COMPARISON OF THREE MODES OF WATER APPLICATION UNDER A CENTER PIVOT SPRINKLER

By

MICHAEL P. HENDERSON

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1990

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1993

COMPARISON OF THREE MODES OF WATER APPLICATION UNDER A CENTER PIVOT SPRINKLER

Thesis Approved:

Thesis Adviser

Michael A. Kizer

Brian J. Carter

Thomas C. Collins

Dean of the Graduate College

ACKNOWLEDGMENTS

I wish to thank Dr. John F. Stone, my major adviser for his patience, guidance, friendship, and advice through my graduate program. I also want to thank Dr. Brian Carter and Dr. Mike Kizer for their guidance, assistance and serving as committee members.

I would also like to thank Stanley (Jay) Solomon Jr. for his support, assistance, friendship and patience throughout my research.

I would also like to express my gratitude to Dr. Kevin J. Donnelly for his guidance and support throughout my education.

Special gratitude is expressed to my mother and father for their support and encouragement of my education.

I wish to thank especially my fiancee, Eva M. Meyer, for her support, understanding and unending patience during my graduate program.

To my friends in Oklahoma and Iowa, I wish to express thanks for the friendship while I was a student and look forward to a continuance of these ties in the future.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Current estimates of population increases coupled with the declining number of people involved in production agriculture has dictated the necessity for greater production on less land. Although agriculture is vital for human survival, the cost of farming continues to increase while the market prices for the products are not changing. This dictates more efficient use of agricultural resources to achieve these higher production yields.

In the High Plains of the United States irrigation is one of the biggest costs of farming. As fuel costs and the cost of maintaining the irrigation wells continue to increase, irrigation technology has become a major concern for the farming community. This is coupled with the constant threat of the decline of the Ogallala Aquifer, the greatest single source for underground water available to irrigators in this area. The water level of the Ogallala Aquifer in southwest Kansas has a long-term average annual decline of 0.5 m (Pabst, 1988). If the aquifer were to be depleted, farming in this area of the country would become insignificant due to the inadequate rainfall.

With the advent of center pivot sprinkler irrigation systems the ability to irrigate more land area in less time with better water application efficiency became possible, as compared to the alternative of furrow irrigation. This in turn produced wide acceptance of the sprinkler and reduced the use of furrow irrigation. Sprinklers had a major drawback of high energy costs due to the high operating pressures of the systems coupled with evaporation losses due to the water being sprayed as a fine mist into a low humidity environment. These disadvantages led to development of the Low Energy Precision Application (LEPA) nozzle system. The LEPA system was developed to run under low operating pressures and brought the nozzles closer to the soil surface. This lowered the energy cost and the increased the water application efficiency.

This project was designed to evaluate three forms of water application under a center pivot sprinkler: Spray, LEPA, and Wide-Spaced Band Irrigation (WSBI). WSBI is a method of water application similar to the Wide-Spaced Furrow Irrigation (WSFI) proposed by Stone et al. (1982). The design of the project allowed a comparison of WSBI to the WSFI results obtained by Tesgaye et al., (1993). Under the WSFI method of water application higher yield was obtained with less water as compared to every furrow water application (EFI).

The objectives of this study were:

1. Compare the crop response and water application efficiencies for three modes of water application; LEPA, WSBI, Spray.
2. Determine if the response to WSBI over LEPA and spray was comparable to the response to WSFI over EFI.
3. Determine whether differences in yield or water application resulted from angle between the pivot lateral and row direction.

These studies were conducted on the Panhandle Research Station at Goodwell, Oklahoma during the summer of 1992.

CHAPTER II

LITERATURE REVIEW

A main objective of the irrigation farmer is to minimize the cost per unit of water applied to a given area for crop benefit. Optimization involves many factors that the farmer may or may not be able to influence. These include the environment, nearest water source, type of irrigation system implemented to apply the water, and other factors over which the farmer has varying degrees of control. One of the most important irrigation factors that the farmer can control is the method of water application. This process involves the distribution of the available water over a surface area in varying degrees of uniformity. The greatest detriments to furrow irrigation are labor intensity and the deep percolation of water near the head end of the field. Estimates of up to 50% of the applied water have been shown to be lost to deep infiltration below the root zone (Pyagay, 1990). Thus, considerable water is lost below the root zone of the growing crop under conventional furrow irrigation. Stone et al. (1979) showed that wide-spaced furrow irrigation (WSFI) could be used on medium to fine textured soils to give greater lint yields in cotton. They defined wide-spaced terminology as referring to furrow spacings of greater than 2.5 m. This practice tended to better distribute the water in the root zone by allowing for more lateral movement of the water, thus allowing less potential for loss below the root zone than the normal practice of every furrow irrigation (EFI). Another benefit of the wide-spaced technique is that it results in a drier soil surface. Since the surface of the soil is drier there is less nonproductive loss of water. Studies done by

Tsegaye et al. (1993) showed that EFI allowed for deeper water movement than for WSFI using the same amount of water. The use of WSFI was also shown by Tsegaye et al. (1993) to have a yield advantage over EFI.

It was shown that cotton lint yield could be increased with the use of WSFI over EFI. This study was carried out at Altus, and Chickasha, Oklahoma from 1969 to 1979. The higher yield was obtained in spite of applying half the amount of water in the WSFI as in the EFI treatments over a given growing season (Stone et al., 1982).

Grimes et al. (1968) found that alternate furrow irrigation increased lint yields on cotton in the San Joaquin Valley in California. They compared the alternate furrow irrigation to EFI on a sandy loam soil. They found that the alternate furrow irrigation used less water and increased lint yields over the EFI.

On a four-year study with soybeans in central Oklahoma on a McLain silty clay loam Crabtree et al. (1985) showed that alternate furrow irrigation significantly reduced the yield over every furrow irrigation. The alternate furrow still produced acceptable yields with 40 to 50% of the water of the every furrow plots. The row spacing was 1 m.

The development of sprinkler irrigation systems increased the uniformity of water distribution across the area being irrigated. The primary type of sprinkler system in the High Plains area is the center pivot irrigation system. Widespread acceptance of the center pivot irrigation system is illustrated by the number of systems now in use. In Texas alone there are approximately 9500 center pivot systems now in operation. These systems irrigate 1.75 million acres (New and Fipps, 1990). With the rapid acceptance of the center pivot irrigation system new technology for better application of the water is essential.

Lyle and Bordovsky (1981) proposed a low energy precision application (LEPA) irrigation system to increase the efficiency by which water is applied by lateral-move as well as center pivot sprinkler systems. The system studied included drop tubes which discharged water directly above a furrow. An orifice or emitter was placed in the drop tube for flow control. They reported uniformities of 94% to 97% (Christiansen's coefficient of uniformity) for the LEPA system. The variations of uniformities were due to hydraulic losses along the lateral and possibly from manufacturing variability among the orifices.

Hanson et al. (1988) showed that LEPA irrigation had a uniformity of infiltrated water of only 80 to 85%. The lack of uniformity was attributed to the infiltration differences across the soil surface as well as influences from the machine movement. The type of system that was used was a lateral move sprinkler.

CHAPTER III

MATERIALS AND METHODS

Field studies were conducted in 1992 under an experimental center pivot irrigation system located at the Oklahoma Agricultural Experiment Station, Goodwell, Oklahoma. Grain sorghum (*Sorghum bicolor,* Moench) was grown under the pivot in rows oriented from southwest to northeast. The soil type was a Sherm clay loam (Fine, montmorillonitic, mesic Aridic Argiustoll), previously known as the Richfield soil series. The block locations were picked along three radii of the pivot system: parallel, forty-five degrees, perpendicular angles between lateral and row direction. Plot layout is shown in Figure 1. The plots consisted of two boom pairs. A boom pair consisted of two booms each controlled by an electric solenoid. Each boom consisted of three nozzles suspended thirty centimeters above the soil surface on drop tubes. The nozzles were spaced on a 2.84 m interval. The booms were situated in overlapping pairs to give a 1.42 m spacing between adjacent nozzles. The solenoid allowed for one of the booms within a pair to be switched off to allow for the wide-spaced band interval of 2.84 m. This band was alternated between wet and dry in the sequence of the irrigation schedule.

Each nozzle had an associated orifice and spray plate. The orifice size was gradually increased with distance from the pivot point. The increase was to compensate for the increased rate of movement toward the outside towers. The gradient was calibrated so all the nozzles would apply the same amount of water per unit area of land. The pressure was maintained at 0.041 MPa by a pressure regulator located directly above each nozzle. The low flow rates of the nozzles near the pivot point required 0.069 MPa pressure for accurate delivery through appropriate orifices. The spray plate for the nozzles was a coarse serrated plate for the inside nozzles and a smooth plate for the outside nozzles. The serrated plates were needed under the low rates of application to insure coarser droplet sizes, reducing the potential for increased evaporation which would occur with fine droplets.

Anhydrous Ammonia was applied at the rate of 200 kg ha^{-1} -N in early March. Grain sorghum 'NC+ 172' was planted in two rows on top of a 1.42 m bed on 19 May and was fully emerged by 26 May. Alachlor was applied at a rate of 4.68 L a.i. ha^{-1} on 21 May. Another application of Buctril and Atrazine mix was applied at a rate of 0.58 L ha^{-1} on 13 July by aerial application.

Neutron access tubes were installed on 25 and 26 June, to a depth of 1.37 meters. The tubes were nominal 38.1 mm EMT, thin wall electrical mechanical tubing. They were installed in pairs positioned in the center of the harvest area, directly opposite each other in adjacent rows of crop. The arrangement dictated that the tubes be 0.61 m apart across the center of the bed and 0.43 m from the center of the furrow. The dikes were 1.42 m apart located such that each tube had a basin in the furrow beside it. A Troxler model 3223 neutron probe moisture gauge was used to measure volumetric water content. Readings were taken at 8 depths per tube on 150 mm intervals.

The harvest area was centered on the neutron access tubes and consisted of four rows 6.12 m long. There were two replications for each treatment located along the each angle contained within a randomized block design. The three treatments were randomized within each block, which gave a total of six replications for each main treatment (Figure 1).

A 7-day interval irrigation schedule was designed for the LEPA and Spray treatments and an alternating three:four day schedule was employed for the WSBI. The WSBI plots received half as much water as did the LEPA and Spray plots for each irrigation.

The WSBI plots maintained wet and dry bands for each irrigation. The first irrigation in the sequence would water one set of bands 2.84 m apart. The following irrigation the alternate set of bands on 2.84 m spacing would be watered. Alternate bands were watered alternately within the irrigation schedule. The plots received 65 millimeters of water in a preplant watering in which all nozzles were set to spray mode. After the neutron access tubes and the dikes were installed another application of 33 millimeters of water in the spray mode was applied to set the dikes. This helped prevent wash out of the dikes due to the erosive nature that the LEPA style application has on the dikes. Experimental design irrigation began on 14 July.

All plots were harvested by hand 16 October. The grain was dried at 49° C. The heads were threshed using a plot thresher.

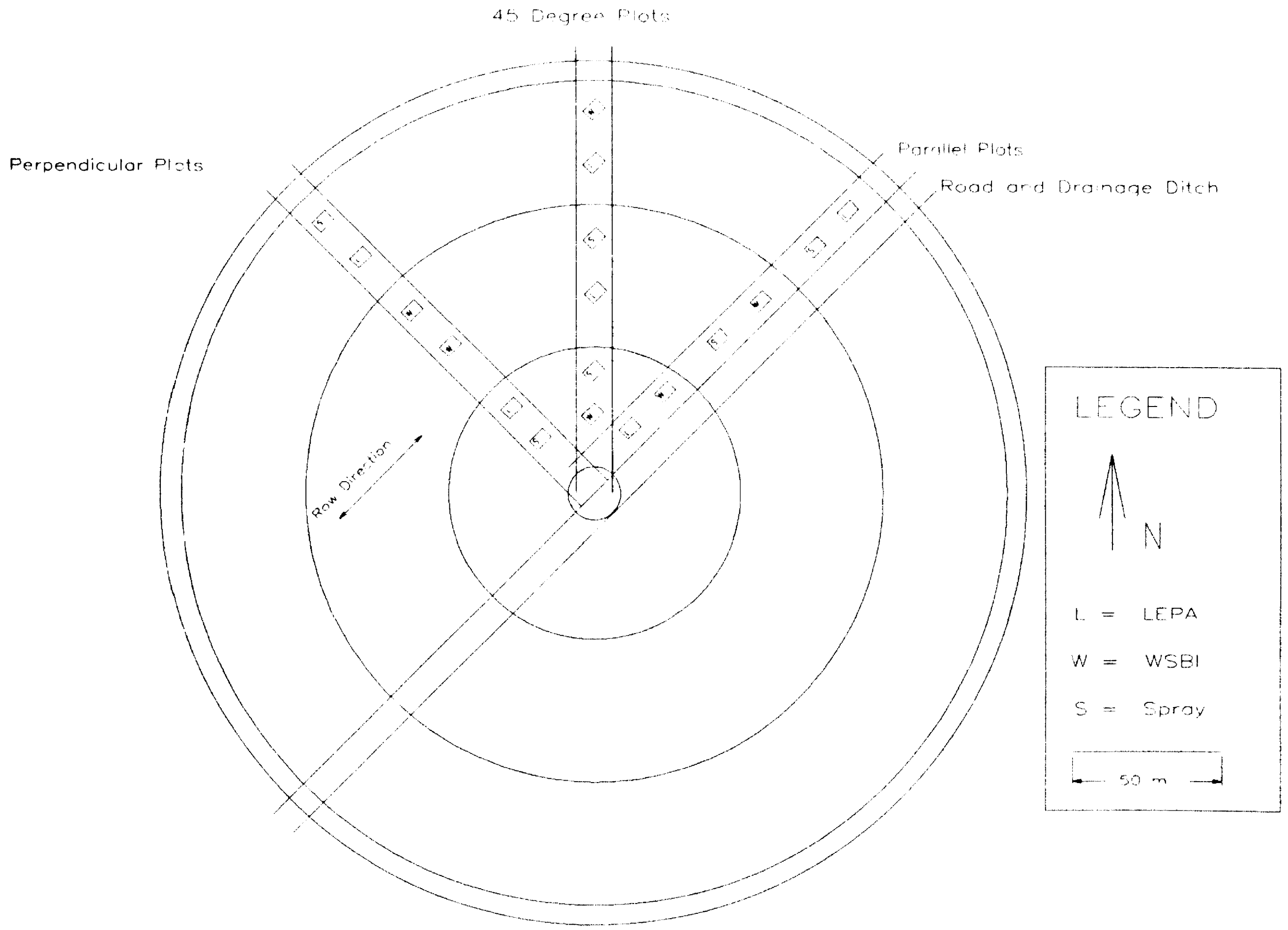

Figure 1. Layout of the plots.

CHAPTER IV

RESULTS

Meteorological Data

The rainfall events, irrigation dates, and neutron tube reading dates are shown in Figure 2. The total amount of rainfall received and irrigation water applied during the growing season is shown in Table I. A rainfall total of 372 mm was recorded for the growing season with the largest individual rainfall of 50 mm received on 8 June. The total amount of irrigation water was 265 mm for the LEPA and spray plots while only 247 mm was applied to the WSBI plots. The average wind speed over the growing season was 2.14 m s^{-1}. The growing season was defined as starting ten days before planting and extended to physiological maturity of the grain, 16 May until 15 September.

TABLE I

RAINFALL AND IRRIGATION TOTALS FOR THE 1992 GROWING SEASON

TREATMENT	RAINFALL mm	IRRIGATION mm
LEPA	372	265
SPRAY	372	265
WSBI	372	247

Yield

Yields were largest in the LEPA plots and were the least in the WSBI plots. Yields are shown in Table II. All yields were high in comparison to the average yields seen in the past studies, which indicates that the sorghum was not stressed due to insect pressure, disease, or lack of water. The test weights for all the plots were between 772 kg m^{-3} and 785 kg m^{-3} which again indicates that the sorghum was not stressed. The yields were not shown to be significantly different at the 95% confidence level. The coefficient of variation was 10.2%. Although the difference between any of the yields was not greater than 6%, the LEPA plots tend to show a greater yield than the WSBI plots. Harvested plot yield for each replication are given in Appendix A, Table VII.

TABLE II

YIELD BY IRRIGATION TREATMENT AND ANGLE OF LATERAL TO ROW

TREATMENT	PERPENDICULAR kg ha^{-1}	45^{o} kg ha^{-1}	PARALLEL kg ha^{-1}	AVERAGES kg ha^{-1}
LEPA	9555	8576	8186	8773
SPRAY	8932	8385	8283	8533
WSBI	8836	8291	7765	8297

Water Use

All plots received the same amount of water for each irrigation owing to the calibration and design of the sprinkler system . The amount of water applied per irrigation was reduced as the year progressed because the dike basins began to fill in with soil. This consequently reduced the water holding capacity of the basin. Over the season the LEPA and spray plots received the same amount of water, but owing to crop maturity, the last half of the last watering was not applied to the WSBI plots. The WSBI plots, therefore, had 18 mm less growing season water than the LEPA and spray plots. The total amount of water applied by irrigation is shown in Table I.

Net Soil Water Depletion (NSWD) is the difference between the amount of water present at the beginning of the growing season and that present at the end of the growing season. A comparison of the soil water content at the beginning of the growing season to the soil water content at the end of the season is shown in Table III and Table IV. The initial water content varied among the treatments, but showed no statistical significance. The final water contents reflect the initial ranking of the treatments. No significant difference was shown for the NSWD.

TABLE III

STARTING AND FINAL SOIL PROFILE WATER STATUS
TO A DEPTH OF 1.37 m. (7-13-92 AND 9-14-92)

TREATMENT	INITIAL WATER mm	FINAL WATER mm	NSWD mm
LEPA	1133	967	166
SPRAY	1109	962	146
WSBI	1082	894	188

Irrigation Water Use Efficiency

In this study the water use efficiency that is used is the given yield (kg ha^{-1}) divided by the sum of the water applied by irrigation (m^3 ha^{-1}) plus the net soil water depletion (m^3 ha^{-1}). The average irrigation water use efficiencies (IWUE) for each treatment were: LEPA 2.08 kg m^{-3} , Spray 2.11 kg m^{-3}, and WSBI 1.92 kg m^{-3} (Table V). The IWUE showed no significant differences at the 95% confidence level. The coefficient of variation was 10.38%. The IWUE for each plot replication are given in Appendix A, Table VIII.

TABLE IV

STARTING AND FINAL SOIL WATER CONTENTS
(1.37 m PROFILE AVERAGE, 7-13-92 AND 9-14-92)

TREATMENT	INITIAL W.C.* m^3 m^{-3}	FINAL W.C.* m^3 m^{-3}	DIFFERENCE** m^3 m^{-3}
LEPA	.213	.178	.030
SPRAY	.206	.175	.035
WSBI	.200	.163	.037

* W.C. = WATER CONTENT; ** = INITIAL W.C. - FINAL W.C.

TABLE V

IWUE BY IRRIGATION TREATMENT AND ANGLE
OF LATERAL TO ROW

TREATMENT	PERPENDICULAR kg m^{-3}	45° kg m^{-3}	PARALLEL kg m^{-3}	AVERAGES kg m^{-3}
LEPA	2.58	1.81	1.85	2.08
SPRAY	2.12	1.98	2.21	2.11
WSBI	2.18	1.74	1.86	1.92

The depth of water infiltration after an irrigation for the only case without an intervening rain event between the irrigation and probe reading is summarized in Table VI.

TABLE VI

MAXIMUM DEPTH OF WATER PENETRATION AFTER AN IRRIGATION.

Date of Irrigation	Treatment	Depth of Penetration, mm
14 July 1992	Spray	310
14 July 1992	LEPA	460
14 July 1992	WSBI	610

The soil water content status over the season graphed with relation to the rainfall events, irrigations, and neutron probe reading dates are given on Figure 3 for an example of a spray plot, Figure 4 for an example of a LEPA plot, and Figure 5 for an example of a WSBI plot. The remaining five replications of each treatment are given in the Appendix B, Figures 6 through 20. Each of the examples given are out of the outside parallel block area. All the remaining replications showed the same general trend.

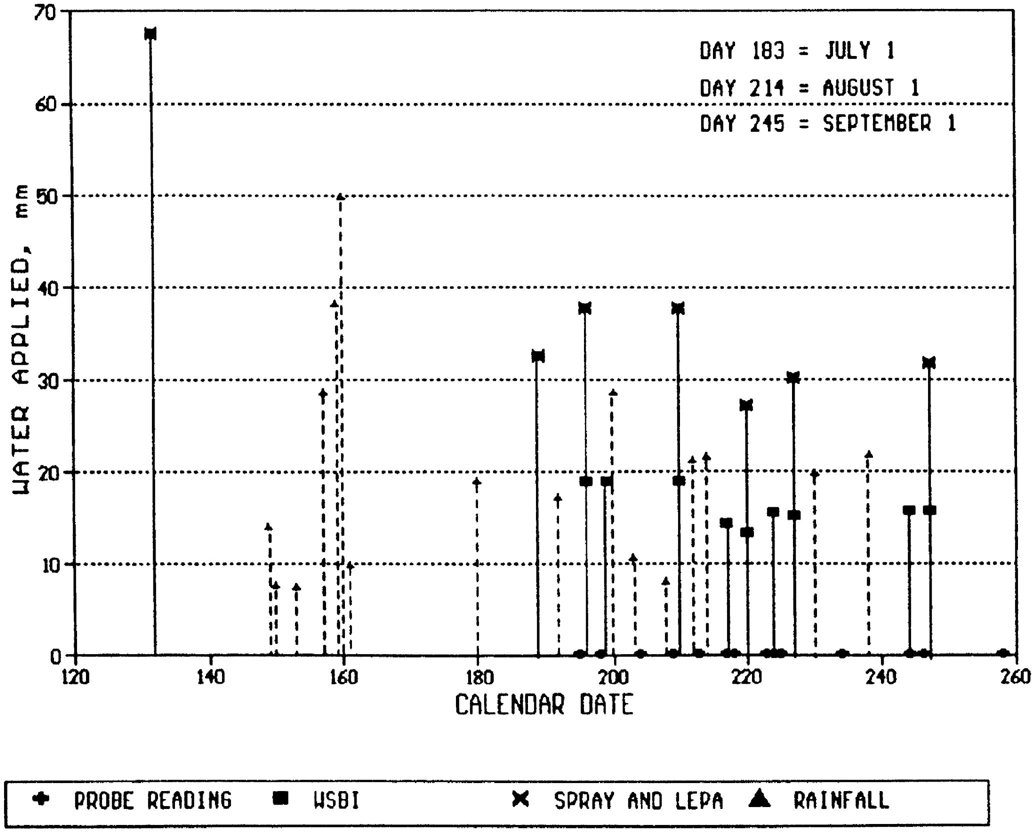

Figure 2. Plot of rain and irrigation events over time.

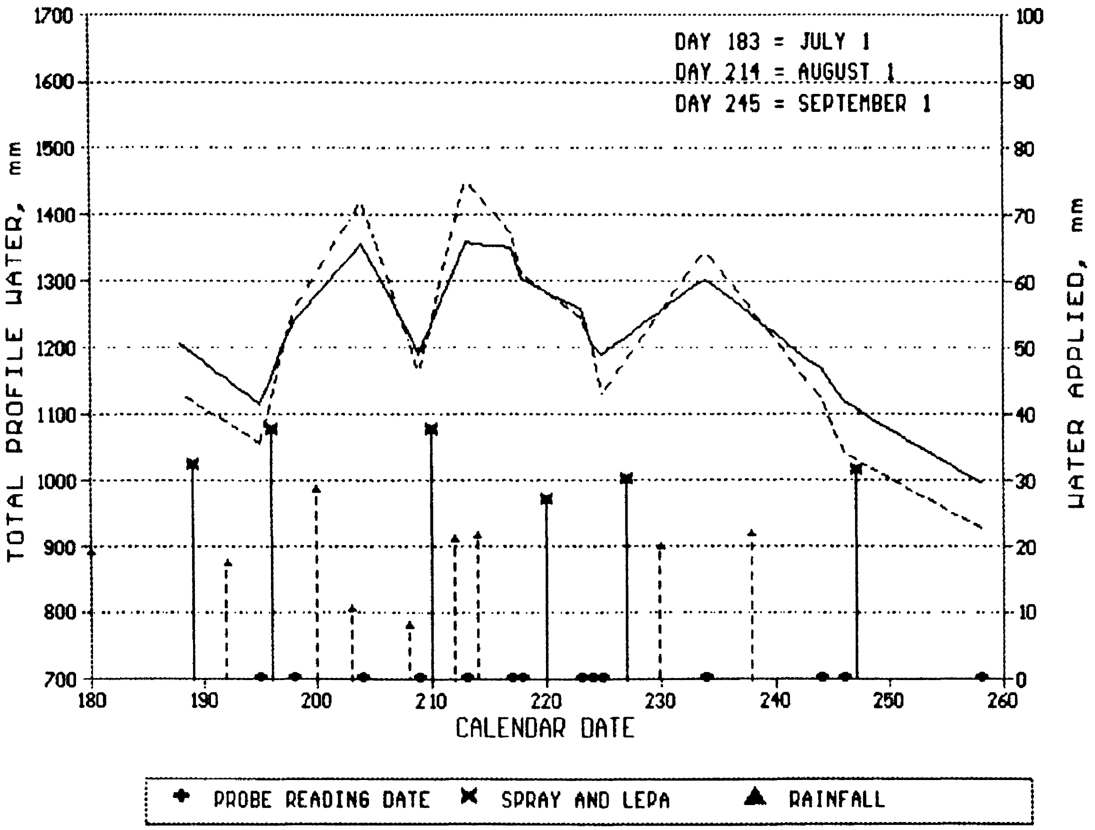

Figure 3. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the outside spray plot of the parallel angle.

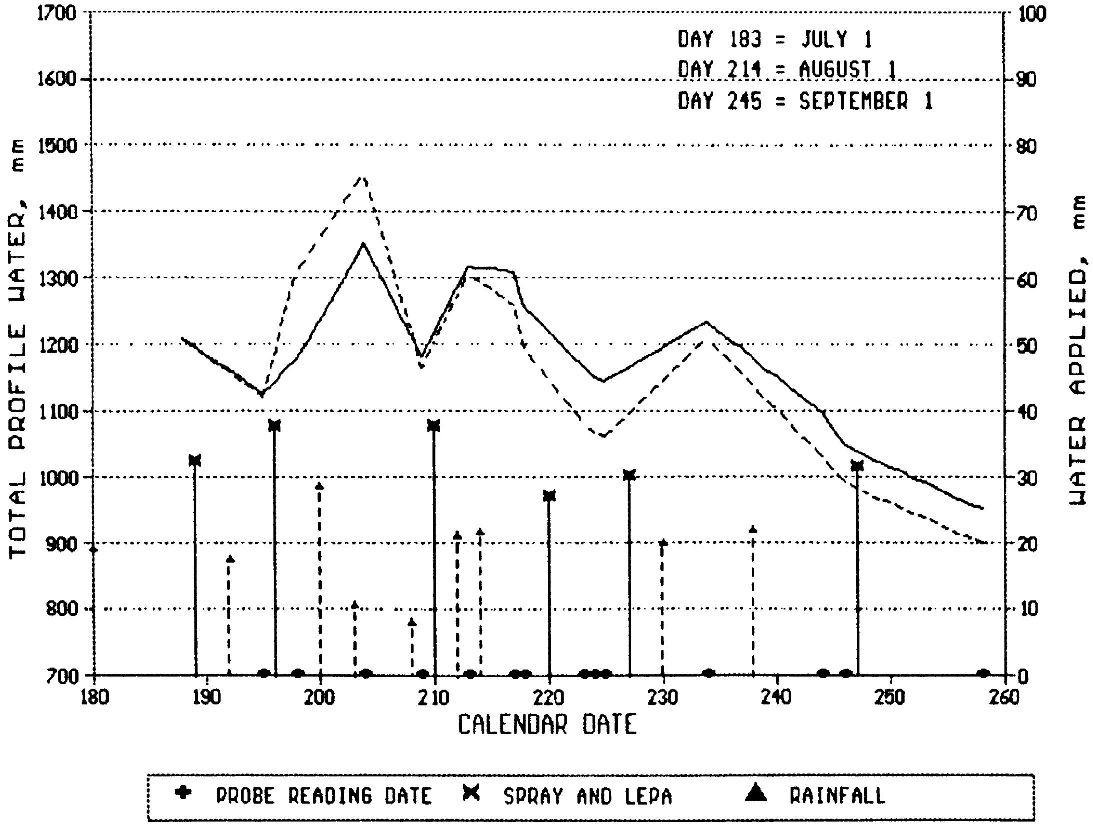

Figure 4. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the outside LEPA plot of the parallel angle.

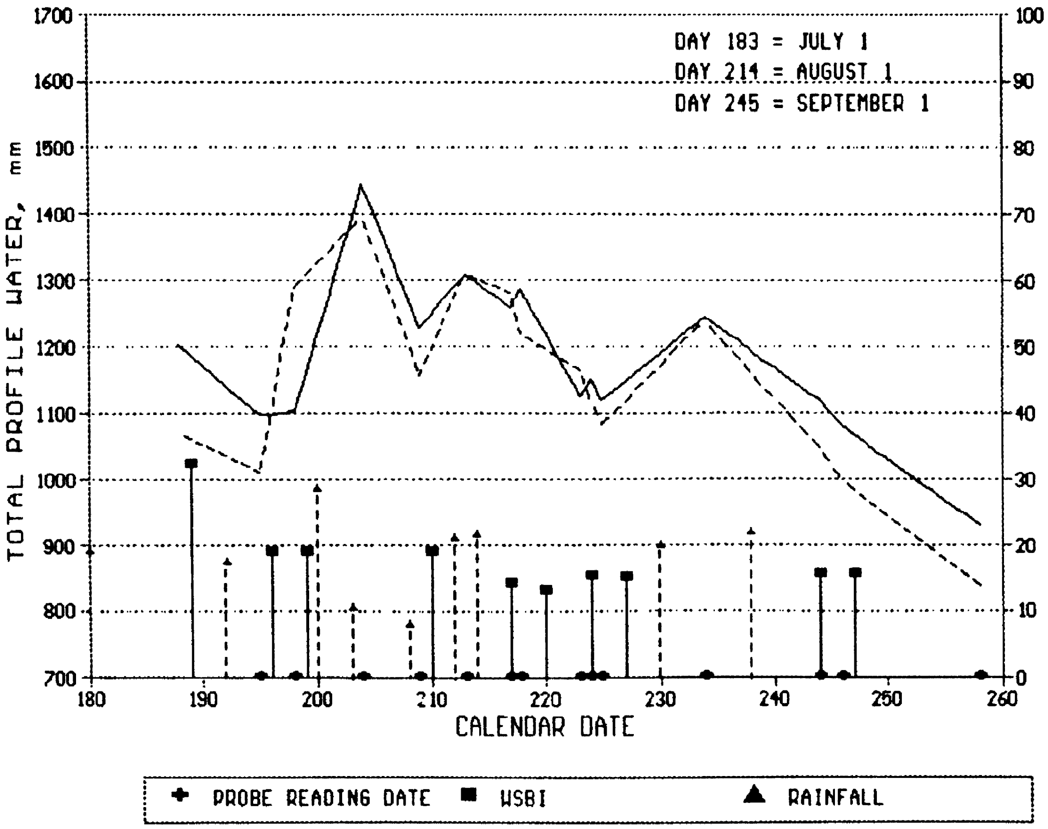

Figure 5. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the outside WSBI plot of the parallel angle.

CHAPTER V

DISCUSSION

The main objective of this research was to test whether WSBI would give higher grain yields than Spray or LEPA with the same amount of water applied in a given growing season. Considering the overall averages the LEPA plots yielded higher than the spray or WSBI plots. The difference seen in Table II between the yields is potentially deceiving because of an apparent advantage in the perpendicular plots that was not related to the treatments being studied. This advantage was apparently due to an alleyway that had been disked across the 1991 crop. An aerial photograph taken after the plots were harvested and the majority of the leaves were brown shows a definite green streak weaving in and out of the plot areas in this angle. This streak corresponds to the old alleyway. One possible factor would be the residual nitrogen carryover from the previous year. Based on average protein contents established for grain sorghum (Bush, 1979; Lance, 1963) the nitrogen content of the total plant biomass at the time of harvest was estimated to be 245 kg ha^{-1}. This estimate is based on the average yield across all the plots at a protein content of 11%. The non-grain plant biomass was estimated to be 11 Mg ha^{-1} at an average protein content of 5.3%. The average nitrogen content of protein was estimated to be 16%. This estimate suggests that the 1992 applied nitrogen of 200 kg ha^{-1} was not adequate for plant needs during the grain filling period. Therefore, the plant would have to rely on residual soil nitrogen pools to obtain adequate nitrogen to produce grain and maintain stalk integrity. These pools would be greater within this streak due to residual nitrogen from the previous year. For this reason any statement of advantage that is based upon the perpendicular plots needs to be approached carefully.

If the perpendicular plots are left out of the yield calculation the averages remain in the same order by rank but the relative difference between the plots changes. The average yields become: LEPA, 8381 kg ha^{-1}; spray, 8333 kg ha^{-1}; and WSBI, 8027 kg ha^{-1}. These averages indicate that with below-canopy water application, no mode of application in this study provided a yield advantage. There was no statistical significance found at the 95% confidence level for the yields with or without the perpendicular plots in the analysis.

The soil water content indicates that no mode of water application in this study had an advantage in efficiency of water application . The soil water content tended to respond the same to all the modes of water application. This trend can be seen on Figures 3, 4, and 5 for the period of time between day 215 and day 228. This period of time has two complete cycles of irrigation with no interveining rainfall events. The soil water content follows the same relative increase or decrease for each mode of water application during this time period. This supports the idea that with below canopy water application the mode of water application does not proivide a significant advantage.

The yields by angle are shown in Table II. The perpendicular angle showed the highest yield for each of the treatments. As stated above this angle needs to be approached very carefully with any statement of yield advantage. The forty-five degree angle tended to show a higher yield than the parallel angle. There was no statistical significance found at the 95% confidence level for the yields between any of the angles.

Several potential reasons that the WSBI showed no yield advantage over the other two modes of application are discussed below. The spray and LEPA plots received more growing season water than the WSBI plots because the grain sorghum reached hard dough stage before the WSBI plots received the last half of the last watering. In addition, true wide spaced ideals were not adhered to precisely with the implementation of the WSBI plots. The wide space theory hinges on the proposition that lateral movement in the soil will be able to provide enough moisture for the crop while wetting less surface area for a given amount of water. Half the amount of water, as compared to the LEPA and spray, was applied to one band across the field at the first watering, then three to four days later half the water was again applied to the alternate band. This possibly confounded the wide space idea by not applying enough water to one band and not allowing enough time for adequate soil water movement and surface drying. Over the one week irrigation interval for the LEPA, the WSBI received the same amount of water and that water was applied over the same surface area of soil. This technique allowed the irrigation water applied to the WSBI plots to be subjected to the same amount of nonproductive evaporation as the LEPA plots. These procedures may have reduced the effectiveness of the WSBI mode of application.

The results of this study do not follow what Tsegaye et al. (1993) found when they compared WSFI to EFI. Tsegaye found that the WSFI showed a yield advantage over the EFI plots in furrow irrigation. The LEPA plots correlate to the EFI plots while the WSBI were supposed to mimic the WSFI plots. Tsegaye used a 7 day irrigation interval for the WSFI. As discussed above, the 3 day irrigation interval used for the WSBI appeared to be too short to permit the wide-spaced advantage in yield. Thus, the 7-day interval used by Tsegaye may be near the minimum irrigation interval for the wide-space technique to show an advantage. The amount of water that can be applied per irrigation by sprinkler irrigation could be the most limiting factor for adoption of the wide-spaced idea to center pivot irrigation.

The furrow dikes maintained their integrity throughout the season and no stray water movement was observed within the plots. There was no water penetration deeper than the 1368 mm depth detected. The majority of the water stayed within the top 600 mm of the soil profile, Table VI. Thus negligible water was lost below the root zone. Net soil water depletion shows that the WSBI plots depleted the greatest amount of water from the soil profile. This follows expectation because these plots did not receive the last half of the last watering. The LEPA showed a greater NSWD than the spray plots.

The irrigation water use efficiency (IWUE) based on the irrigation water applied plus the NSWD did not follow the trends seen in the yield. The spray plots tended to have the best overall IWUE. The perpendicular plots appear to contradict the overall average with the LEPA showing the highest IWUE. When these plots are omitted from the average, the LEPA and WSBI plots show nearly the same IWUE. The parallel and angle plot averages are: LEPA, 1.83 kg m^{-3}; spray, 2.10 kg m^{-3}; WSBI, 1.8 kg m^{-3}. The fact that there is very little difference between the LEPA and WSBI plots supports the conclusion that the water in the WSBI plots was subjected to the same amount of nonproductive loss as was the LEPA plots.

The results obtained under the circumstances of 1992 provide some insight as to potential mechanics of irrigation under a center pivot. This was a wet and cool season with the total rainfall between 1 May and 15 September being 371 mm. Out of that rainfall only 324 mm came in rainfall events larger than 6.4 mm. Many rainfall events of less than 6.4 mm have been previously cited as being negligible to plant benefit (Stone et al., 1966; Elliott et al., 1988) . Although this season had above average rainfall, it still did not totally mask the effects of the WSBI water movement trends. The neutron tube near the watered basin always showed a greater increase in water content than the tube that did not receive water regardless of the amount of rain received between the irrigation and the neutron probe reading (Figure 5). Similarly, when the spray and LEPA plots are compared (Figures 3 and 4) the irrigation on day 210 (28 July) with a corresponding rain on day 212 (30 July) increased the soil water content while a decrease or very slight increase in soil water was noted for the rain on day 214 (1 August). This trend was also seen on all the plots of which are shown in Appendix B, Figures 5 through 19. This seems to indicate that the rainfall did not provide as great an effect on the soil water as did the succeeding irrigation.

This brings the question up as to the effectiveness of rainfall in this region. Several visual observations were made after rain events of greater than 13 mm to determine if the soil surface dried out quicker or at about the same rate as after an irrigation. It was observed that the soil surface dried out much faster after a rain event than after an irrigation of comparable amount. This coupled with the fact that the rainfall did not mask the irrigation effects tends to confirm that small rainfall did not contribute to the soil moisture as effectively as an irrigation of comparable amount. A possible cause that the rainfall would not contribute as much to the soil moisture is the fact that the crop canopy must be completely wetted before the moisture reaches the soil, where as with this study the irrigation water was applied below the crop canopy. The rainfall event was usually associated with a 24-hour period that had a relatively large evaporative demand, 13 to 19 mm as compared to the average growing season evaporation of 10 mm per day calculated from open pan evaporation. A typical rain event scenario would be for the morning and early afternoon to be calm and humid as the storm system was developing with wind speed increasing toward midcontinue to increase to over 10 m s^{-1} with gusts up to 16 m s^{-1}. The rain would come quickly in the evening (about 6:00 to 7:00 p.m.) and end before sunset. The wind would blow for a while after sunset (until about midnight). Many times the wind would be strong enough to cause the leaves of the sorghum to become ragged and appear to have been hailed on even though no hail was produced from the storm. This period of wind after the rain event would rapidly evaporate the moisture that was on the crop canopy. The amount of water that is required to wet the canopy was estimated to be 6 mm, therefore, rainfall less than 6 mm could be disregarded as it would not contribute to the soil moisture content.

CHAPTER VI

CONCLUSIONS

All modes of water application were sufficient in providing adequate water for the sorghum as evidenced by the high yields and test weights. No significant differences were seen among the three modes of water application in either yield or in soil water content. This indicates that there is no significant crop response to nozzle discharge patterns studied when nozzles are below canopy level.

The LEPA and spray plots tended to show a yield advantage over the WSBI plots. This does not follow previous studies using wide-spaced furrow irrigation in which the wide-spaced technique showed a yield advantage. The wide-spaced advantage may not have been seen in this study due to the irrigation interval and amount of water applied per irrigation. The 7 day irrigation cycle facilitated the need to water the WSBI plots on an alternating three:four day cycle. Within this 7-day cycle the wet and dry bands were alternated so that both bands received water during the cycle. The frequency at which the wet and dry bands were alternated may have been too short to allow full benefit of the wide space mechanisms to take effect. This might be modified to apply both irrigations within a week onto the same band and alternate between weekly irrigation cycles. Implementation of the wide-spaced technique may not be feasible for use under a center pivot system because of the limited quantity of water that can be applied per irrigation without over-topping the basin dikes..

No significant differences in crop response to irrigation were shown among the three orientations of the lateral. This indicates that the water application efficiency under a center pivot system with below canopy nozzles is not influenced by the row direction.

LITERATURE CITED

Bush, L.J., 1979. Livestock Feeding. Dept. of Animal Science, Oklahoma State University, Stillwater, OK.

Crabtree, R.J., A.A. Yassin, I. Kargougou, and R.W. McNew. 1985. Effects of Alternate-Furrow Irrigation: Water Conservation on the Yields of Two Soybean Cultivars. Agric. Water Manage. 10:253-264.

Elliott, R.L., S.L. Harp, G.D. Grosz, and M.A. Kizer. 1988. Crop Coefficients for Peanut Evapotranspiration. Agric. Water Manage. 15:155-164.

Grimes, D.W., V.T. Walhood, and W.L. Dickens. 1968. Alternate-Furrow Irrigation for San Joaquin Valley Cotton. Calif. Agric. 22:4-6.

Hanson, B.R., L. Schwankl, A. Fulton. 1988. Uniformity of Infiltrated Water Under a Low Energy Precision Application (LEPA) Irrigation System. Trans. ASAE 31(5):1463-1468.

Lance, R.D., D.C. Foss., C.R. Krueger, B.R. Baumgardt, and R.P. Niedermeier. 1964. Evaluation of Corn and Sorghum Silages on the Basis of Milk Production and Digestibility. J. Dairy Sci. 47:254-257.

Lyle, W.M., and J.P. Bordovsky. 1981. Low Energy Precision Application (LEPA) Irrigation System. Trans. ASAE 24 (5):1241-1245

New, L., and G. Fipps. 1990. LEPA Conversion and Management. Texas Agricultural Extension Service Publication B1691.

Pabst, B.J. 1988. January 1988 Water Levels, and Data Related to Water-Level Changes, Western and South-Central Kansas. Open-File Report 88-342. U.S. Geological Survey.

Pyagay, E.T. 1990. Regulation of the Soil Water Regime Under Furrow Irrigation. Pochvovedeniye. 2:78-88.

Stone, J.F., J.E. Garton, B.B. Webb. H.E. Reeves, and J. Keflemarium. 1979. Irrigation Water Conservation Using Wide-spaced Furrows. Soil Sci. Soc. Amer. Jour. 43:407-411.

Stone, J.F., J.E. Garton, and B.B. Webb. 1966. Alternate Row Irrigation. Research Progress Report, Oklahoma Irrigation Research Station, Altus, Oklahoma, Processed Series, P-548.

Stone, J.F., H.E. Reeves, and J.E. Garton. 1982. Irrigation Water Conservation by Using Wide-Spaced Furrows. Agric. Water Manage. 5:309-317.

Tsegaye, T., J.F. Stone, and H.E. Reeves. 1993. Water Use Characteristics of Wide-Spaced Furrow Irrigation. Soil Sci. Soc. Amer. J. 57: 240-245.

APPENDIXES

APPENDIX A

YIELD AND IRRIGATION WATER USE EFFICIENCY BY PLOT

TABLE VII

GRAIN SORGHUM YIELD BY PLOT*

TREATMENT	LOCATION	PERPENDICULAR kg ha^{-1}	45^{o} kg ha^{-1}	PARALLEL kg ha^{-1}
LEPA	INSIDE	8985	8087	8073
LEPA	OUTSIDE	10126	8073	8299
SPRAY	INSIDE	10226	8124	7511
SPRAY	OUTSIDE	7638	8645	9054
WSBI	INSIDE	9194	7462	7370
WSBI	OUTSIDE	8479	9119	8159

* Harvested area plot^{-1} = 0.0017 hectare

TABLE VIII

IRRIGATION WATER USE EFFICIENCY BY PLOT*

TREATMENT	LOCATION	PERPENDICULAR kg m^{-3}	45^{o} kg m^{-3}	PARALLEL kg m^{-3}
LEPA	INSIDE	2.24	1.77	1.90
LEPA	OUTSIDE	2.92	1.85	1.80
SPRAY	INSIDE	2.68	2.09	2.08
SPRAY	OUTSIDE	1.57	1.89	2.33
WSBI	INSIDE	2.28	1.79	1.72
WSBI	OUTSIDE	2.09	1.68	1.97

* Harvested area plot^{-1} = 0.0017 hectare

APPENDIX B

GROWING SEASON SOIL WATER CONTENT IN RELATION TO THE RAINFALL AND IRRIGATION EVENTS

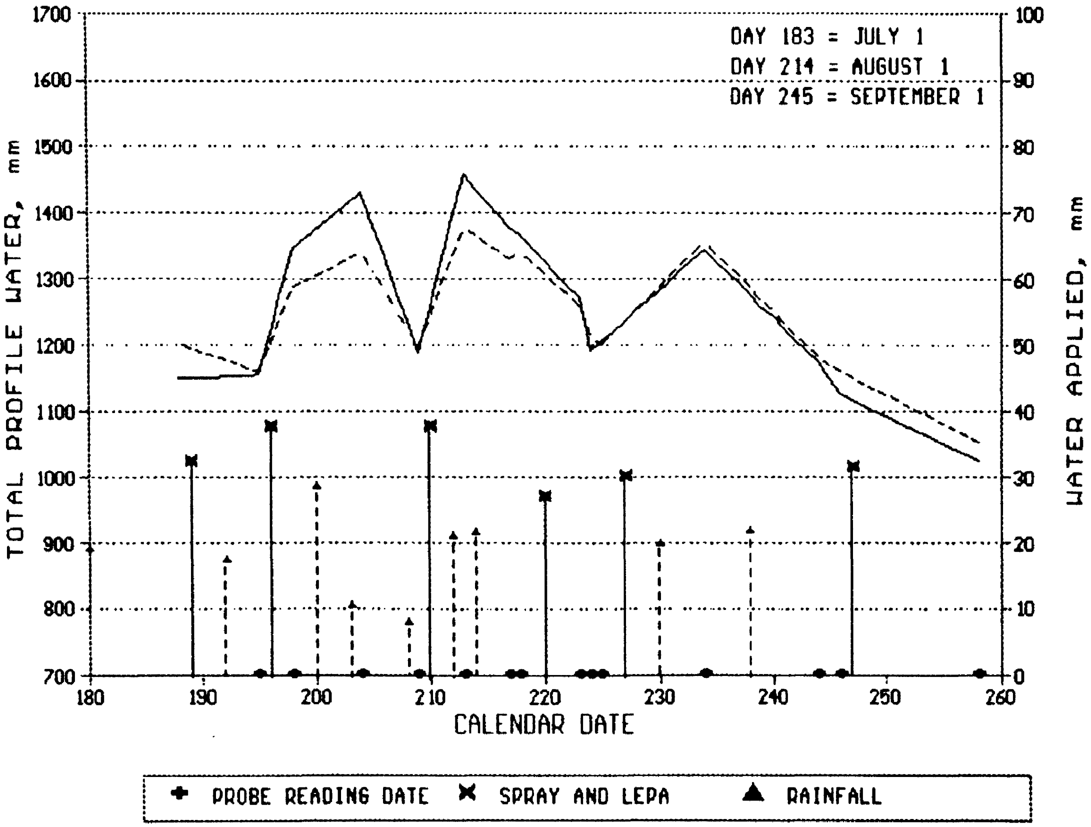

Figure 6. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside spray plot of the perpendicular angle.

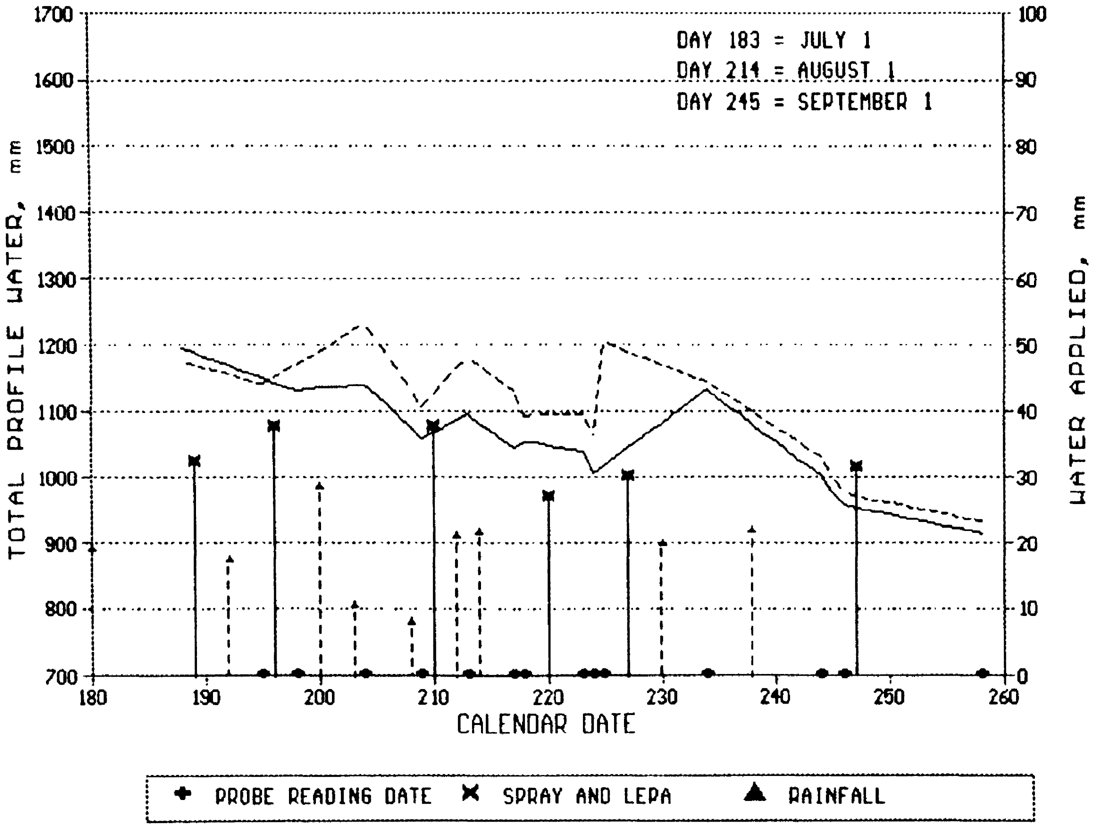

Figure 7. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the outside spray plot of the perpendicular angle.

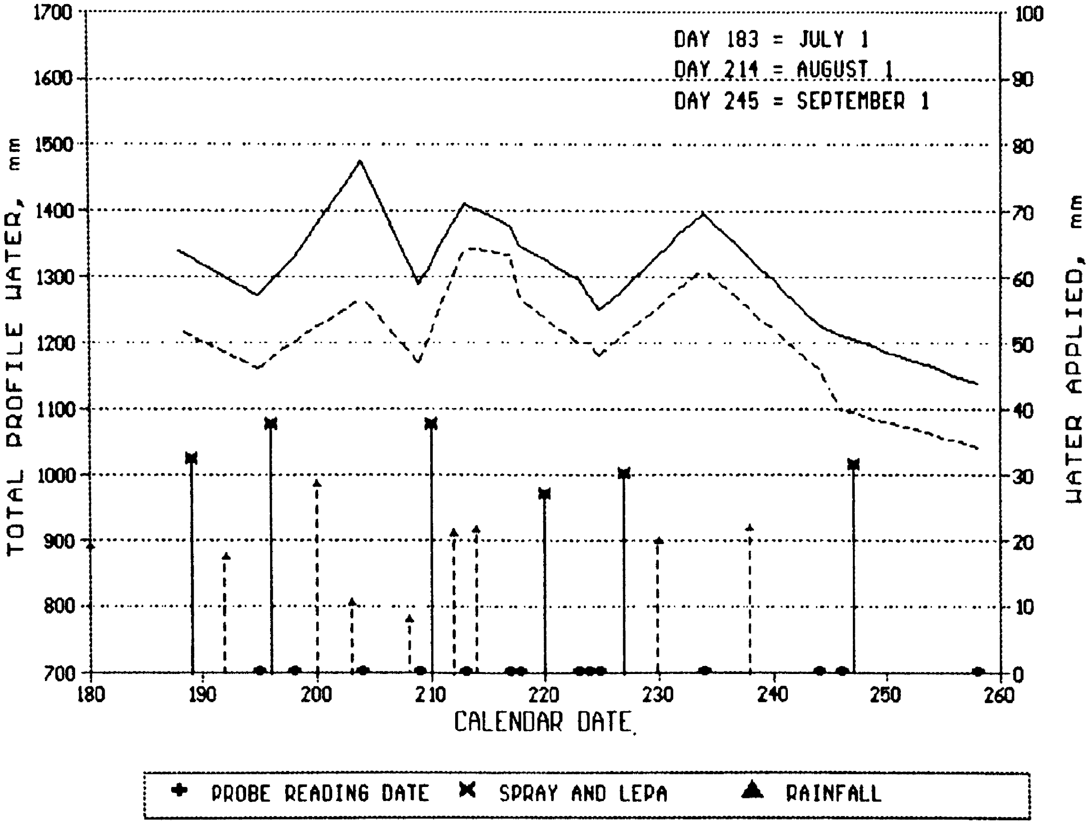

Figure 8. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside spray plot of the forty-five degree angle.

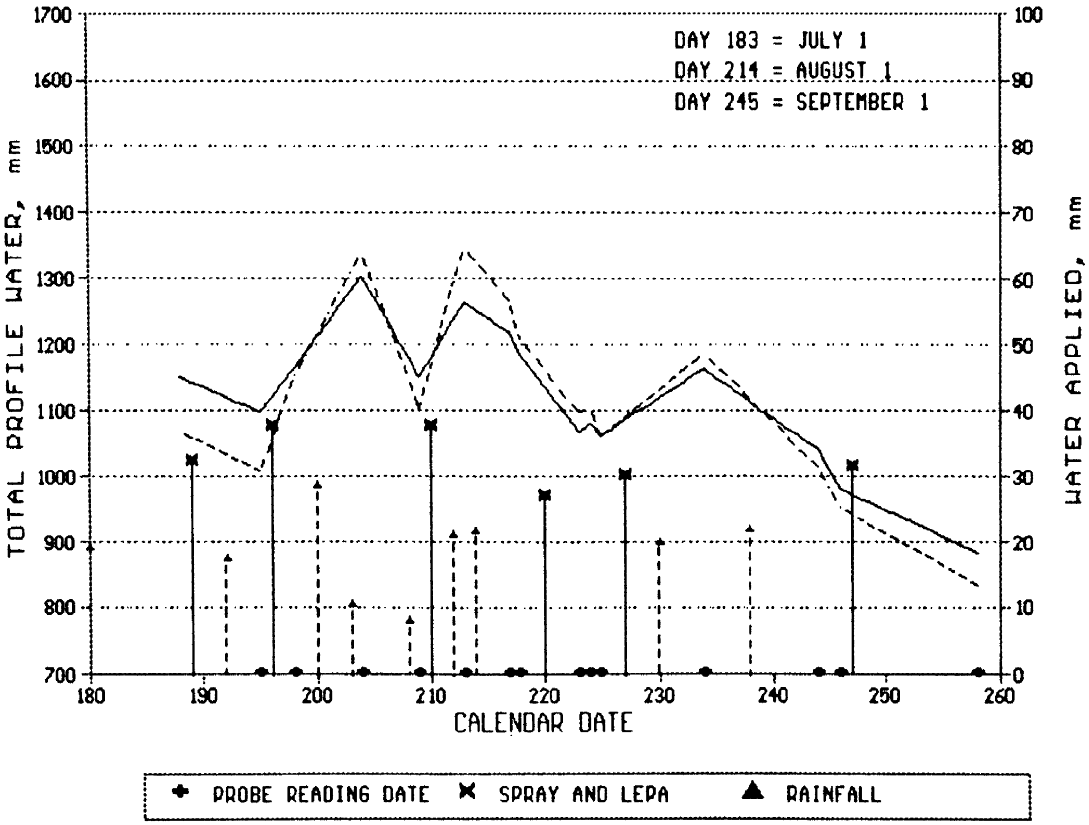

Figure 9. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the outside spray plot of the forty-five degree angle.

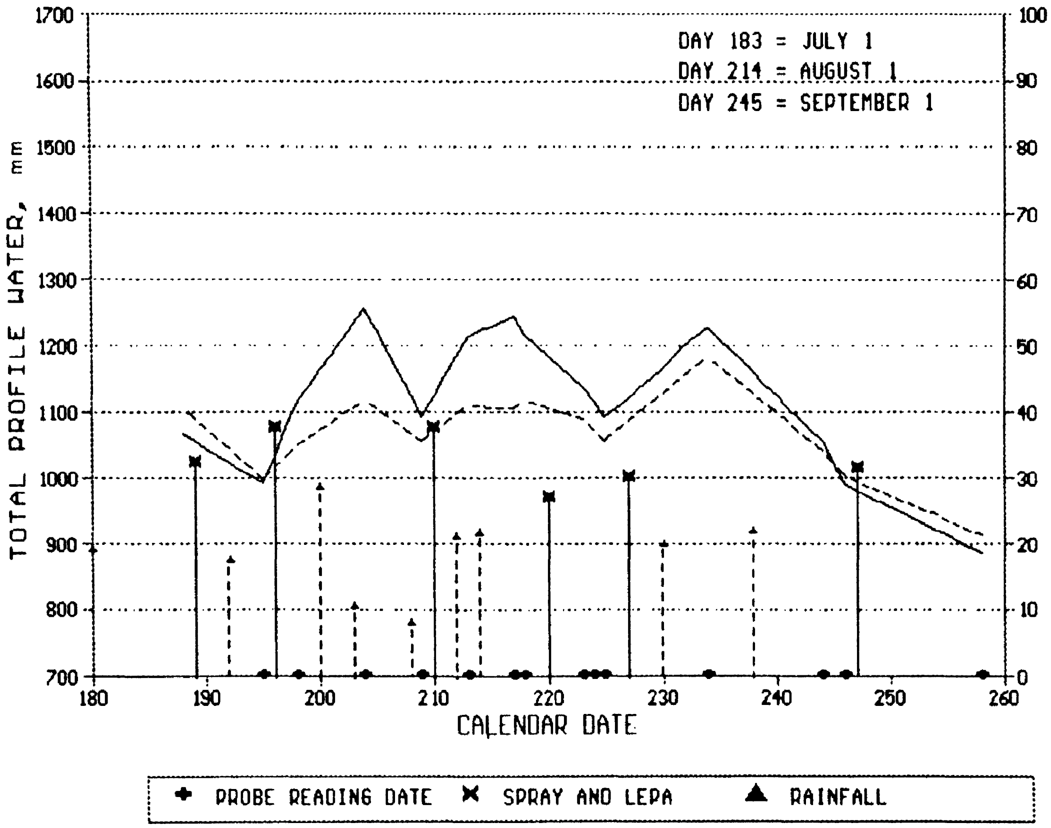

Figure 10. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside spray plot of the parallel angle.

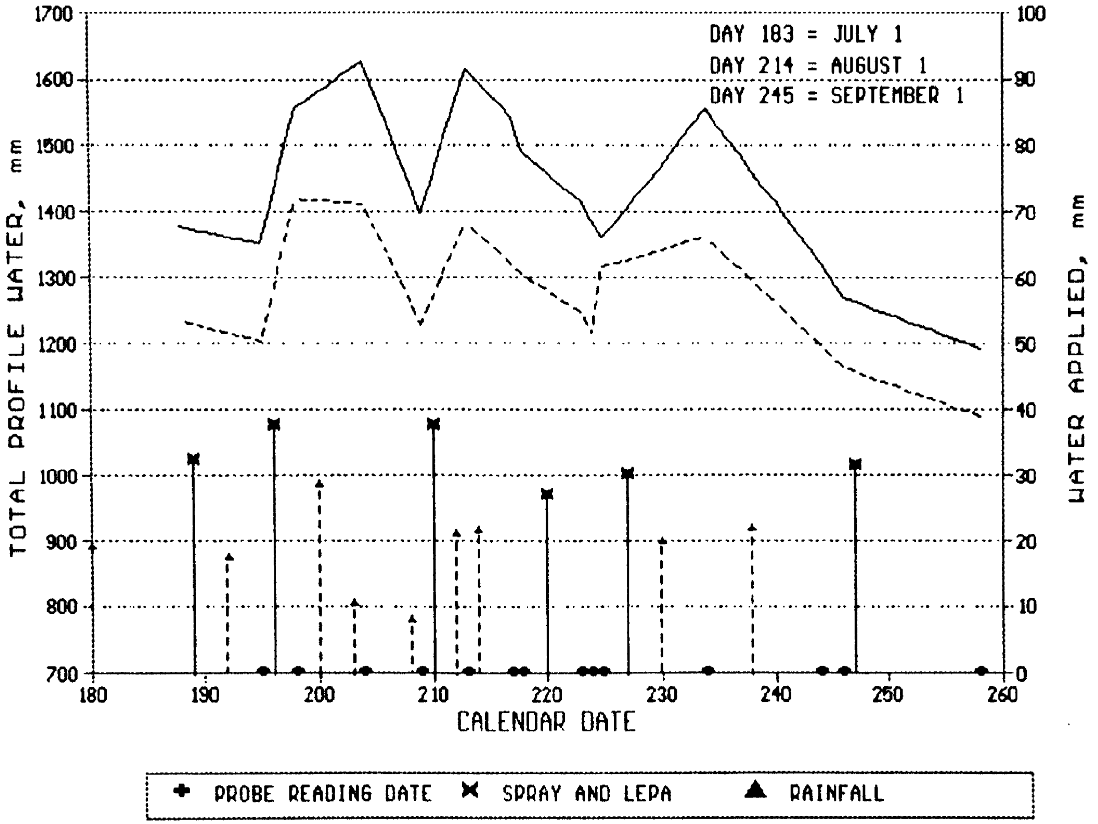

Figure 11. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside LEPA plot of the perpendicular angle.

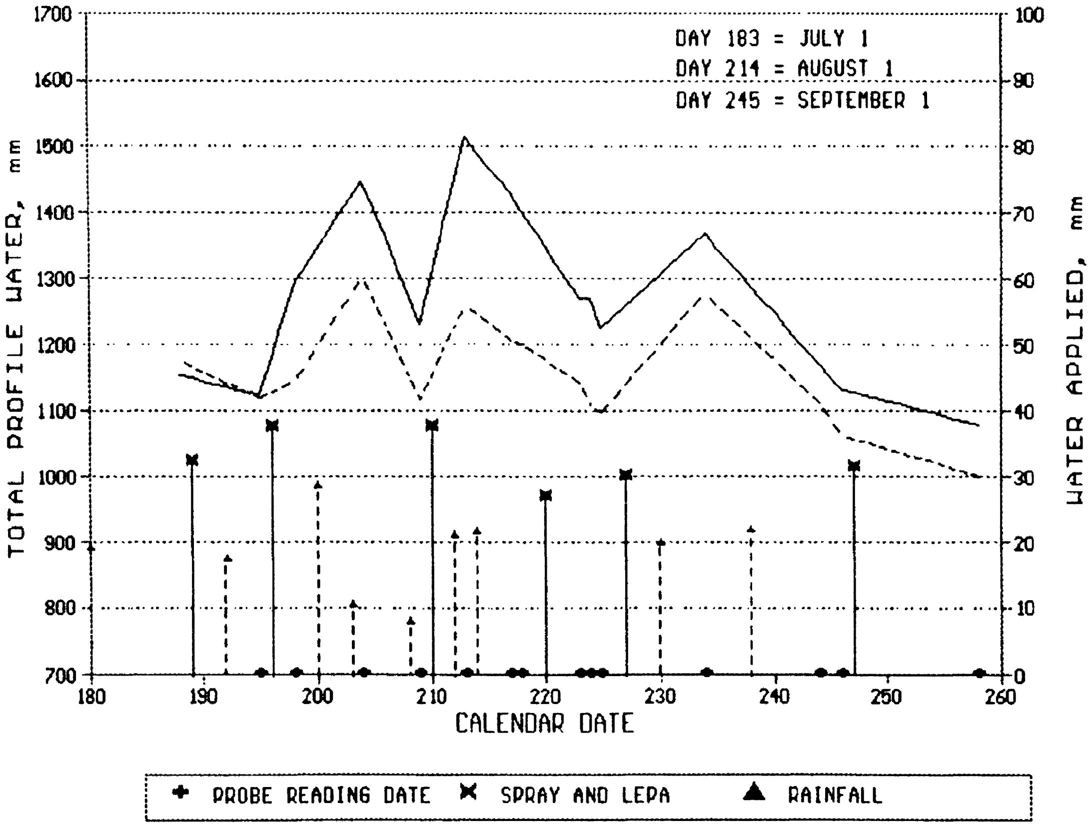

Figure 12. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the outsideLEPA plot of the perpendicular angle.

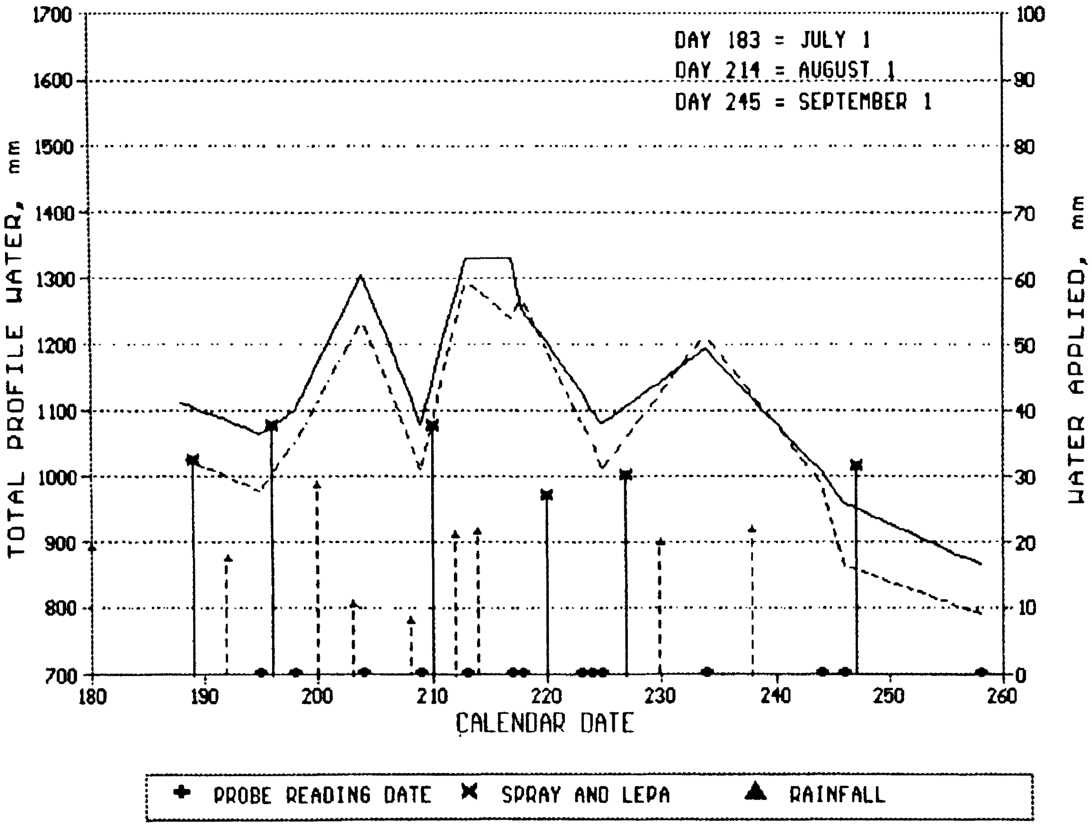

Figure 13. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside LEPA plot of the forty-five degree angle.

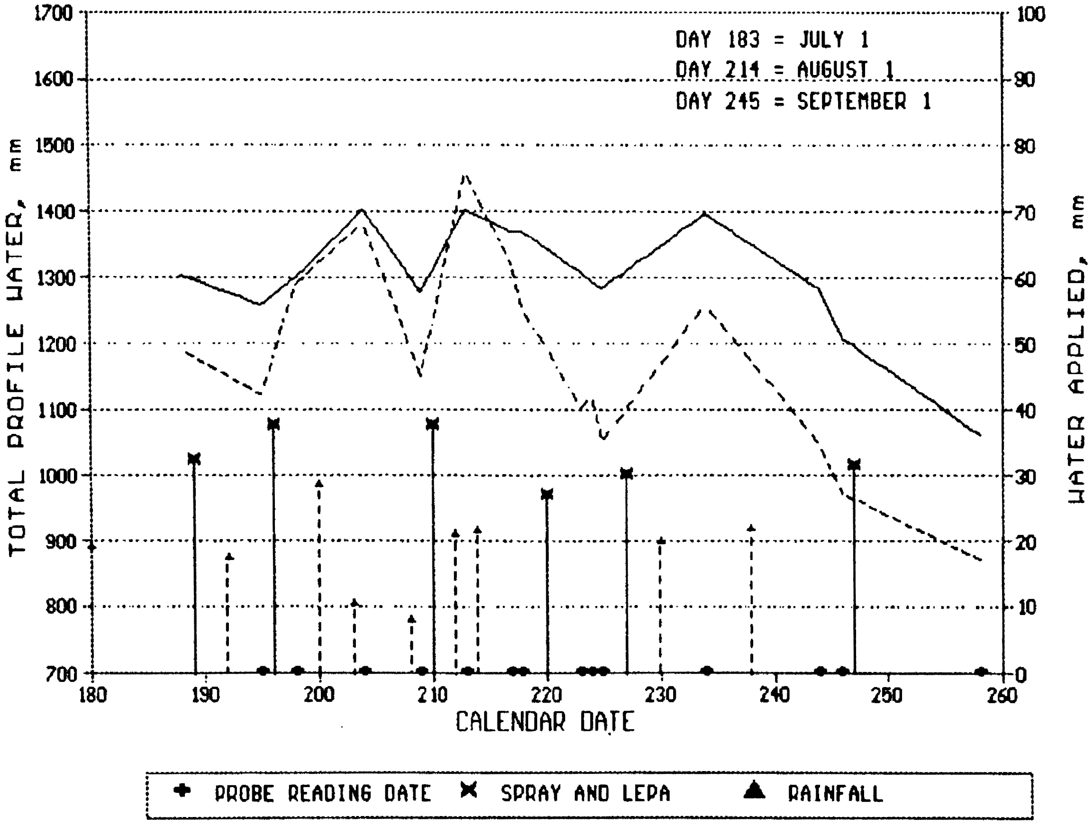

Figure 14. Plot of rain and irrigation events relation to the profile water content over the growing season for both neutron tubes in the outside LEPA plot of the forty-five degree angle.

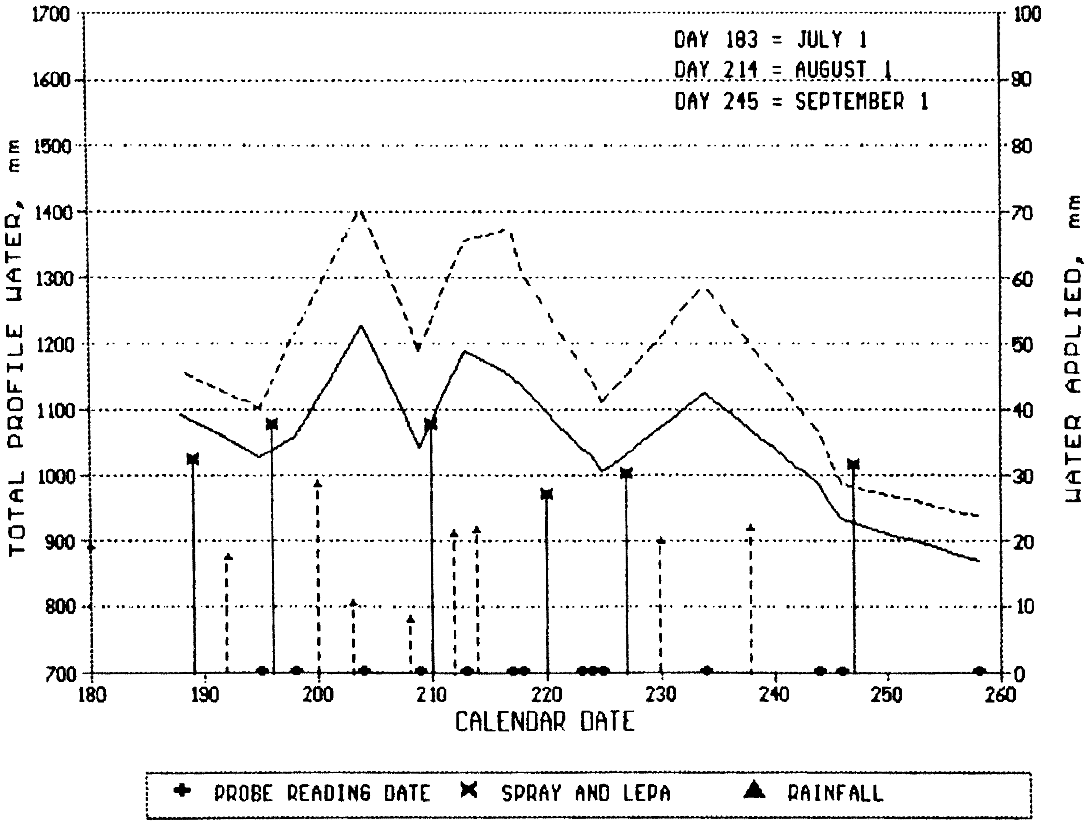

Figure 15. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside LEPA plot of the parallel angle.

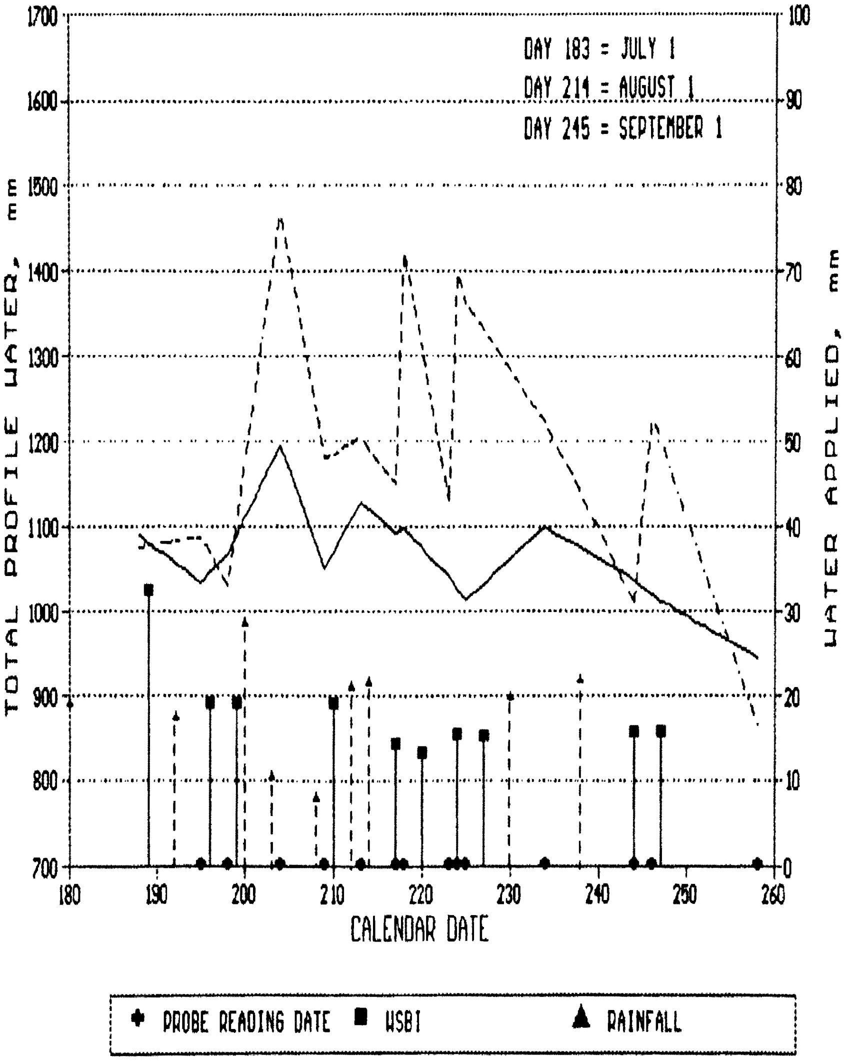

Figure 16. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside WSBI plot of the perpendicular angle.

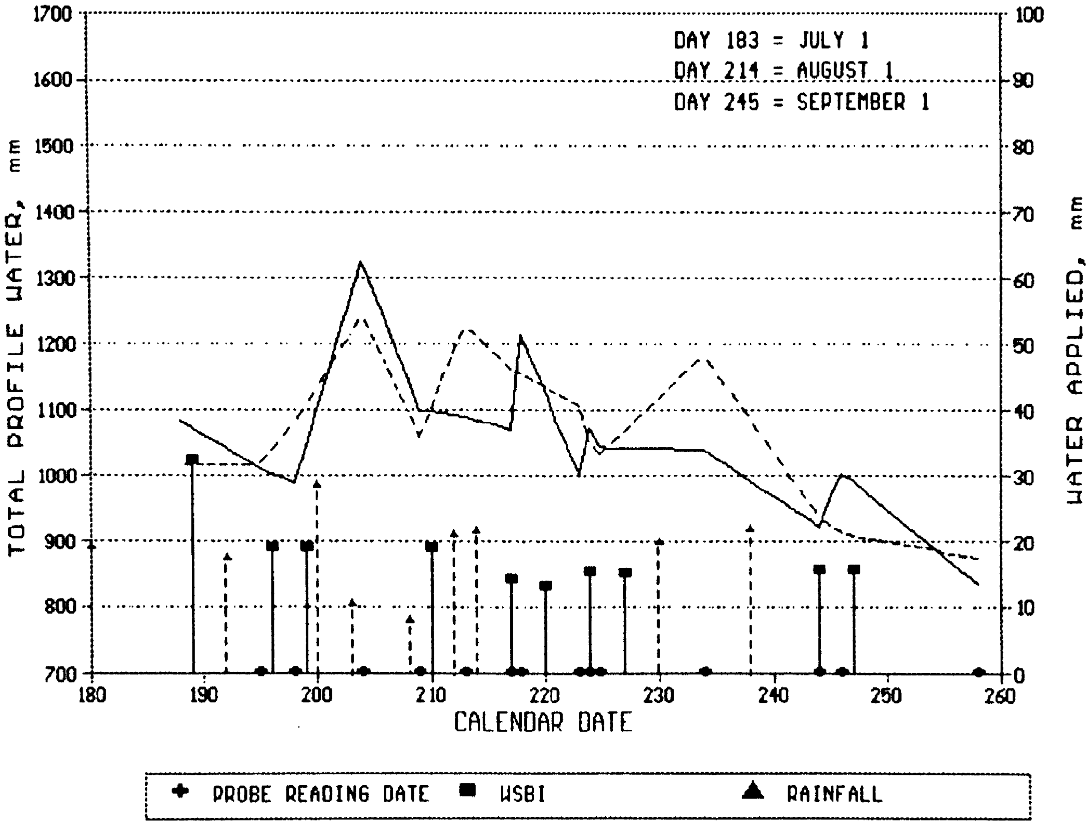

Figure 17. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the outside WSBI plot of the perpendicular angle.

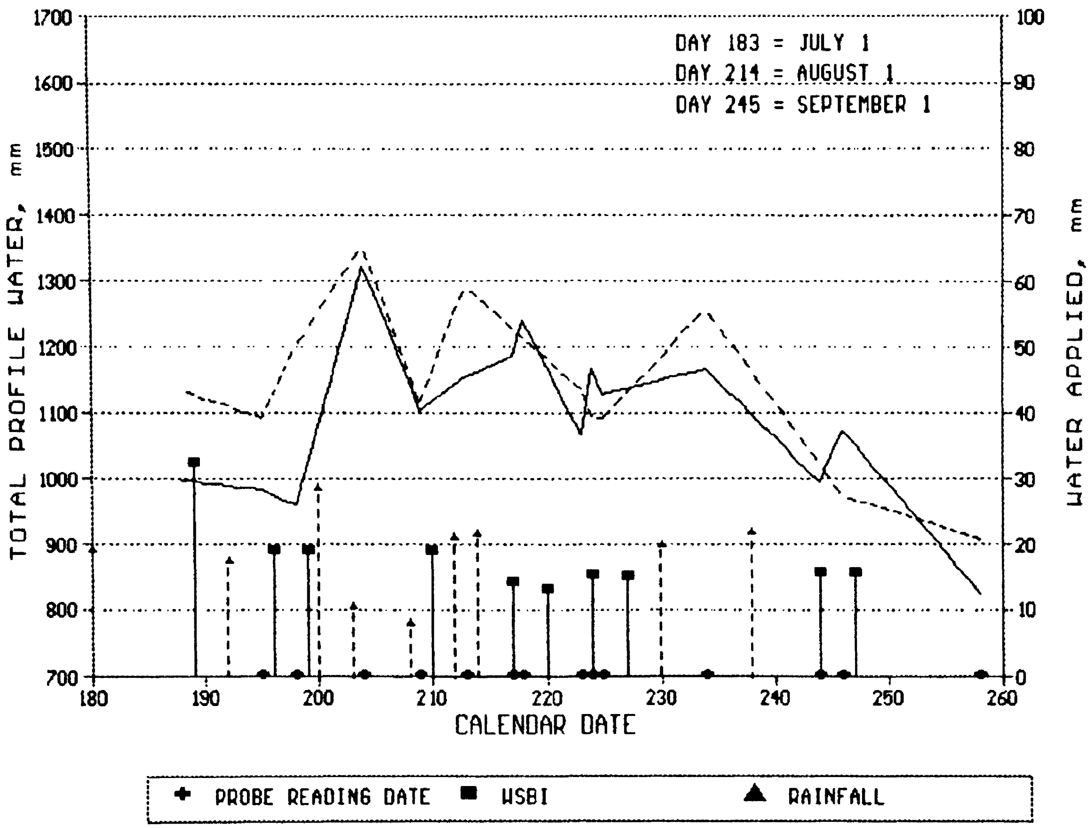

Figure 18. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside WSBI plot of the forty-five degree angle.

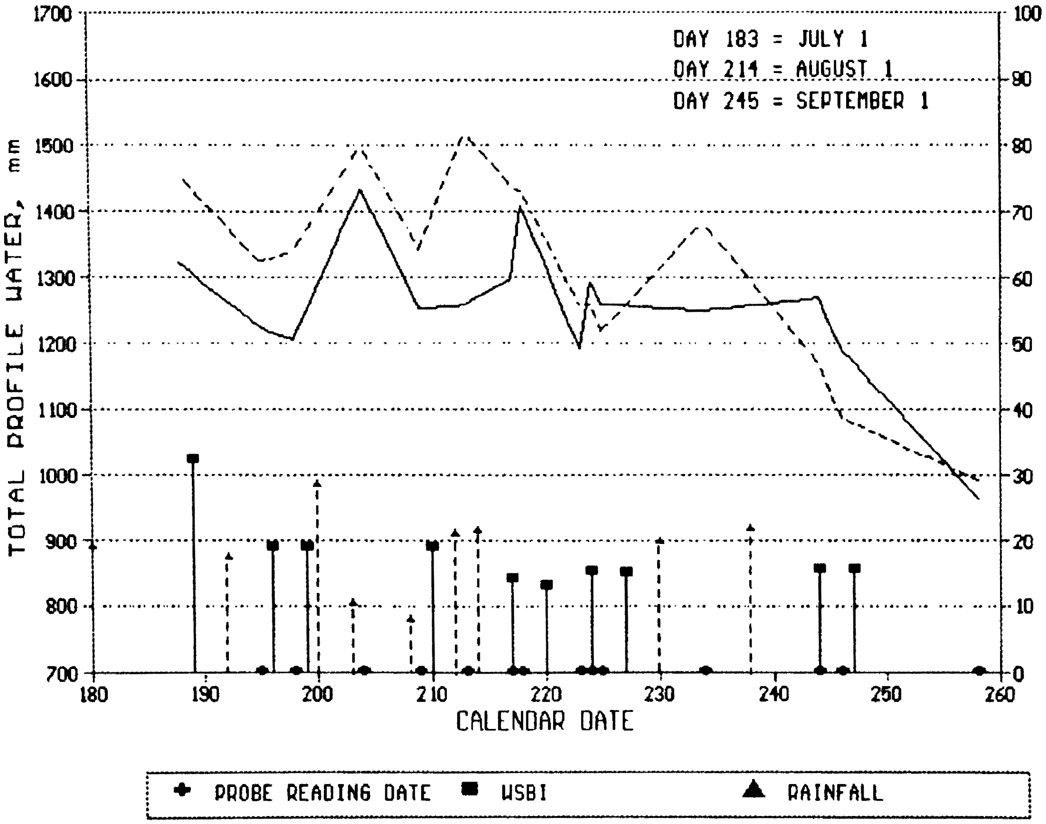

Figure 19. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the outside WSBI plot of the forty-five degree angle.

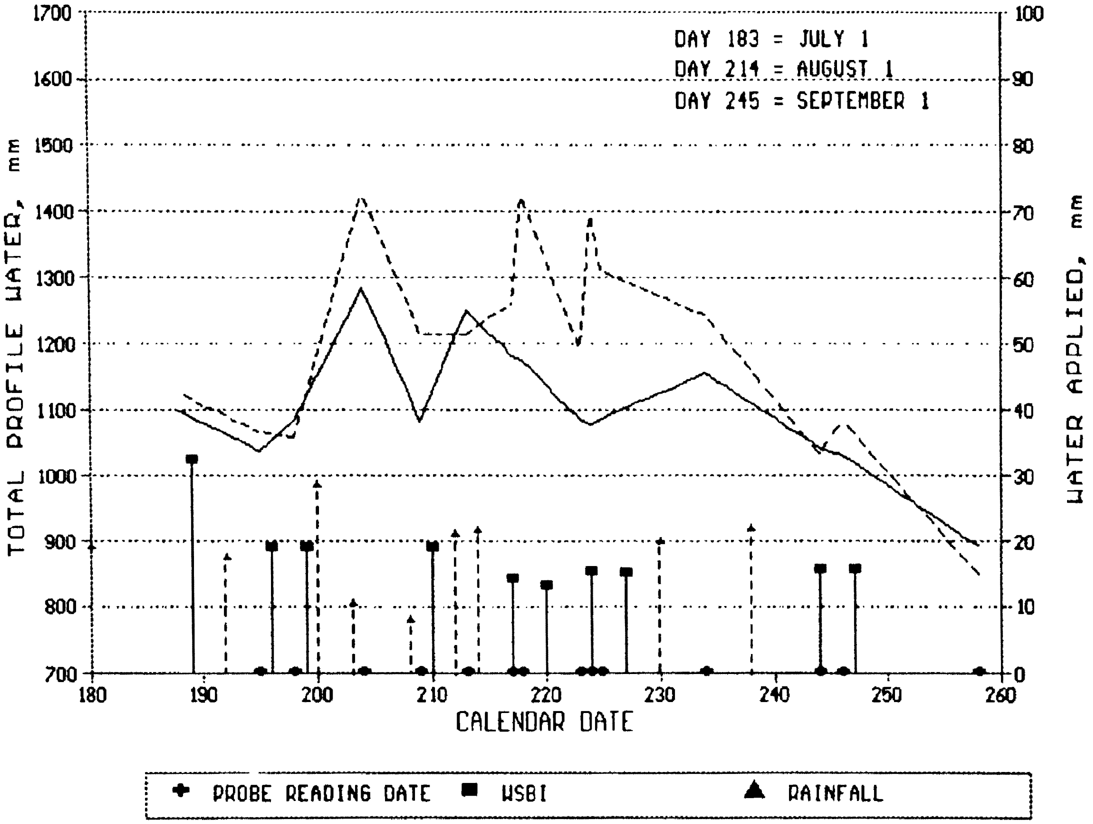

Figure 20. Plot of rain and irrigation events in relation to the profile water content over the growing season for both neutron tubes in the inside WSBI plot of the parallel angle.

VITA

Michael P. Henderson

Candidate for the Degree of

Master of Science

Thesis: COMPARISON OF THREE MODES OF WATER APPLICATION UNDER A CENTER PIVOT SPRINKLER

Major Field: Agronomy

Biographical:

Personal Data: Born in Dimmitt, Texas, March 12, 1969, the son of John C. and Loreta M. Henderson.

Education: Graduated from Texhoma High School in Texhoma, Oklahoma, May, 1987; received Bachelor of Science degree in Agronomy from Oklahoma State University, Stillwater, Oklahoma, December, 1990; completed requirements for the Master of Science degree in Agronomy at Oklahoma State University, Stillwater, Oklahoma, May, 1993.

Professional Experience: Employed by Oklahoma State University, Stillwater, Oklahoma, Laboratory Assistant, January 1990 to December 1990; employed by Oklahoma State University, Teaching Assistant, Stillwater, Oklahoma, January 1991 to December 1991; managed 1800 acres of irrigated farmland in a partnership with my brother, Griggs, Oklahoma, May 1987 to November 1992; employed by Oklahoma State University, Research Assistant, Stillwater, Oklahoma, May 1992 to May 1993.