. Musick (1970) found efficiencies of stored rainfall of 30-50% on dry soils to 10% on wet soils. A late spring irrigation yielded a 33% efficiency (Musick, 1971). He also states that preseason irrigation did not appreciably increase yields, but did delay the need for early seasonal irrigation one out of three years.

Again, 1/3-1/2 of spring applied water, be it rainfall or irrigation, was conserved in a dry profile. The efficiencies drop drastically in a wet profile, since the applied water is partly lost to deep drainage.

Soil Water Movement

Frozen soil. The effects and movement of water in the soil after fall irrigation through the winter season is of interest. It has been found that dry soils freeze deeper and faster than wet soils and that the former thaws upward while the latter thaws from both directions (Willis, 1961). The percolation rate of water in frozen soil decreases with increasing moisture content. When the soil is alternately frozen and thawed, there is no change in the percolation rate at 15 atmospheres pressure, an increase in the rate at field capacity and a decrease in the percolation rate at high moisture contents (0.1 atm.). The decrease at high moisture contents is believed due to the destructive effects of freezing and thawing on the soil aggregates (Hinman, 1973). Ferguson (1964) states that at depths in frozen soil as deep as 180 cm. and 235 cm., water held at low tensions (5 atm.) moved to the frozen zone from the unfrozen zone. For every centimeter of available water, a decrease of 0.22 cm. of stored water was found.

If the soil profile is below or equal to field capacity at the time of freezing in the fall, it appears that water may be frozen without deleterious effects.

Deep drainage. The movement of water in the soil profile should also be considered to help determine where the water losses occur. Miller (1971) ascertained that deep drainage decreased as evapotranspiration increased. In a 31-day field study, 6 cm. of water was lost to deep drainage in a 150 cm. profile. It was also found that there was an upward movement of water whose rate reached a maximum of

0.20 cm./day (Stone, 1973). Wilcox (1959) discovered that with increased depth, the total drainage increased, but the net rate of loss per meter decreased. Miller (1972) performed tests which showed a delay between the end of irrigation and the start of drainage. Van Schaik (1970) noted that on Chin loam and Cavendish loamy sand soils, much of the soil moisture loss over winter is due to the capillarity of the soil.

Soil Moisture Stress Effects on Spring Wheat and Alfalfa

What are the effects of soil moisture stress on a crop? Dubetz (1970) states that with increasing soil moisture in spring wheat, an increase in yield but a decrease in protein content was achieved. In alfalfa, lower temperatures and low soil moisture stress gave a higher yield and digestibility of alfalfa (Vough, 1971). Constant soil moisture stress has a tendency to lower the yield approximately as a linear function of the severity of stress. The magnitude of reduction of yield from occasional stress is dependent on the evapotranspiration rate, the severity of stress and most importantly, the physiological stage of growth of the plant. The most critical physiological stage is from flowering to maturity (Downey, 1972). Lucey (1965) found that for forage, the moisture absorption is greatest in the upper 15 cm. of soil. The absorption decreases when the soil moisture reaches less than 25-30%

of the available moisture and at a value of less than 15%, plant stress is apparent.

Since it is obvious that causing moisture stress during the reproductive stage of the plant reduces yields, one will have to be careful at which stage he cuts off irrigation in order to dry out the profile, as suggested by some investigators.

Optimum Soil Temperatures for Crop Growth

The application of off-season irrigation is expected to have an effect on soil temperature. Such changes may or may not have an adverse effect on plant growth. Various investigators have determined optimum temperatures for the growth of different crops. Mack (1965) found that barley, regardless of soil moisture, grew best at 18°C. For spring wheat, Mack (1973) determined a range of 10-18°C for optimum growth, while temperatures from 18-28°C significantly reduced yields. Sosulski (1966) reports that Thatcher wheat yielded more at 18°C than at 24°C. Smika (1974) tested two spring wheat varieties, Lee and Crim, and found a somewhat lower optimum soil temperature at crown depth, 12.5 and 14.5°C, respectively, than other investigators. Wheat emergence was 100% at 20-25°C while it was very low at 5°C (Singh, 1972). In yet another experiment, Boatwright (1976) found that spring wheat has an optimum surface soil temperature (0-3 cm.) of 19-22°C. At less than these temperatures, yields were reduced significantly. He further states that the crown seems to be the most sensitive part of the plant to low soil temperatures. For barley, Power (1963) determined an optimum temperature of 15°C. Alfalfa, subjected to day and night temperatures of 18° and 10°C, respectively, gave higher yields than when under a 32/24°C regime (Smith, 1969).

For spring grains, a mean optimum temperature of 18°C appears to be the best. A wide range was found which resulted in optimum temperatures from 10-25°C. Alfalfa has not been tested as extensively but a reasonable value would also be in the 18°C range for optimum growth.

Soil Temperature Changes Due to Irrigation

Several investigators have measured soil temperature changes due to irrigation. At a 10 cm. depth, soil irrigated daily was 2°C below that of a soil which had been irrigated one week earlier (Kohl, 1973). Wierenga (1971) states that soil temperatures at 5 and 10 cm. depths were affected for less than 24 hrs. by warmer (27°C) and cooler (14°C) irrigation water. At a depth of 30 cm., the effects of the cooler and warmer water lasted less than 60 hrs. He also found that soil temperatures were reduced by evaporative cooling in mid-April but not in mid-February. He concludes that early spring irrigation would delay warming of the soil profile. In New York on forest soils, Leonard (1971) measured the effects of water which was 0-5.5°C warmer than the surface temperature. He found, at the 300 cm. depth, that the soil warmed to 10°C 1-1½ months sooner than nontreated areas and the soil cooled to 10°C about one week later than non-treated areas.

The effects of water temperature on the soil temperature depends on whether the water is of a higher or lower temperature than the soil. Using warm water warmed up the profile sooner while cooler water will tend to delay warming of the profile. This needs to be investigated more thoroughly.

Cultivation and Irrigation of Crops

Alfalfa. The irrigation and cultivation of alfalfa and spring wheat is important to understand. Ditterline (1976) recommends an irrigation on alfalfa in Montana before fall freezeup and 2-3 seasonal irrigations. He adds that an irrigation early in the spring is desirable unless there is available moisture. However, another investigator states that the first spring irrigation should be delayed until the soil warms up (Stanberry, 1955). Daigger (1970) found that, in western Nebraska, the average evapotranspiration ratio over a three-year period was 680. It was found that the first cutting was most profitable. Daigger recommends filling the soil profile to a depth of 2.5 m. early in the season. Evapotranspiration varies throughout the season and it is thought that it increases from early spring to late spring, then decreases through the summer. Advection, the horizontal movement of drier air over a crop, is an important factor which contributes to the late spring peak (Rosenberg, 1969). With three different levels of irrigation through three seasons in southern Alberta, Krogman (1965) determined evapotranspiration rates of 0.31-0.91 cm./day with an average of 0.51 cm./day. Ditterline (1976) emphasizes the importance of avoiding severe soil moisture stress in alfalfa while permitting slow, steady growth. With water in the soil profile immediately before freezeup, heaving of the soil may be a problem. Stanberry (1955) states that winterkilling is dependent on variety, plant vigor, the soil moisture and soil type. Soils which are fine-textured and saturated heave plants, leaving them exposed to low temperatures and dessication. In well-drained soils, the problem of heaving is less serious. Holmes (1960) determined that the severity of heaving at Ottawa, Canada, increases with alternate thawing and freezing, which moves water to the soil surface. A layer of snow is good protection against occurrences of this type. In a poorly drained soil in Illinois, Portz (1967) found that damage due to heaving was moderate to severe in a moderate winter. Soils at or near field capacity seemed to be more susceptible.

If a soil is well-drained where heaving is not a problem, fall irrigation may be feasible. Early spring irrigation may also be desirable if there is a shortage of water in the profile to take advantage of efficient water use by alfalfa early in the season.

Spring wheat. Early spring irrigation of spring wheat at Pullman, Washington, prior to the boot is not economical unless wilting is evident, according to Robins (1962). It has been recommended to irrigate winter wheat in the fall to a depth of 180 cm., thereby avoiding early spring (March and April) irrigation (Grimes, 1962). He further states that irrigation is beneficial at the boot stage if rainfall is below normal and is especially necessary at the milk stage in extremely dry years. Dougherty (1974) arrived at a rather surprising conclusion that irrigation of wheat in New Zealand just before and after ear emergence reduced yields. Robins (1962) reports that moisture stress caused yield reductions of 10-35% and was maximum during and after heading. He adds that the soil moisture should not be totally depleted before maturity. El Nadi (1969) supports this finding in reporting from the Sudan that flowering, grain filling and maturation are more sensitive to moisture stress than the vegetative phase of plant development. In comparing one fall irrigation with one spring irrigation, Koehler (1974) reports that the latter yielded 9 q/Ha. more than the former at Pullman, Washington. Raney (1960) recommends early spring irrigation on winter wheat during a dry spring in north central Kansas. However, he adds, care must be taken to prevent lodging if rainfull should occur after irrigation.

It appears to be questionable if early spring irrigation of spring wheat is desirable. Most investigators do not recommend it save in case of a severe water shortage because of the delay in warming the soil profile. Fall irrigation may be a better alternative. Hobbs

(1971) notes that at Vauxhall, Alberta (p. 17):

> Spring irrigation is not feasible throughout most of the area because water is not available in the distribution systems. It is also difficult to irrigate uniformly and adequately the bare soils of unseeded or newly seeded fields. Consequently, in the irrigated areas of the Canadian prairies, if fall soil moisture content is in the lower half of the available range, it is advisable to fall-irrigate.

Musick (1971) says of preseason irrigation on sorghum on the southern High Plains of Texas (p. 97):

> Preseason irrigation did not influence grain yields appreciably where all treatments received the same two or three seasonal irrigations. Preseason irrigation, which increased total irrigation-water application by one-fourth to one-third, was inefficiently used for grain production and reduced the water use efficiency of total irrigation water applied.

Soil Moisture Depletion--Jensen Equation

Numerous equations have been formulated to predict soil moisture depletion. Jensen (1969) developed one such equation based on four parameters: (1) daily minimum and maximum air temperatures, (2) daily solar radiation, (3) average dew-point temperature at 8:00 a.m., and (4) daily wind run at a known height. He states that in the absence of parameters 3 and 4, a two-parameter equation based on parameters 1 and 2 can be used if advection is not severe.

Conclusion

From previous research, most areas of interest to the present project have been investigated to some extent. The question of seasonal carryover has been partially answered. Whether the efficiencies already determined are high enough to make off-season irrigation economical remains to be seen. Much work has to be done yet in determining the effects of lowered soil temperatures on crops. Some work has been done on optimum temperatures for crops and on the changes on soil temperature due to irrigation, but a combination of the two effects has not been studied. Findings seem to indicate that irrigation system size may not be affected to a large extent, but this needs to be determined more thoroughly. With the data from the experiment, some of the now-unanswered questions should be satisfied.

DEFINITIONS

Available moisture--Total soil moisture available for plant use as determined by the difference in measured soil moisture level and wilting point.

Efficiency of over-winter storage--The amount of fall-applied water stored in the soil profile over-winter divided by the total amount of fall irrigation, multiplied by 100.

Field capacity--Moisture content of soil after gravitational water is removed, usually two days after irrigation.

Gain-ratio--The ratio of precipitation stored in the soil profile to the total precipitation received during a period.

Late fall irrigation--Application of water to the soil after removal of the crop and before freezing with the intent of storing a portion of the water over-winter for seasonal use.

Preseason irrigation--Early spring irrigation after thawing of the soil profile but before active growing of the crop, with the intent of storing a portion of the water for seasonal use.

Soil profile--The portion of the soil from which the roots of the plant actively withdraw water.

Wilting point--Moisture content of soil at which plants can no longer remove water.

Chapter 2

PROCEDURES

The experimental procedures and physical characteristics of the project need to be outlined to gain a better understanding of the basis for the results of the experiment. These include the location, soil properties, plot layout, irrigation system and instrumentation to monitor soil moisture, soil temperatures and climatological variables.

LOCATION AND SOIL PROPERTIES

The site selected for the experiment is on the Montana State University Field Research Laboratory farm located six miles west of Bozeman, Montana, on U. S. Highway 191. The soil is an Amsterdam silty clay loam with an approximate slope of 1-2% in a northerly direction. The characteristics of the soil are given in Table 1, p. 17.

DISPOSITION OF PLOTS AND TREATMENTS

The two crops grown were alfalfa and spring wheat in plots measuring 10 meters by 10 meters. Three different irrigation treatments were applied to the alfalfa plots with three replications of each treatment, resulting in nine plots of alfalfa. The spring wheat plots received five different treatments, three replications per treatment, for a total of fifteen plots. The treatments for the spring wheat and alfalfa are summarized in Table 2, p. 18. These plots were laid out

Table 1

Water Holding Properties and Bulk Densities of Amsterdam Silty Clay Loam at Research Site

Depth, cm.	Field Capacity, %	Wilting Point, %	Bulk Density
30	22.9	11.7	1.27
60	22.4	10.4	1.25
90	22.4	9.2	1.24
120	24.0	12.4	1.27
150	23.0	12.2	1.24
180	21.4	10.0	1.24
210	19.0	8.5	1.24

Table 2

Description of Irrigation Treatments

Crop	
Alfalfa	Spring Wheat
(1) Fall	(1) Fall
(2) After each cutting	(2) Fall + boot stage
(3) Fall + spring preseason + after each cutting	(3) Boot stage
	(4) Joint stage + boot stage
	(5) Fall + joint stage + boot stage

adjacent to each other on the site in blocks of three plots by five plots for the spring wheat and three plots by three plots for the alfalfa with two-meter lanes between the plots and a four-meter lane between the alfalfa and spring wheat blocks. See Figure 1, p. 20, for a schematic of the layout. The plots were randomized according to treatments but the spring wheat plots were later derandomized to some extent due to technical problems to be explained later.

IRRIGATION SYSTEM

The plots were irrigated individually at different times during the season according to the treatment. Due to the randomized nature of the plots, it was necessary to design a sprinkler irrigation system which would irrigate any plot at any time without affecting adjacent plots which were not to be irrigated. This was accomplished by laying two-inch diameter laterals down each lane of the alfalfa and spring wheat plots from a four-inch main line which was situated in the four-meter lane between the crops. Couplers were placed along the two-inch laterals so that each coupler would serve two corners of adjacent plots, except at each end of the block, where one corner was served by each coupler (See Figure 2, p. 21.) The couplers which served two corners were fitted with a T-arrangement so that two quarter-circle sprinkler heads could be utilized from each coupler, with one head irrigating each plot. The Heads were attached to the Tee by a quick-

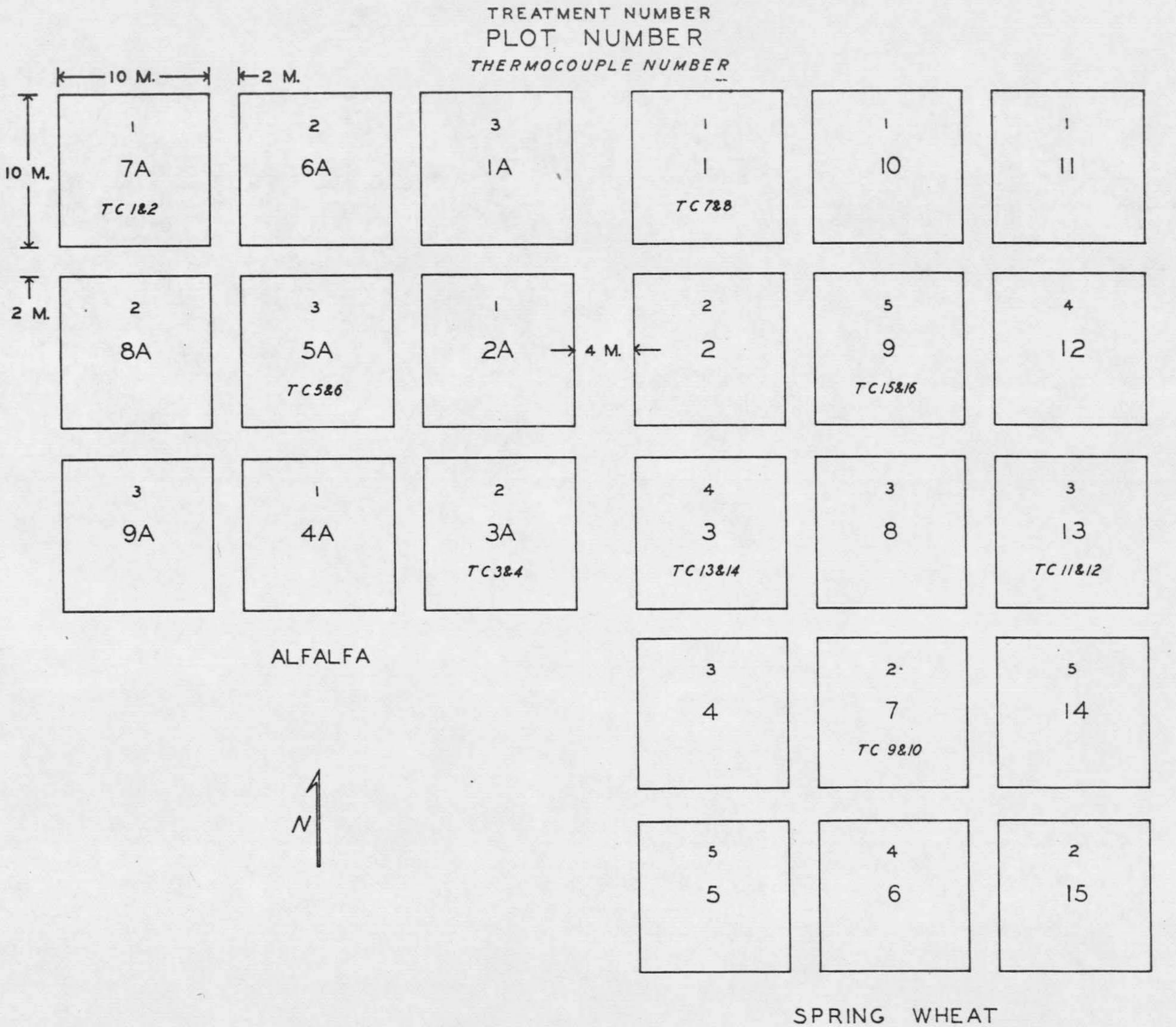

Figure 1. Schema of research plots.

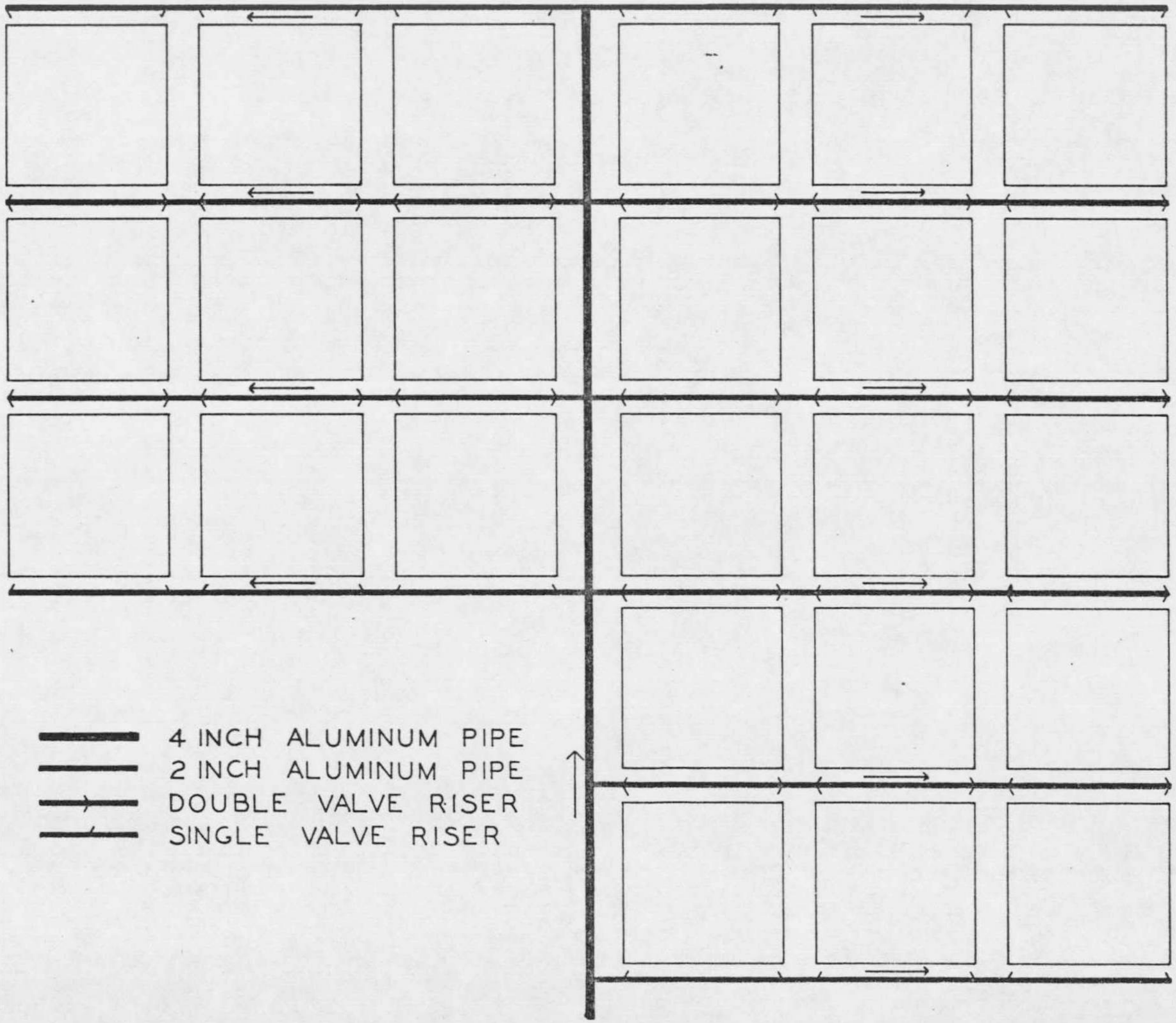

Figure 2. Research irrigation system.

couple valve and key combination in order to be able to selectively insert sprinkler heads in the pressurized line in none, one or two of the valves at each coupler, according to the irrigation treatments. See Figures 3 and 4, p. 23. Each plot was thus irrigated by four quarter-circle sprinklers operating from each corner of the plot. See Figure 5, p. 24. Commercially available Rainbird 25PJDA sprinkler heads with a single nozzle 1/8" in diameter were used at a pressure of 40 psi. They came equipped with splash guards to reduce spray outside of the desired area.

INSTRUMENTATION

Soil Moisture Measurement

To monitor soil moisture throughout the season as well as during the off-season with a neutron moisture meter, a Troxler 2651 Scaler-Rate Meter and 104A probe with Am/Be source, aluminum tubes were installed in the center of each plot to a depth of 180 cm. in the spring wheat and 210 cm. in the alfalfa. The moisture was measured at depths of 22.5, 45, 75, 105, 135 and 165 cm. in the spring wheat and at an additional increment of 195 cm. in the alfalfa. The moisture was measured before and after each irrigation on the plots to be irrigated, at regular intervals throughout the season on all plots and at monthly intervals during the off-season on all plots. Only two of three replications were monitored during the off-season on the spring wheat plots.

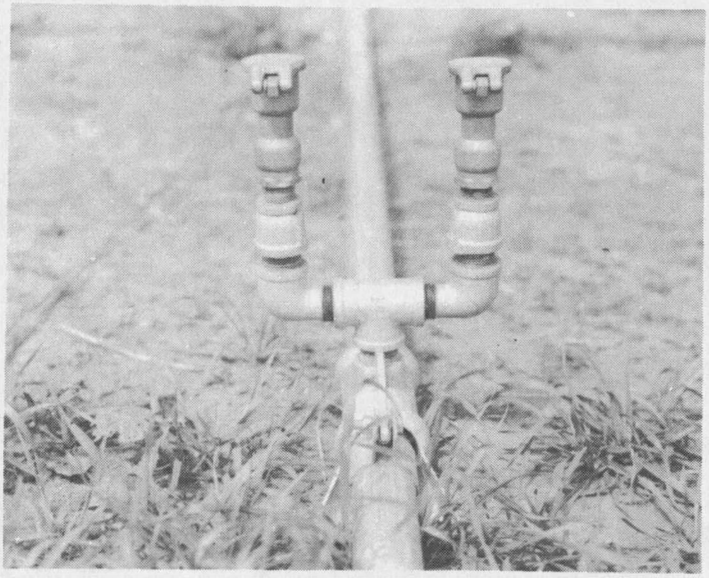

Figure 3. Two-inch coupler with double valve riser.

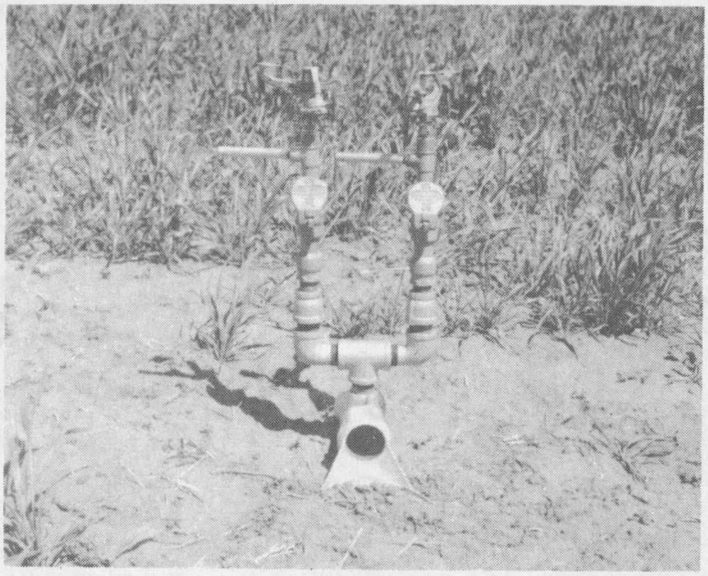

Figure 4. Two-inch coupler and double valve riser with keys and sprinkler heads inserted.

Figure 5. Irrigation system in operation.

Soil Temperature Measurement

Daily maximum and minimum soil temperatures were recorded at depths of 5 and 20 cm. using a Leeds and Northrup Speedomax W 24-point copper-constantan thermocouple recorder. Because of instrument limitations, soil temperatures were observed on only 1 of 3 replications for each treatment. The data was compiled on a weekly basis.

Climatological Variable Measurement

Climatological data was compiled monthly from records obtained from the Bozeman 6W weather station approximately 1/2 mile west of the research site. These data included daily maximum and minimum air temperatures, precipitation, daily incoming solar radiation, daily wind run, relative humidity and evaporation from a standard pan.

Yield Measurement

Spring wheat yields for the 1977 season were obtained with a small plot combine with a 4.5 ft. header. One pass was made through each plot from one side to the other side. The sample was collected and tagged after each pass through a plot. The length of the pass was then measured. By weighing each sample and knowing the area harvested, the yield for each plot was calculated.

Chapter 3

RESULTS

During the 1977 growing season, the irrigation system was not yet completed at the time of the required irrigation treatments on the spring wheat. The spring wheat was well past the first joint stage and entering the boot stage so it was decided to irrigate all plots requiring either or both of these treatments with the farm irrigation system. Since this included all treatments except treatment 1 (fall irrigation) and the system was not capable of selectively irrigating plots, treatment 1 plots were derandomized and grouped at the north end of the spring wheat block. This also derandomized some of the other plots but did allow irrigation of treatments 2-5. Tables 3 and 4, pp. 27 and 28, summarize the cultural practices on the alfalfa and spring wheat during the 1977-78 season. Tables 5 and 6 on pages 29 and 30 summarize the dates and events of soil moisture readings during the 1977-78 season.

YIELD VS. WATER APPLIED RELATIONSHIPS --1977 SEASON

Since the spring wheat was not irrigated at the specified stages of growth, the only relationship which can be investigated is the correlation between yield and total amount of water applied during the 1977 season. The amount applied varied from 7.32 cm. on plot 9 to 18.92 cm. on plot 13. See Table 7, p. 31. The variation was due to edge effects

Table 3

Cultural Practices on Spring Wheat
--1977-78 Season

April 25, 1977	Plots were seeded with 50 lb./A. Norana semi-dwarf spring wheat, no fertilizer.
June 29 and 30, 1977	Treatments 4 and 5 were partially irrigated with a temporary system. Approximately 5 cm. water was applied.
July 5 and 6, 1977	Treatments 2-5 were irrigated with farm system.
September 9, 1977	All plots were harvested. Yield samples were gathered.
November 8, 1977	All plots requiring fall irrigation were irrigated with approximately 3 cm. water.

Table 4

Cultural Practices on Alfalfa
--1977-78 Season

April 19, 1977	All plots were top-dressed with 200 lb./A. of 0-45-0 fertilizer.
May 2, 1977	Plots were seeded with 12-15 lb./A. Ladak-65.
July 5 and 6, 1977	All plots were irrigated with farm system.
August 9, 1977	All plots were harvested. No yield data was taken.
November 9, 1977	Treatments 1 and 3 were irrigated with approximately 3 cm. water.

Table 5

Log of Soil Moisture Readings on Spring Wheat
--1977-78 Season

Gregorian Date	Julian Date	Event
6-21-77	7172	Initial reading
7-1-77	7182	Post-irrigation
7-5-77	7186	Pre-irrigation
7-7-77	7188	Post-irrigation
7-8-77	7189	Post-irrigation
8-2-77	7214	Check
10-20-77	7293	Pre-irrigation
11-14-77	7318	Post-irrigation
12-29-77	7363	Check
1-23-78	8023	Check
2-22-78	8053	Check
3-30-78	8089	Check

Table 6

Log of Soil Moisture Readings on Alfalfa
--1977-78 Season

Gregorian Date	Julian Date	Event
7-7-77	7188	Initial reading Post-irrigation
8-2-77	7214	Check
10-28-77	7301	Pre-irrigation
11-14-77	7318	Post-irrigation
12-29-77	7363	Check
1-23-78	8023	Check
2-22-78	8053	Check
3-30-78	8089	Check

Table 7

Amount of Water Applied to Spring Wheat, cm.--1977 Season

Plot Number	Julian Date						Applied Water, cm.
	7172	7179	7182	7186	7188	7189	
1	--	--	--	--	--	--	0
2	44.92	--	--	39.66	49.40	--	9.74
3	46.08	--	--	40.83*	--	54.11	13.28
4	46.13	--	--	40.88*	--	56.09	15.21
5	49.47	--	--	44.22*	--	52.64	8.42
6	44.94	--	--	39.69*	--	48.68	9.99
7	46.42	--	--	41.17*	--	52.82	11.65
8	45.82	--	--	40.55	57.72	--	17.17
9	--	--	46.61	45.11*	52.43	--	7.32
10	--	--	--	--	--	--	0
11	--	--	--	--	--	--	0
12	43.94	41.92*	46.01	--	51.79	--	9.87
13	45.42	--	--	40.17*	--	59.09	18.92
14	46.33	--	--	41.08*	--	56.98	15.90
15	44.72	--	--	39.49	--	46.78	7.29

*Estimated from evapotranspiration rates of Plots 2, 8 and 15 from 7172 to 7186. ET_2 = (44.92 - 39.66)/14 days = 0.376 cm./day; ET_8 = (45.82 - 40.55)/14 days = 0.376 cm./day; ET_{15} = (44.72 - 39.49)/14 days = 0.374 cm./day.

of the sprinkler distribution pattern of the farm system. Graphing total applied water vs. yield (see Table 8, p. 33) showed considerable scatter in the data. See Figure 6, p. 35. The average yield by treatment is given in Table 9, p. 34. A second order regression correlation (Lund, Smith E.), eliminating one data point from plot 5 because the point was not representative of the treatment, yielded an equation which indicates that yield increases with increasing water up to a point, then decreases. The equation, $Y = 50.15 + 1.397x - 0.0507x^2$, gives a maximum at x = 13.78 cm., Y = 59.77 q./Ha. A value of $r^2 = 0.7804$ was computed for this regression.

Yield data for the alfalfa was not taken from the one cutting during the 1977 season because the stand was in the process of becoming established.

CONDITIONS OF FALL IRRIGATION

On November 8, 1977, the bare plots requiring fall irrigation which were to be seeded to spring wheat the following spring were irrigated with approximately 3 cm. water. The amount applied was not the same on each plot because of system difficulties and freezing of sprinkler heads. On November 9, 1977, the alfalfa plots requiring fall irrigation (treatments 1 and 3) were irrigated with approximately 3 cm. water.

Table 8

Spring Wheat Yield Data--1977 Season

Plot Number/ Treatment No.	Sample Net Wt., lb.	Sample Area x 10^3, A.	Yield* Bu./A.	Yield q./Ha.
1/1	15.28	3.36	75.85	51.06
2/2	16.59	3.36	82.35	55.43
3/4	17.94	3.36	89.06	59.95
4/3	16.81	3.36	83.45	56.17
5/5	13.23	3.41	64.68	43.54
6/4	17.59	3.25	90.09	60.64
7/2	17.21	3.31	86.77	58.41
8/3	17.94	3.36	89.06	59.95
9/5	17.09	3.36	84.84	57.11
10/1	14.73	3.31	74.26	49.99
11/1	14.31	3.31	72.15	48.57
12/4	18.38	3.36	91.24	61.42
13/3	18.28	3.41	89.37	60.16
14/5	17.71	3.36	87.91	59.17
15/2	18.54	3.41	90.64	61.01

*Assume 60 lb./Bu.

Table 9

Average Spring Wheat Yield by Treatment
--1977 Season

Treatment	Plots	Bu./A.	q./Ha.
1	1-10-11	74.09	49.87
2	2-7-15	86.59	58.28
3	4-8-13	87.29	58.75
4	3-6-12	90.13	60.67
5	5-9-14	79.14	53.27

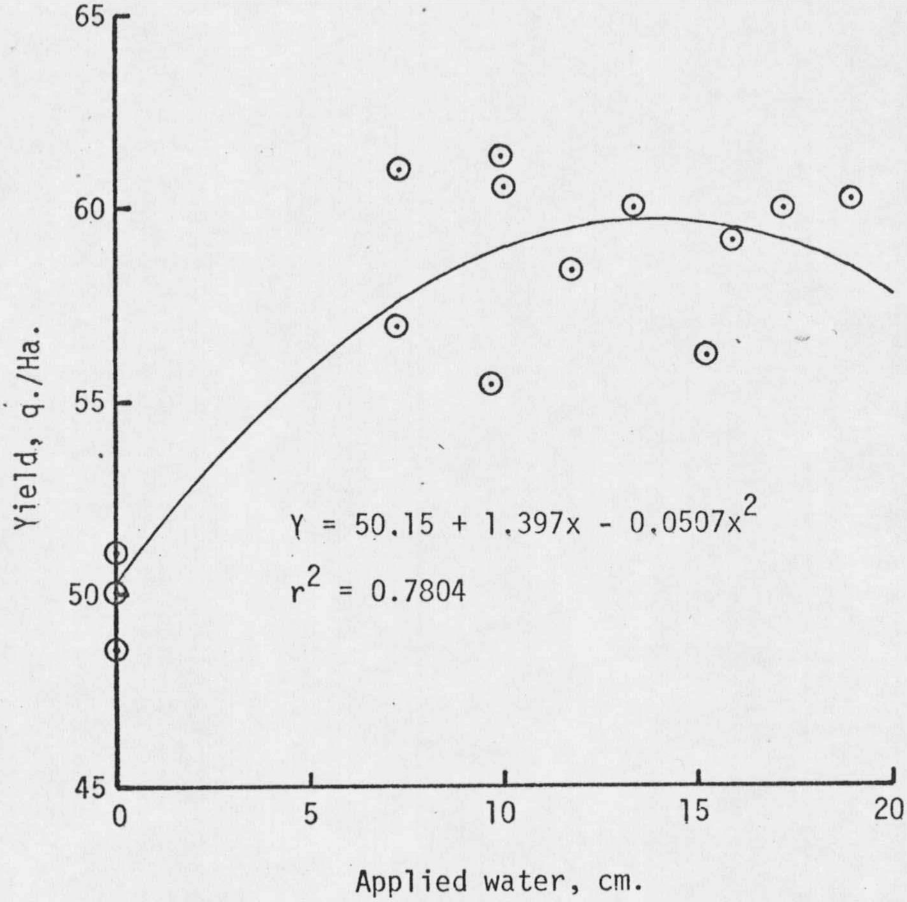

Figure 6. Yield vs. applied water correlation, spring wheat 1977.

MIGRATION OF SOIL WATER OVER-WINTER

Throughout the winter, monthly soil moisture readings were taken on two of three replications of all treatments in the spring wheat plots and on all alfalfa plots. From these readings, the total centimeters of water in each 30 cm. soil profile interval were computed for each date on which readings were taken. This data is summarized in the appendix. A family of graphs for each plot monitored over-winter was constructed showing the movement of soil water for each successive soil moisture reading. See Figure 7, pp. 37-41. In general, the graphs show an increase in soil moisture in the 90-150 cm. zones, mixed gains and losses in the 0-90 cm. zones and relatively little change in the zones from 150-210 cm.

GAIN OR LOSS OF SOIL WATER OVER-WINTER

From the data summary, the irrigated spring wheat plots showed no discernible tendency to gain or lose moisture over-winter from December 29, 1977, to February 22, 1978. Three plots gained from 0.10-0.65 cm. with an average of 0.32 cm. while three plots lost from 0.14-0.59 cm. with an average of 0.39 cm. Of the four non-irrigated plots, three gained from 0.42-0.94 cm. with an average of 0.65 cm. while one plot lost 2.63 cm.

During the same period, the six fall-irrigated alfalfa plots gained 1.15 to 2.57 cm. over-winter with an average of 2.10 cm. The

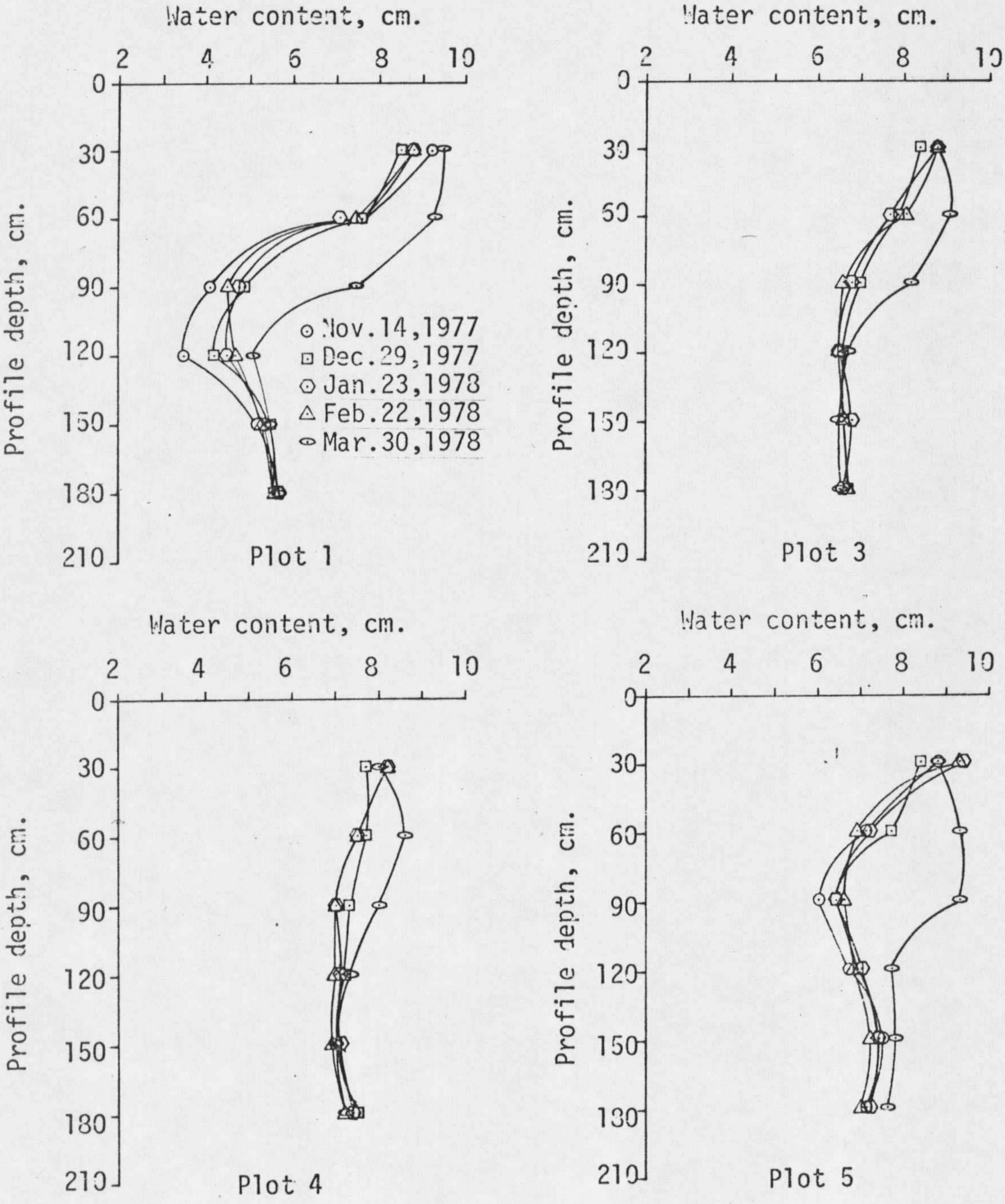

Figure 7. Disposition of moisture in soil profiles over-winter.

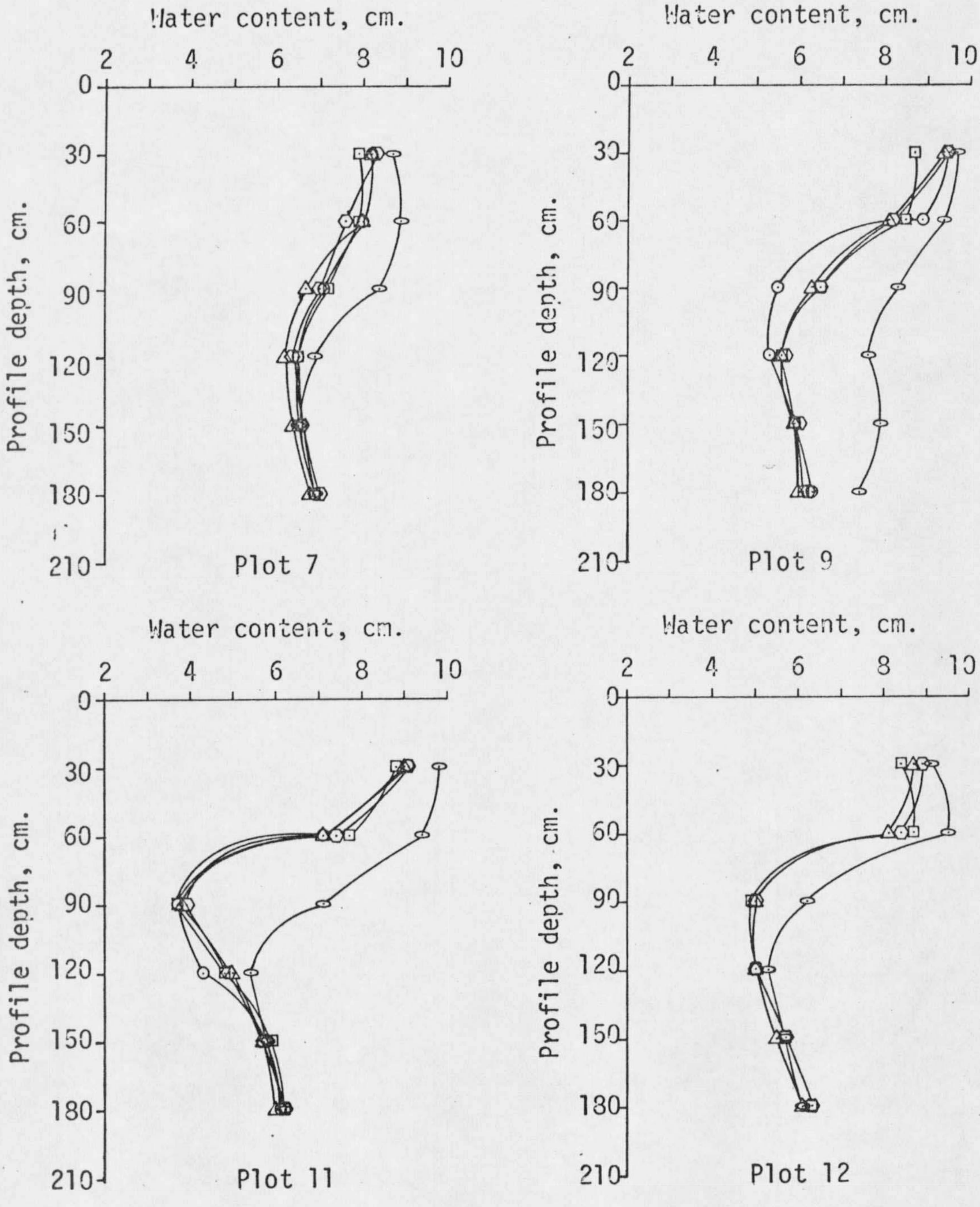

Figure 7. (Continued).

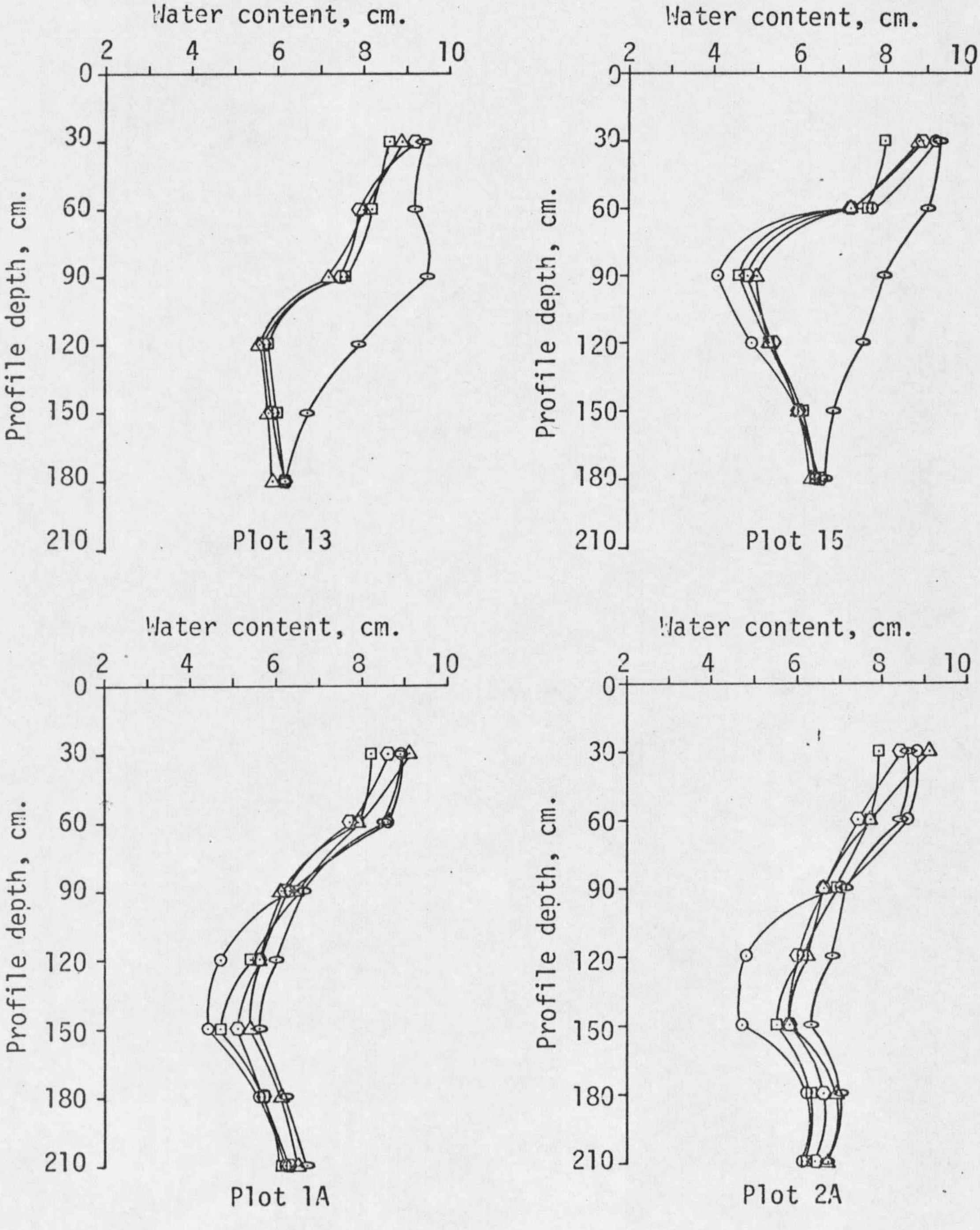

Figure 7. (Continued.)

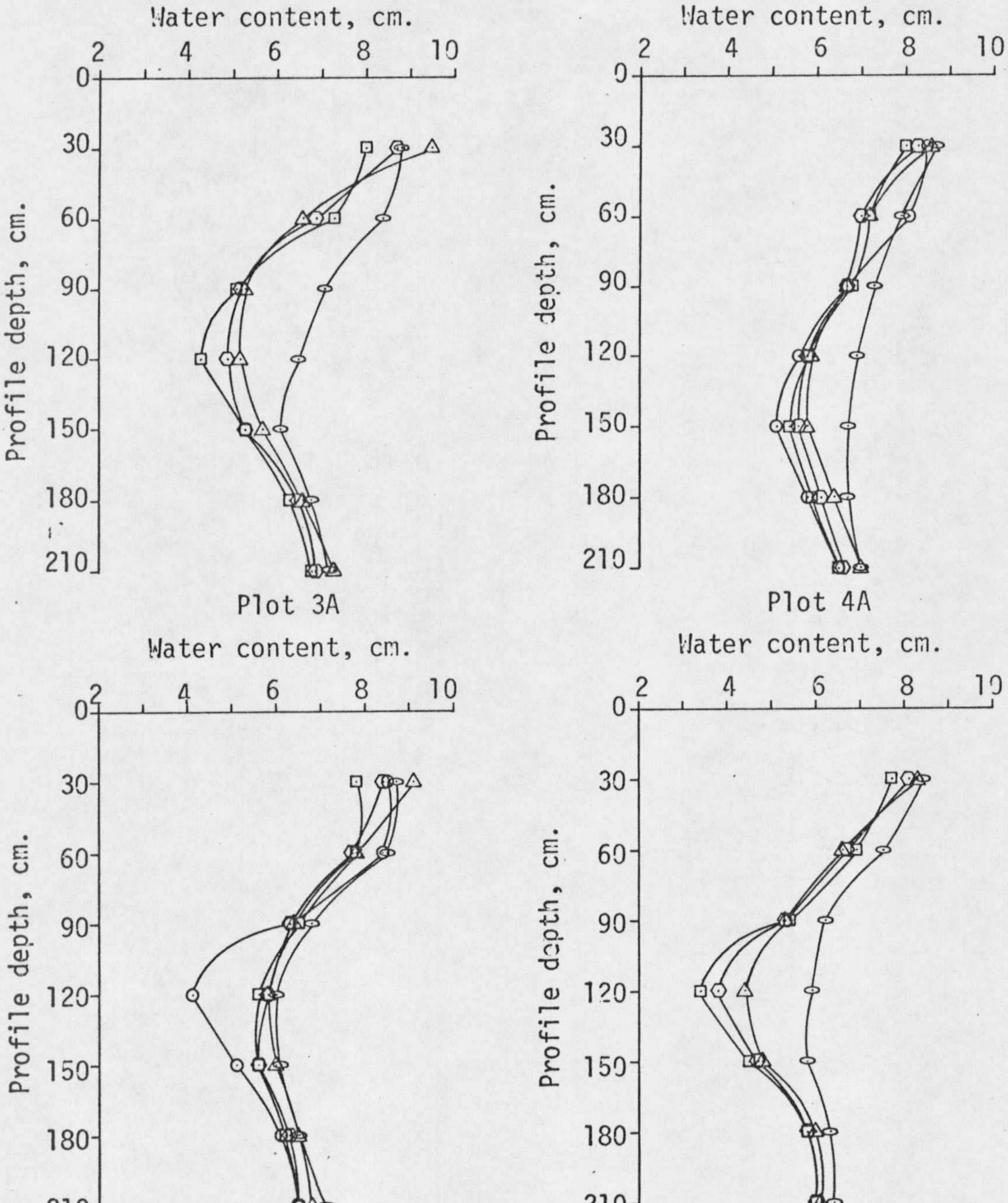

Figure 7. (Continued.)

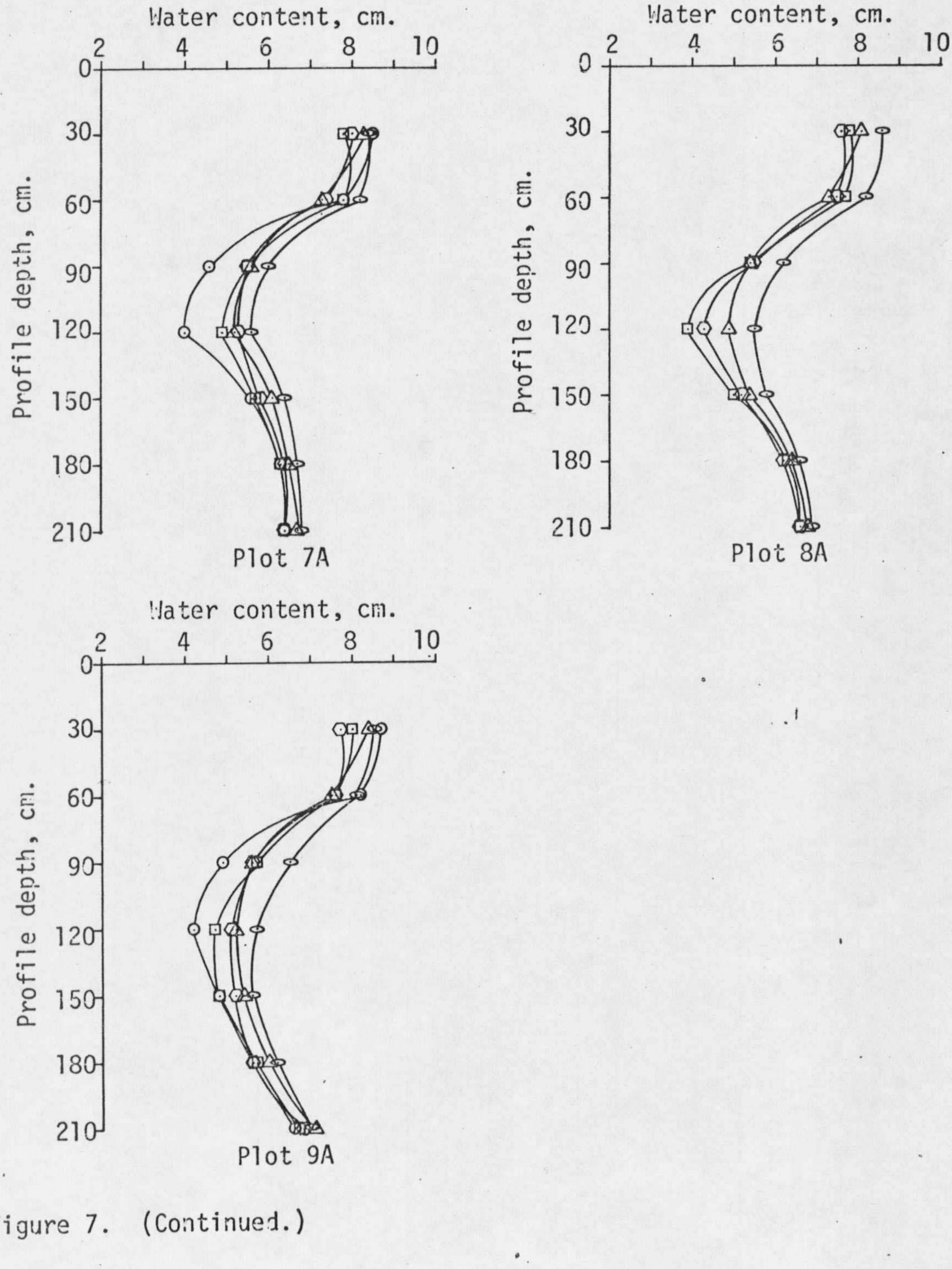

Figure 7. (Continued.)

three non-irrigated plots gained from 1.63 to 2.98 cm. with an average of 2.16 cm.

Water Storage in Spring Wheat

Effective precipitation entering profile. To determine the percentage of over-winter precipitation which entered the soil profile, treatments which received no fall irrigation were evaluated. Any gain in moisture in the profile is due solely to precipitation. For the spring wheat treatments 3 and 4, plots 4, 13, 3 and 12 were monitored over-winter from December 29, 1977, to March 30, 1978. The precipitation during this period was 6.2 cm. as summarized in Table 10, p. 43. These plots gained, respectively, 1.6, 6.5, 2.7 and 2.9 cm. water during this period. The gain ratios, the ratio of amount gained to precipitation, are 0.25, 1.05, 0.44 and 0.47, respectively. The variances and the ratio over 1.0 are probably due to differences in snow drifts on the plots. The average of these four ratios is 0.55. Applying this ratio to the period from November 14, 1977, to March 30, 1978, in which 10.29 cm. of precipitation was received, the effective precipitation stored by the soil is 5.66 cm. But, adding this amount to the soil moisture recorded on November 14, 1977, gives, in all cases, an amount less than that recorded on March 30, 1978. This means that some of the water in the profile is excess and is unaccounted for. The maximum amount that can have entered is assumed to be 10.29 cm., the amount of

Table 10

Precipitation Summary
--Bozeman 6W Station

Date	Inches	Centimeters
11/14/77-12/29/77	1.61	4.09
12/29/77-1/23/78	0.61	1.55
1/23/78-2/22/78	0.89	2.26
2/22/78-3/30/78	0.94	2.39
Total	4.05	10.29

precipitation during the period. The minimum amount is the difference between the soil moisture levels on November 14, 1977, and March 30, 1978. The average difference for all spring wheat plots which were fall-irrigated is 7.15 cm. This was averaged with the maximum, 10.29 cm., for a value of 8.72 cm. which entered the profile. This gives a gain ratio of 0.85.

Storage efficiency. The efficiency of storage was then calculated, assuming that 8.72 cm. of the total precipitation entered the soil profile. The efficiency was calculated by taking the sum of the total moisture level on November 14, 1977, in centimeters, and the effective precipitation, then subtracting the total moisture level on March 30, 1978, in centimeters. This gives the total amount of water lost over-winter. The efficiency is thus the amount of water applied minus that lost divided by the amount of water applied times 100.

Treatment 1, plots 1 and 11, yielded efficiencies of 63 and 65%, respectively. Plots 7 and 15 of treatment 2 gave efficiencies, respectively, of -217 and 105%. This signifies that plot 7 lost more water than was applied to it by irrigation and that plot 15 gained more water than was applied to it. The efficiencies of treatment 5, plots 5 and 9, were 43 and 105%, respectively. Again, plot 9 gained more water than was applied. The calculations are summarized in Table 11, p. 45.

Table 11

Water Storage Efficiency in Spring Wheat

	Treatment					
	1		2		5	
Plot Number	1	11	7	15	5	9
Cm. water applied on 11/8/77	3.72	3.51	1.86	2.75	2.39	3.70
Total cm. water/180 cm. depth on 11/14/77	35.33	36.09	43.42	38.32	43.11	41.35
Effective precip. from 11/14/77 to 3/30/78	8.72	8.72	8.72	8.72	8.72	8.72
Total cm. water applied	44.05	44.81	52.14	47.04	51.83	50.07
Total cm. water/180 cm. depth on 3/30/78	42.66	43.58	46.25	47.18	50.46	50.37
Total cm. water lost over-winter	1.39	1.23	5.89	-0.14	1.37	-0.20
Efficiency, %	63	65	-217	105	43	105

Water Storage in Alfalfa

Effective precipitation entering profile. The efficiency of storage in alfalfa was calculated in the same manner as the spring wheat. To account for precipitation entering the profile, the gain ratio was calculated by determining the amount of water stored over-winter in non-fall irrigated plots. The ratio for plots 3A, 6A and 8A of treatment 2 were 1.24, 1.08 and 0.82, respectively. The average of these three ratios is 1.05. An average of the two lower ratios is 0.95. Since this still seems high, a value of 0.90 was assumed. The effective precipitation for the period November 14, 1977, to March 30, 1978, is thus 0.90 x 10.29, or 9.26 cm.

Storage efficiency. The efficiencies as computed in Table 12, p. 47, were all negative, with one exception. Plot 4A of treatment 1 had a 25% efficiency. The negative efficiencies indicated that more water was lost from the profile over-winter than was applied in fall irrigation. The plots did however exhibit a gross gain in moisture.

Additional Data from South Dakota

South Dakota State University at Brookings, South Dakota, is performing the same experiment with alfalfa and spring wheat, as well as corn and winter wheat. As a means of comparison, over-winter soil moisture data (Carlson, 1978) for the alfalfa and spring wheat plots

Table 12

Water Storage Efficiency in Alfalfa

	Treatment					
	1			3		
Plot Number	2A	4A	7A	1A	5A	9A
Cm. water applied on 11/9/77	4.38	6.05	2.38	3.49	3.47	3.41
Total cm. water/ 210 cm. depth on 11/14/77	46.21	46.38	43.17	44.66	45.07	43.04
Effective precip. from 11/14/77 to 3/30/78	9.26	9.26	9.26	9.26	9.26	9.26
Total cm. water applied	55.47	55.64	52.43	53.92	54.33	52.30
Total cm. water/ 210 cm. depth on 3/30/78	50.90	51.11	48.07	48.55	49.70	47.60
Total cm. water lost over-winter	4.57	4.53	4.36	5.37	4.63	4.70
Efficiency, %	-4	25	-83	-54	-33	-38

were evaluated. The treatment numbers are the same as they are for the Montana experiment.

Efficiency in spring wheat. An evaluation of the gain ratio for three spring wheat plots yields an average of 0.44. The precipitation during the over-winter period from October 26, 1976, to April 7, 1977, was 22.78 cm. The effective precipitation is thus 9.99 cm. Treatments 1 and 2 received 15.24 cm. of fall-applied water while treatment 5 received 25.24 cm. Plots 59 and 66 of treatment 1 were each 57% efficient in storing fall irrigation. Plot 61 of treatment 2 was 55% efficient. Plots 51, 53 and 55 of treatment 5 were, respectively, 73, 75 and 71% efficient.

Efficiency in alfalfa. The average gain ratio for six non-fall irrigated alfalfa plots was 1.07. The minimum gain ratio was 0.79. It was assumed that the gain ratio was less than 1.0 but greater than 0.79. The gain ratio assumed was 0.90. The effective precipitation was then 0.90 x 22.78 cm. or 20.50 cm. Treatment 1 efficiencies were 19, 29 and 25% for plots 69, 73 and 76. Plots 68, 74 and 75 of treatment 3 were 42, 13 and 43% efficient.

WATER STORAGE EFFICIENCIES VS. PERCENT FIELD CAPACITY

In an attempt to determine at what moisture content fall irrigation becomes feasible, the efficiency of storage of each plot vs. the percent field capacity prior to irrigation were graphed. See Figure 8. The total field capacity to 180 cm. depth is 40.83 cm. in the spring wheat and 46.53 cm. to 210 cm. depth in the alfalfa. The moisture content of the soil in the fall prior to irrigation should be an indicator of whether to irrigate or not. A considerable scatter in the points is evident and no good correlation was established.

RELIABILITY OF DATA

The soil moisture readings were found to be 3-10% higher than correspondent gravimetric samples when using the manufacturer's calibration tables. Therefore, numerous gravimetric samples were collected at different moisture content levels while readings were taken with the neutron meter. The moisture content was then calculated using the neutron meter manufacturer's tables and also from the gravimetric samples. These two values were linearly correlated so that a correction of the instrument's readings could be made. The values obtained through this process were good to excellent, but it was necessary to recheck the correlation with new field data regularly to ascertain that the correlation was still valid. This was a problem throughout the project and continues to be so, despite recalibration of the instrument by the manufacturer. For some still undetermined reason, the calibration tables supplied with the instrument are not valid for the soil of this experiment.

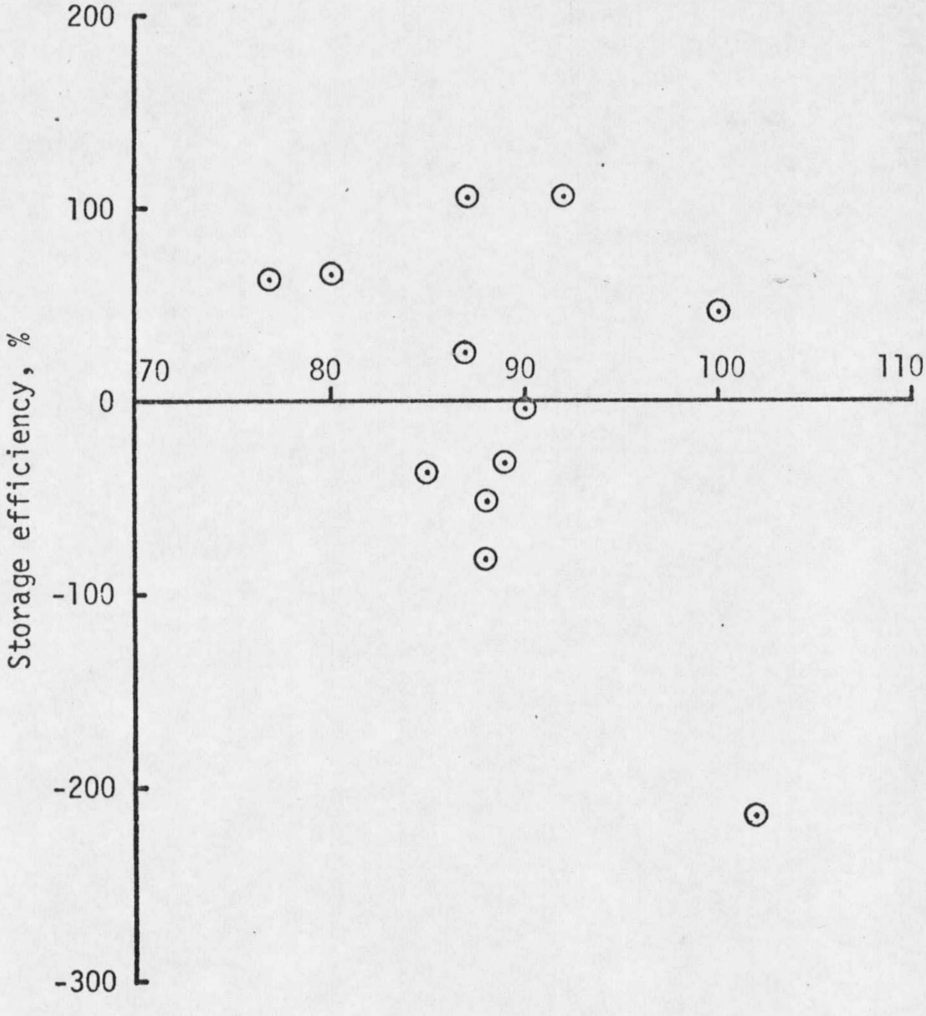

Figure 8. Water storage efficiencies vs. percent field capacity prior to irrigation.

The amount of water applied in the fall was very variable between plots. The amount was also small, due to limited time of irrigation. The small amount applied needs to be measured more accurately since small errors in measurement will cause large errors in efficiency calculations. The calculated efficiencies at best give an idea of the magnitude of efficiencies and generally show the effects of a dry profile vs. a wetter profile.

The efficiency calculations were also complicated by the uncertainty of how much of the over-winter precipitation actually entered the profile. Snow depths and drifts need to be monitored more closely to take these effects into consideration in efficiency calculations.

South Dakota applied 15-25 cm. water in the fall while Montana applied only 3 cm. This makes a difference in calculations. A small error in measurement will cause a larger error in the Montana data than in the South Dakota data.

Chapter 4

CONCLUSIONS

From the evaluation of the data, there are some general relationships which can be inferred with respect to yield vs. applied water, water storage efficiency and storage efficiencies vs. percent of field capacity. Because of a lack of data and some inaccurate data, precise relationships are difficult to obtain.

YIELD VS. WATER APPLIED

A good general relationship between amount of water applied and yield for the 1977 season was obtained. The second order correlation did show a definite peak in yield after which an increase in water decreased yields. This is to be expected, since common sense tells one that yield will not increase indefinitely with increasing water.

WATER STORAGE EFFICIENCIES

It appears that a part of the fall-applied water can be stored over-winter, if the soil profile is dry enough prior to fall irrigation. Profiles which were wetter did not have as high efficiencies as the drier profiles did. This is because the drier profiles have more storage room than the wetter profiles. Water applied to wet profiles has no place to be stored and thus is flushed through the profile and is lost to deep drainage. It is not clear yet what the maximum soil moisture level should be before fall irrigation is not feasible.

The South Dakota data yielded similar results. Their data, however, was more consistent and the efficiencies calculated were more uniform within treatments. Again, the drier profiles had higher efficiencies than the wet profiles.

WATER STORAGE EFFICIENCIES VS. PERCENT FIELD CAPACITY

Upon plotting efficiency vs. percent field capacity before fall irrigation, a considerable scatter in the data is evident. Positive efficiencies were found in profiles which were at 100% of field capacity and negative efficiencies were found in profiles which were at 85% of field capacity. The alfalfa plots all showed a negative efficiency with one exception. This is to be expected because the soil profiles were generally wetter in the alfalfa than in the spring wheat. A general trend that may be observed is that the efficiences tend to get more positive with drier soil profiles. This trend would have to be verified by more accurate and extensive data.

Chapter 5

SUMMARY

The disposition of late-fall applied irrigation water in the soil profile over-winter was investigated. This was to determine the effectiveness and feasibility of late-fall irrigation. The amount of water within the soil profile was monitored monthly during the winter season on alfalfa and spring wheat plots at incremental depths of 30 cm. to a depth of 180 cm. in the spring wheat and 210 cm. in the alfalfa to determine the movement of water in the profile and the efficiency of storage of fall-applied water during the period.

PROCEDURES

The plots were irrigated in early November with approximately 3 cm. of water by a sprinkler system. Soil moisture was monitored monthly on all plots, fall irrigated and non-fall irrigated, by the neutron attenuation method. Daily maximum and minimum soil temperatures at 5 and 20 cm. depth and meteorological data were also recorded but not analyzed in this paper.

YIELD VS. APPLIED WATER

Spring wheat yield data from the 1977 season was correlated with total amount of water applied. A good correlation ($r^2 = 0.7804$) was obtained with a second order regression evaluation. It shows that yield increases with increased irrigation until a peak is reached, then starts to decline.

DISPOSITION OF SOIL WATER OVER-WINTER

Water movement in the profile over-winter was generally the same for all plots. The 90-150 cm. zones gained moisture while the 0-90 cm. zones showed no definite trend to gain or lose moisture. Water at depths of 180-210 cm. showed relatively little movement, except in the spring when the profile was being filled by spring runoff. Alfalfa plots, irrigated and non-irrigated, tended to have a gross gain in total water in the profile over-winter, while spring wheat plots were about even in the number of plots gaining or losing moisture.

STORAGE EFFICIENCIES

Efficiencies of storage of fall applied water varied widely. In the spring wheat, two treatment 1 plots were 63 and 65% efficient while treatment 2 plots were -217 and 105% efficient. Treatment 5 plots were 43 and 105% efficient. Out of six alfalfa plots which were fall irrigated, only one had positive efficiency, 25%. The soil profiles of the alfalfa were typically wetter in the fall than were the spring wheat profiles.

Data from the same experiment in South Dakota (Carlson, 1978) were also analyzed. In the spring wheat, two treatment 1 plots both yielded efficiencies of 57%. One plot in treatment 2 was 55% efficient. Treatment 5 plots were 73, 75 and 71% efficient. The alfalfa plots showed a little more variability. Treatment 1 plots were 19, 29 and 25% efficient. Efficiencies of treatment 3 plots were 42, 13 and 43%.

RECOMMENDATIONS FOR FURTHER RESEARCH

It has been shown that a portion of fall-applied irrigation water can be successfully stored over-winter in the soil profile. It is not clear, though, at what moisture content fall irrigation is efficient. This needs to be studied more thoroughly and with more accurate data. It needs to be determined at what percent of field capacity fall irrigation becomes inefficient, so that an irrigator can measure the soil moisture in the fall and decide if fall irrigation is desirable.

Another problem encountered in the project was the effect of over-winter precipitation on soil water. How is the effective amount of precipitation entering the profile best determined? Do snowdrifts have an effect? How much water runs off in the spring and how much infiltrates? These are questions which were difficult, if not almost impossible, to answer satisfactorily in the analysis of the data in this paper.

CONCLUSIONS

From the regression analysis of spring wheat yield vs. water applied, it is clear that there is a point where additional water will cause no further increase in yield. During a dry fall or dry spring, off-season irrigation is beneficial. Heavy fall precipitation or infiltration from spring runoff will tend to flush any applied water through the profile, thus losing it to deep drainage. From the data, it is not clear at what maximum percentage of field capacity prior to fall irrigation that fall irrigation becomes inefficient. In the range of percentages encountered in this study, from 75-100% of field capacity, there was no definite pattern. Intuitively, it would seem that at ranges of 50-75% of field capacity, higher efficiencies would be obtained. This needs to be studied more thoroughly.

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Appendix. Summary of Over-winter Moisture Levels in Spring Wheat and Alfalfa--1977-78 Season.

PLOT NUMBER 1

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
9.19000	8.45000	8.75000	8.76000	9.51000
7.63000	7.58000	7.11000	7.52000	9.33000
4.08000	4.88000	4.76000	4.53000	7.53000
3.53000	4.21000	4.46000	4.74000	5.11000
5.23000	5.47000	5.38000	5.31000	5.51000
5.65000	5.62000	5.65000	5.57000	5.65000
TOTAL CM WATER AT 180CM DEPTH				
35.3300	36.2400	36.1200	36.4500	42.6600

PLOT NUMBER 3

JULIAN DATE

7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH			
8.36000	8.82000	8.79000	8.77000
7.94000	7.66000	8.06000	9.09000
6.95000	6.79000	6.59000	8.18000
6.60000	6.50000	6.54000	6.65000
6.60000	6.75000	6.58000	6.54000
6.65000	6.62000	6.66000	6.52000
TOTAL CM WATER AT 180CM DEPTH			
43.1200	43.1500	43.2500	45.7800

PLOT NUMBER 4

JULIAN DATE

7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH			
7.65000	8.23000	8.22000	8.04000
7.74000	7.55000	7.45000	8.57000
7.31000	7.05000	6.97000	7.97000
7.16000	7.14000	7.03000	7.25000
7.03000	7.09000	6.92000	6.99000
7.48000	7.44000	7.20000	7.18000
TOTAL CM WATER AT 180CM DEPTH			
44.3900	44.5100	43.8000	46.0200

PLOT NUMBER 5

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
8.75000	8.40000	9.38000	9.28000	8.80000
7.05000	7.67000	7.24000	6.87000	9.33000
6.02000	6.39000	6.37000	6.58000	9.28000
6.69000	6.93000	7	6.79000	7.70000
7.46000	7.38000	7.37000	7.22000	7.75000
7.11000	7.10000	7.23000	6.99000	7.56000
TOTAL CM WATER AT 180CM DEPTH				
43.1100	43.9000	44.6100	43.7600	50.4500

PLOT NUMBER 7

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
8.21000	7.93000	8.32000	8.21000	8.67000
7.97000	7.87000	7.58000	7.98000	8.88000
7.14000	7.20000	7	6.70000	8.44000
6.53000	6.47000	6.42000	6.24000	6.90000
6.62000	6.54000	6.55000	6.44000	6.45000
6.92000	6.92000	7.04000	6.78000	6.88000
TOTAL CM WATER AT 180CM DEPTH				
43.4200	42.9500	42.9400	42.3600	46.2500

PLOT NUMBER 9

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
9.47000	8.68000	9.54000	9.35000	9.65000
8.92000	8.48000	8.17000	8.11000	9.44000
5.48000	6.45000	6.50000	6.27000	8.33000
5.30000	5.58000	5.74000	5.60000	7.63000
5.85000	5.86000	6.01000	5.92000	7.91000
6.29000	6.12000	6.23000	6.03000	7.38000
TOTAL CM WATER AT 180CM DEPTH				
41.3500	41.2100	42.2200	41.3100	50.3600

PLOT NUMBER 11

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
9.10000	8.79000	9.05000	8.96000	9.82000
7.07000	7.70000	7.35000	7.14000	9.36000
3.73000	3.68000	3.86000	3.77000	7.07000
4.27000	4.75000	4.89000	4.97000	5.35000
5.81000	5.87000	5.67000	5.66000	5.80000
6.08000	6.17000	6.18000	6	6.15000
TOTAL CM WATER AT 180CM DEPTH				
36.0900	36.9900	37.0300	36.5400	43.5700

PLOT NUMBER 12

JULIAN DATE

7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH			
8.40000	8.86000	8.67000	9.05000
8.66000	8.37000	8.10000	9.45000
4.86000	5.01000	5.04000	6.16000
4.99000	5	5.04000	5.34000
5.65000	5.73000	5.51000	5.67000
6.29000	6.25000	6.06000	6.10000
TOTAL CM WATER AT 180CM DEPTH			
38.8700	39.2500	38.4500	41.7800

PLOT NUMBER 13

JULIAN DATE

7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH			
8.57000	9.16000	8.85000	9.41000
8.22000	7.91000	8.01000	9.16000
7.58000	7.45000	7.21000	9.51000
5.76000	5.73000	5.63000	7.85000
5.96000	5.89000	5.76000	6.65000
6.20000	6.24000	5.88000	6.15000
TOTAL CM WATER AT 180CM DEPTH			
42.3100	42.4000	41.3700	48.7600

PLOT NUMBER 15

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
9.19000	7.95000	8.90000	8.82000	9.31000
7.66000	7.57000	7.18000	7.17000	8.95000
4.10000	4.61000	4.83000	4.99000	8.02000
4.91000	5.32000	5.43000	5.34000	7.50000
5.99000	6.07000	6.02000	5.96000	6.80000
6.44000	6.43000	6.48000	6.31000	6.57000
TOTAL CM WATER AT 180CM DEPTH				
38.3200	37.9700	38.8700	38.6200	47.1700

PLOT NUMBER 1A

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
8.88000	8.19000	8.64000	9.12000	8.90000
8.59000	7.89000	7.69000	7.89000	8.49000
6.27000	6.47000	6.15000	6.10000	6.64000
4.70000	5.44000	5.61000	5.59000	6
4.42000	4.74000	5.13000	5.43000	5.64000
5.58000	5.67000	5.73000	6.07000	6.17000
6.19000	6.11000	6.29000	6.53000	6.68000
TOTAL CM WATER AT 210CM DEPTH				
44.6500	44.5400	45.2500	46.7600	48.5400

PLOT NUMBER 2A

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
8.82000	7.91000	8.40000	9.05000	8.64000
8.58000	7.65000	7.43000	7.70000	8.35000
6.99000	6.85000	6.64000	6.62000	7.09000
4.82000	6.10000	6.04000	6.22000	6.84000
4.71000	5.53000	5.76000	5.84000	6.26000
6.16000	6.26000	6.60000	6.91000	6.96000
6.10000	6.15000	6.35000	6.68000	6.71000
TOTAL CM WATER AT 210CM DEPTH				
46.2000	46.4800	47.2500	49.0500	50.8900

PLOT NUMBER 3A

JULIAN DATE

7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH			
8.04000	8.65000	9.50000	8.76000
7.32000	6.85000	6.60000	8.40000
5.13000	5.17000	5.33000	7.10000
4.33000	4.89000	5.23000	6.50000
5.28000	5.29000	5.65000	6.07000
6.26000	6.47000	6.59000	6.77000
6.83000	6.85000	7.28000	7.23000
TOTAL CM WATER AT 210CM DEPTH			
43.2200	44.2200	46.2000	50.8600

PLOT NUMBER 4A

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
8.51000	7.99000	8.28000	8.64000	8.65000
8.09000	7.24000	7.01000	7.22000	7.86000
6.74000	6.79000	6.71000	6.72000	7.31000
5.57000	5.76000	5.81000	5.94000	6.86000
5.14000	5.40000	5.60000	5.78000	6.65000
5.77000	5.85000	6.11000	6.39000	6.73000
6.52000	6.48000	6.60000	7	7.02000
TOTAL CM WATER AT 210CM DEPTH				
46.3700	45.5400	46.1400	47.7200	51.1000

PLOT NUMBER 5A

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
8.52000	7.81000	8.43000	9.09000	8.74000
8.44000	7.81000	7.69000	7.83000	8.48000
6.27000	6.50000	6.29000	6.39000	6.80000
4.12000	5.63000	5.75000	5.82000	5.96000
5.08000	5.60000	5.64000	6	6.10000
6.13000	6.19000	6.25000	6.54000	6.53000
6.47000	6.52000	6.51000	6.79000	7.07000
TOTAL CM WATER AT 210CM DEPTH				
45.0600	46.0900	46.5800	48.5000	49.7000

PLOT NUMBER 6A

JULIAN DATE

7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH			
7.73000	8.11000	8.31000	8.37000
6.92000	6.65000	6.61000	7.46000
5.42000	5.34000	5.25000	6.23000
3.35000	3.81000	4.43000	5.89000
4.49000	4.66000	4.83000	5.75000
5.77000	5.81000	5.98000	6.29000
5.97000	5.95000	6.10000	6.40000
TOTAL CM WATER AT 210CM DEPTH			
39.6600	40.3700	41.5400	46.4200

PLOT NUMBER 7A

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
8.53000	7.83000	7.95000	8.31000	8.35000
7.77000	7.84000	7.39000	7.28000	8.20000
4.56000	5.49000	5.45000	5.55000	6.02000
4.01000	4.90000	5.26000	5.21000	5.55000
5.60000	5.65000	5.78000	6.10000	6.42000
6.30000	6.34000	6.39000	6.51000	6.74000
6.38000	6.43000	6.43000	6.69000	6.76000
TOTAL CM WATER AT 210CM DEPTH				
43.1600	44.5200	44.6700	45.6700	48.0600

PLOT NUMBER 8A

JULIAN DATE

7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH			
7.83000	7.61000	8.13000	8.56000
7.67000	7.48000	7.28000	8.17000
5.35000	5.45000	5.41000	6.16000
3.94000	4.34000	4.87000	5.46000
4.95000	5.24000	5.41000	5.80000
6.30000	6.22000	6.37000	6.57000
6.55000	6.61000	6.76000	6.93000
TOTAL CM WATER AT 210CM DEPTH			
42.6300	42.9800	44.2600	47.6800

Appendix. Continued.

PLOT NUMBER 9A

JULIAN DATE

7318	7363	8023	8053	8089
TOTAL MOISTURE CONTENT, CM., AT 30,60,90...CM DEPTH				
8.69000	7.95000	7.72000	8.39000	8.49000
8.16000	7.61000	7.63000	7.46000	8.07000
4.89000	5.65000	5.62000	5.60000	6.49000
4.16000	4.69000	5.14000	5.23000	5.71000
4.82000	4.82000	5.17000	5.39000	5.64000
5.64000	5.71000	5.63000	6.02000	6.16000
6.64000	6.67000	6.82000	7.08000	7
TOTAL CM WATER AT 210CM DEPTH				
43.0400	43.1400	43.7500	45.1900	47.5900