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WATER CONSERVATION with IMPROVED IRRIGATION METHODS and MANAGEMENT

PROJECT REVIEW
27 January 1994
Bushland, Texas USA

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Dr. Ahmed El-Sahrigi - Egypt

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AGENDA

Welcome (R.N. Clark)	9:00 am
Introduction Project Overview (T.A. Howell)	9:10 am
Drip Irrigation Experiment Design (A.D. Schneider)	9:30 am
1993 Drip Irrigation Results (T.A. Howell)	9:50 am
Break	10:10 am
1993 LEPA Experiment Results (T.A. Howell)	10:20 am
1993 Sprinkler Irrigation Results (A.D. Schneider)	10:30 am
1993 Sorghum Evapotranspiration Results (S.R. Evett)	10:50 am
Soil Water Measurement Devices (S.R. Evett)	11:10 am
Discussions	11:30 am
Lunch (in Amarillo)	11:45 am
Field Tours (Bushland Research Sites)	1:15 pm
ET Modeling (S.R. Evett)	2:10 pm
Egypt Drip Experiments (T.A. Howell)	2:30 pm
Break	2:50 pm
Egypt and Bushland Lysimeter Design (A.D. Schneider)	3:00 pm
Summary (T.A. Howell)	3:30 pm
Discussions (and laboratory tours)	3:50 pm

INTRODUCTION PROJECT OVERVIEW

This project was funded by NARP (National Agricultural Research Project) through USDA-OICD to USDA-ARS in the U.S. through a reimbursable agreement and through NARP in Giza, Egypt to the SWRI (Soils and Water Research Institute) in Giza, Egypt. The project initiation date was 1 October 1993, but funding for FY-93 was a few weeks late. The project was proposed as a two-year study with potential extension (with additional funding) to a third year. The project is in the second year with the 1993 experimental year being completed.

PROJECT OBJECTIVES.

The overall project objectives are to evaluate and adapt irrigation systems that can improve on-farm application efficiency and uniformity and management methods that can guide irrigation scheduling decisions to minimize irrigation water usage while maintaining or improving crop yields.

Specific objectives are the following:

a. Evaluate the potential for mechanical sprinkler systems and micro-irrigation (drip/trickle/subsurface, etc.) (called drip hereafter in this report) to improve the irrigation water distribution uniformity and reduce irrigation application losses from water droplet evaporation in the air, evaporation from wetted foliage, soil water evaporation, profile drainage (in excess of that necessary for salinity management), and subsequent water table problems, and field runoff.

b. Evaluate the potential to improve irrigation management to avoid critical levels of crop water deficits, particularly at sensitive crop development stages, and to reduce percolation below the rootzone (except for necessary leaching) using irrigation scheduling methods based on weather, soil water balance, soil water profile measurements, and direct measurements of crop water status using infrared thermometry.

PROJECT PLANS.

Initial plans were to conduct simultaneous experiments in Egypt and the U.S. on drip and sprinkler irrigation with the U.S. projects focussing on sprinkler with some new drip research and for the Egypt projects to focus on crop water requirements and drip irrigation. Two existing USDA-ARS irrigation experiments on sprinkler methods and LEPA (low energy precision application) were integrated into the project along with on-going ARS projects on evapotranspiration of irrigated crops. Irrigation facilities for drip irrigation research needed to be installed at Bushland. Drip irrigation facilities existed at New Boustan in the western Egyptian desert adjacent to the Nile Delta. New facilities were planned for Ismailia in the eastern Egyptian desert near the Suez Canal along with an automated weather station and weighing lysimeters. Due to delays needed for planning, infrared thermometer research and application for irrigation scheduling in both the U.S. and Egypt was delayed until the FY-94 year.

In 1994, experiments will be conducted at Bushland on corn evapotranspiration under sprinkler irrigation, corn response and crop water deficits as affected by deficit LEPA irrigation, corn response to surface and subsurface drip irrigation as influenced by irrigation frequency and amount, corn response to sprinkler irrigation methods, and grass reference ET. These experiments will use the ENWATBAL -- energy water balance model, the USDA-SCS irrigation scheduling model (version 3.0), and CERES-Maize (version 2.0). Infrared thermometer measurements of crop canopy temperature will be taken on the LEPA and drip experiments and compared to soil water status and to plant water status (leaf water potential).

In 1994, experiments will be completed at New Boustan on potato response to surface and subsurface drip irrigation with three water levels, corn response to drip irrigation will again be studied under three irrigation regimes, corn ET will be measured at Ismailia under drip irrigation, alfalfa ET will be measured at Ismailia under sprinkler irrigation, hourly climatic data will be collected at Ismailia in combination with the ET data, and new drip irrigation experiments at Ismailia will be initiated. These experiments will be used to validate the CERES-Maize model and the USDA-SCS irrigation scheduling model for conditions in Egypt.

PROJECTS ACCOMPLISHMENTS - 1993.

U.S. Experiments on sprinkler irrigation methods of sorghum, LEPA irrigation of corn, drip and subsurface irrigation of corn, and evapotranspiration of sprinkler irrigated sorghum were completed at Bushland. A non-nuclear soil water guage was evaluated for a sandy soil similar to that in Egypt at the project sites and found inaccurate for research purposes. Design of a new weighing lysimeter (1.5 m by 1.5 m surface area and 2.3 m deep) containing a Pullman clay loam soil monolith at Bushland was completed and installation begun. This lysimeter will be used to measure ET from irrigated grass for comparison to irrigation scheduling models. The lysimeter is similar to the ones designed for Egypt for this project. This report will highlight these accomplishments.

Egypt. In 1993, experiments on corn using drip and subsurface irrigation were conducted at New Boustan in Egypt. A second experiment on potato was started and will be completed in early 1994. Two weighing lysimeters (2 m by 1.5 m in surface area and

1.5 m deep) were designed, constructed, and installed at Ismailia in Egypt. The lysimeters will be used to measure corn and alfalfa ET. The alfalfa ET will be used as the "reference ET" for irrigation scheduling models. Infrared crop temperatures will be periodically measured for the corn and alfalfa crops at Ismailia and used to determine crop water deficit conditions.

ACKNOWLEDGEMENTS

We are indebted to the project support personnel involved in this project. Don Dusek provided great assistance in the corn production in the LEPA and drip experiments and in the sorghum ET experiment. Karen Copeland analyzed and organized the ET data and most of the neutron and plant growth data for the LEPA and drip experiment. Jim Cresap made the neutron, plant growth, and yield measurements on the sorghum ET experiment. Joe Serda operated the sprinkler irrigation equipment for the sprinkler experiment and did the field sorghum production work. Cal Stone operated the drip and LEPA experiments. Brandon Smith worked on most all the field experiments and yield data processing. Kevin von Netzer and Damon Flowers assisted in the summer field work and particularly in the drip equipment installation. The sorghum ET work is part of the Bushland ET team's research, and this team includes Dr. Jean Steiner and Dr. Judy Tolk besides the ET team members directly involved with this NARP project (Howell, Schneider, and Evett).

DRIP EXPERIMENT DESIGN AND INSTALLATION

A field plot area reasonably close to irrigation water and electrical power was selected just south of the existing ET weather station site. This site had been laser leveled into 10.7-m wide borders several years previously and uniformly cropped since that time. The field plot was limited in size and was irregularly shaped as a triangle. Figure 1 shows the field plot layout with 21 level border plots each 27.4-m long and 10.7-m wide. This permitted twelve 0.76 m spaced rows, which is the common corn row spacing for this

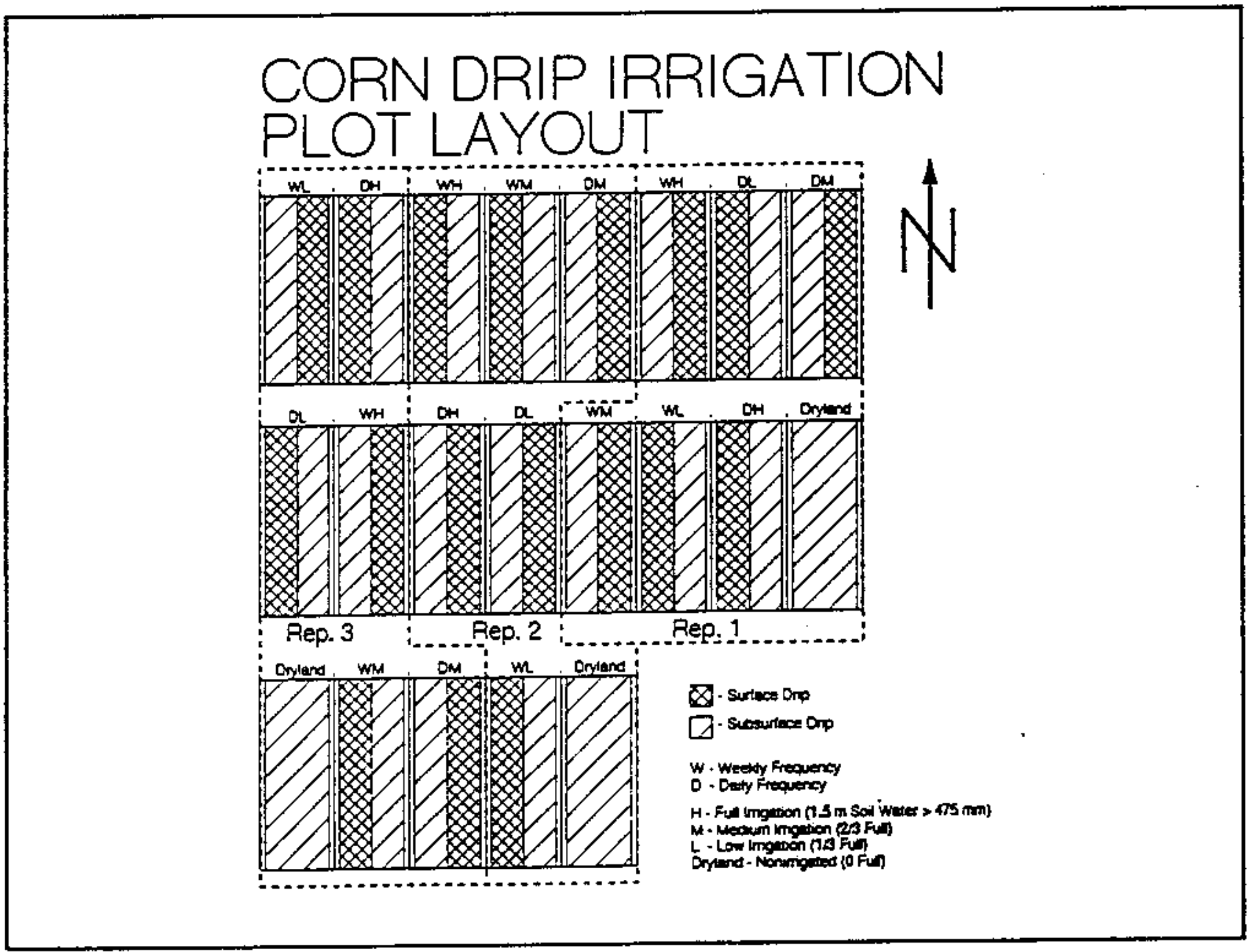


Figure 1. Schematic layout of drip irrigation plots.

area. The main treatment variables were irrigation frequency -- weekly or daily; irrigation amount -- 100% (T-100), 67% (T-67), and 33% (T-33) soil water replenishment rates based on the 100% treatment; and drip irrigation application method -- surface and subsurface. The irrigation method treatments were split plots. A dryland (non irrigated) treatment (T-0) was included. Each treatment was replicated three times. Netafim typhoon 2.27 L/h (0.6 gph) tubing was selected with 0.46 m spacing between emitters. The plots were designed to have six laterals 27.4-m long with 360 emitters. Drip lines were 1.52 m apart and equally spaced between two corn rows. Flow control was provided to each plot with Dole flow control valves set for 908 L/h (4 gpm) with the resulting operating pressure of 79 kPa (11.4 psi). Each treatment (3 plots) had an individual water meter, solenoid valve, and screen filter (120 mesh). A multi-station irrigation timer was used to control the operation of each treatment via its solenoid valve. The resulting application rate was 3.62 mm/h (or L m^{-2} h^{-1}) or 16.6 min/mm. Irrigation time could be controlled to the nearest 1 min for most settings. Water was supplied from an above-ground reservoir which was supplied from wells into the Ogallala aquifer. A submersible pump delivered water from the reservoir to the plots under constant pressure. A screen filter (150 mesh) removed trash and sand particles from the water. A water-driven chemical injection system controlled by a water meter was used to inject fertilizer and phosphoric acid into the drip lines. The phosphoric acid was diluted 1:10 before injection and a constant injection rate of 13 mg/kg of P (ppm of P) was maintained. Urea was injected at variable rates from 113 mg/kg of N (ppm of N) to 75 mg/kg of N. The injection rates for both P and N were proportional to flow rate so each plot and treatment received N and P in proportion to its irrigation application.

The plots were designed with permanent subsurface installation and removable surface lines. The subsurface lines were installed using a Sundance drip tubing installation chisel plow (3 lines per pass) at a depth of approximately 0.3 m. The downstream ends of the subsurface lines were connected to a common flush line for each plot to permit periodic flushing. The surface lines were not manifolded for flushing, but could be individually flushed. The chisel plow was found to have excessive draft for the soil conditions at Bushland. A new chisel shank was constructed following a design from ARS in California. Plans were developed to measure and compare the draft of these two types of chisels with an instrumented tractor, but our cooperators with the tractor were unable to get their software operational. If they complete their software, this work may be conducted in 1994 at Bushland and at sandy soil site.

1993 DRIP EXPERIMENT RESULTS

The plots were planted to corn (Pioneer 3245) on 27 May (DOY 147) at about 8 seeds/m^2. This planting date is about one month later than optimum for this area. The delay was due to irrigation equipment installation. All the plots had all been chiseled (including the surface drip plots) and fertilized with anhydrous ammonia at 15 g(N)/m^2 previously. Establishment irrigations were necessary due to the dry soil conditions following the tillage operations and the generally "rough" field conditions. Large irrigations were applied uniformly to pre-wet the plots and to germinate the crop. These irrigation amounts were 46 mm on DOY 152, 39 mm on DOY 153, and 46 mm on DOY 154. These application amounts will be reduced in 1994 to evaluate the ability of drip and subsurface irrigation to establish crops in this region, and we anticipate much lower irrigation amounts being used. These amounts are not excessive but were probably slightly more than necessary. The corn began emerging on 2 June and completed emerging by 12 June. This variable emergence was mainly due to the shallow planting and poor field conditions following system installation. Neutron tubes were installed to 2.5-m depth in all plots on 15 June, and the first readings were taken on 16 June (DOY 167).

The corn grew rapidly and tasseled on 3 August (DOY 215) and silked on 10 August (DOY 222). The corn was harvested on 14-15 October (DOYs 287 and 288), and the plant density was 7.4 plants/m^2. All nitrogen fertilizer was turned off on 4 August (DOY 216) at silk emergence. The crop was normal in all respects, but somewhat taller than other corn planted earlier. Southwestern corn borers damaged the plots late in the season. The plots were aerial sprayed for insect control, but because of timing differences with other corn the borers seemed to do more damage in these plots. Since the yield was largely established before major problems developed, the corn borer damage was largely cosmetic. The T-33 (33% soil water replenishment) treatment and the dryland check plot suffered severe water deficits. The dryland plots were practically dead following silking, but they produced some small yield amounts. The resulting fertilizer applications were as follows:

Treatment	Nitrogen	Phosphorous	Irrigation
T-100	17 g(N)/m^2	8 g(P)/m^2	657 mm
T-67	11 g(N)/m^2	5 g(P)/m^2	445 mm
T-33	6 g(N)/m^2	3 g(P)/m^2	250 mm
T-0	0 g(N)/m^2	0 g(P)/m^2	0 mm

The T-33 treatment received slightly more irrigation than design due to early controller setting errors, but the differences were usually small. The weekly irrigation T-100 and T-33 treatments did receive 80 mm and 39 mm more irrigation than the daily treatments, respectively, again due to incorrect timer settings and rainfall interferences. If significant rainfall was received, daily irrigations were often omitted, but it was difficult to adjust the weekly treatments.

The irrigations were controlled by the daily surface and subsurface T-100 plots. On Tuesday of each week, soil water was measured by neutron attenuation in these 6 plots and compared to a fixed value of 500 mm for a 1.5-m profile (0.33 m^3 m^{-3} average water content). Irrigation applications were determined for the T-100 treatments to maintain their soil water content near this 500 mm value (about 90% of field capacity). The timers were set to apply the desired amounts to each treatment at the desired frequency -- daily or weekly. Usually, the weekly irrigations were applied on Thursday, and the weekly schedule was Wednesday through Tuesday. The surface applied irrigations wetted most of the area between the adjacent rows. The subsurface applications wet a smaller area on the soil surface but did keep the soil surface wet above the drip lines. The alternate rows without drip lines generally remained dry, except for rains. The plots were diked to prevent and minimize runoff and plot runon. No detectable emitter plugging occurred for the subsurface lines, and all lines maintained nearly equal operating pressures.

Drip experiment yield and yield components are shown in Table 1 below. Grain yields varied from 0.084 kg m^{-2} for the dryland check (T-0) to 1.314 kg m^{-2} for T-100 with

Table 1. 1993 DRIP EXPERIMENT YIELD AND YIELD COMPONENTS.

TREATMENT	GRAIN YIELD [1] kg m^{-2}	HARVEST INDEX [2] kg kg^{-1}	BIOMASS YIELD [2] kg m^{-2}	KERNEL MASS mg $kernel^{-1}$	KERNEL NUMBER # m^{-2}	KERNELS per EAR # ear^{-1}
DAILY SURFACE T-100	1.240ab [3]	0.513ab	2.604ab	309a	4014abc	579a
DAILY SUBSURFACE T-100	1.169abc	0.542ab	2.966a	317a	3698bcd	543abc
WEEKLY SURFACE T-100	1.314a	0.509ab	2.704ab	315a	4174a	577ab
WEEKLY SUBSURFACE T-100	1.307a	0.542ab	2.889ab	324a	4036abc	566ab
DAILY SURFACE T-67	1.100bc	0.511ab	2.353bcde	293ab	3763abcd	539abc
DAILY SUBSURFACE T-67	1.088c	0.488b	2.458abc	286abc	3815abc	569ab
WEEKLY SURFACE T-67	1.097bc	0.521ab	2.363bcde	269bc	4074ab	574ab
WEEKLY SUBSURFACE T-67	1.080c	0.565a	2.426abcd	302ab	3586cd	516cd
DAILY SURFACE T-33	0.654d	0.495ab	1.601f	228d	2867f	447e
DAILY SUBSURFACE T-33	0.666d	0.526ab	1.794ef	247cd	2699f	439e
WEEKLY SURFACE T-33	0.753d	0.481b	1.973cdef	226d	3343de	528bcd
WEEKLY SUBSURFACE T-33	0.626d	0.478b	1.866def	212d	2955ef	488de
DRYLAND CHECK T-0	0.084e	0.187c	0.645g	147e	577g	239f
$LSD_{0.05}$	0.148	0.078	0.585	39	461	50

[1] Harvest area 10 m^2.

[2] Harvest sample 8 plants.

[3] Numbers followed by different letters are statistically different ($P<0.05$) based on the least significant difference (LSD). Shaded cells are the maximum parameter values.

the weekly frequency and surface drip. Subsurface drip yield was not significantly different from surface drip although grain yield was usually a little less and biomass yield a little greater. Grain yield was affected almost equally by kernel mass and by kernel numbers. Plant grain yield was linearly correlated ($r^2 = 0.918$) with plant biomass yield with the resulting regression equation: G_p (g/plant) = $0.628 * B_p$(g/plant) - 35.6 with

Table 2. 1993 DRIP EXPERIMENT IRRIGATION AND WATER USE.

TREATMENT	GRAIN YIELD kg m^{-2}	SEASONAL IRRIGATION mm	WATER USE [1] mm	WATER USE EFFICIENCY [2] kg m^{-3}	SOIL WATER DEPLETION [3] mm
DAILY SURFACE T-100	1.240ab [4]	617	839b	1.48a	23g
DAILY SUBSURFACE T-100	1.169abc	617	832b	1.40ab	16g
WEEKLY SURFACE T-100	1.313a	696	932a	1.41ab	37fg
WEEKLY SUBSURFACE T-100	1.307a	696	956a	1.37ab	60ef
DAILY SURFACE T-67	1.100bc	446	716cd	1.54a	71de
DAILY SUBSURFACE T-67	1.088c	446	707cd	1.48a	61ef
WEEKLY SURFACE T-67	1.097bc	444	727cd	1.51a	84cde
WEEKLY SUBSURFACE T-67	1.080c	444	738c	1.46a	95bcd
DAILY SURFACE T-33	0.654d	231	544f	1.20bc	115ab
DAILY SUBSURFACE T-33	0.666d	231	549f	1.21bc	119ab
WEEKLY SURFACE T-33	0.753d	269	569ef	1.33ab	101bc
WEEKLY SUBSURFACE T-33	0.626d	269	581e	1.08c	113bc
DRYLAND CHECK T-0	0.084e	0	344g	0.24d	144a
$LSD_{0.05}$	0.148		30	0.22	30

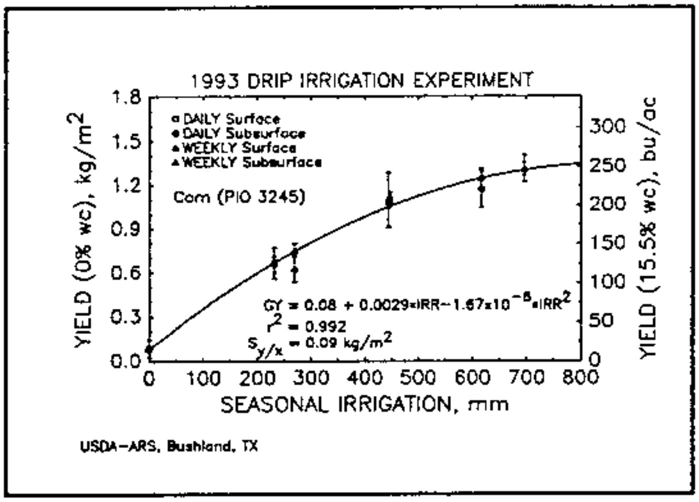
[1] Sum of seasonal irrigation, seasonal rainfall (199 mm), and growing season 2.5-m profile soil water depletion. Assumes deep percolation and runoff were negligible. Plots were diked to minimize field runoff.

[2] Ratio of grain yield to water use.

[3] Measured soil water depletion over the 2.5-m profile from DOY 167 to DOY 285 by neutron attenuation.

[4] Numbers followed by different letters are statistically different ($P<0.05$) based on the least significant difference (LSD). Shaded cells are the maximum parameter values.

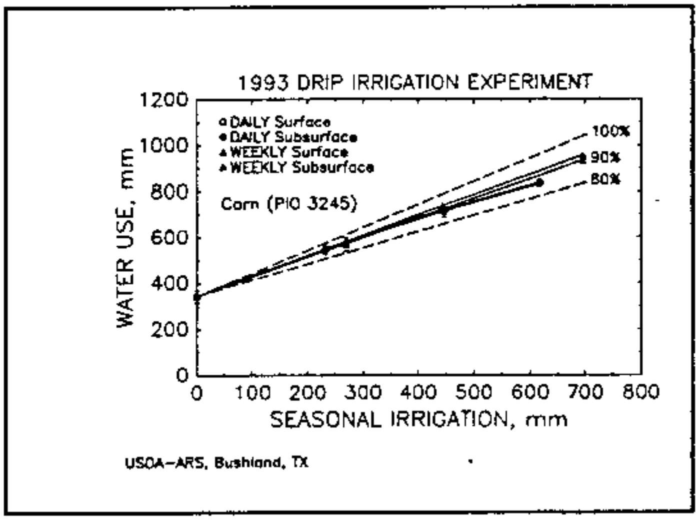
$S_{y/x}$ = 12.2 g/plant. Table 2 shows irrigation, water use, and water use efficiency summary data. Water use varied from 344 mm for the dryland check (T-0) to 956 mm for T-100 for the weekly frequency and surface drip irrigation. Soil water depletion increased from a mean of 34 mm for T-100 to a mean of 112 mm for T-33.



USDA-ARS, Bushland, TX

Figure 2. Corn yield response to drip irrigation method, frequency, and amount in 1993 at Bushland, TX.

Grain yield was related to seasonal irrigation as shown in Figure 2. Grain yield was linearly related to ET up to an ET value of about 900 mm and then plateaud (data not shown). The drip irrigation management and application efficiency were very good resulting in almost 90% of the applied water being consumed in ET as shown in Figure 3. Only small amounts of applied water remained in the soil profile (above initial values), little water was lost to runoff, and both deep percolation and soil water evaporation are included in the water use values. Deep percolation was believed to be minimal because of soil physical characteristics and constant lower soil profile water contents.



USDA-ARS, Bushland, TX

Figure 3. Water use by corn in relation to water applications by drip irrigation in 1993. Dashed lines represent constant partitioning fractions of 100, 90, and 80%.

1993 LEPA EXPERIMENT RESULTS

The LEPA experiment was conducted with a 3-tower center pivot system equipped with Senninger Quad IV LEPA heads spaced 1.52 m apart (alternate rows). LEPA socks (Fangemeier type) were attached to the base of the LEPA heads. Furrow dikes were installed with a commercial trip-roll type diker at spacings of about 1.5 m. The dikes could hold approximately 57 L of water before the bed or dike was over topped. This volume represents approximately 25 mm of LEPA depth (alternate rows double the volume) or 50 mm of rainfall depth. The LEPA socks permitted the application to fill a basin without washing out the dike as the system moved. The plots were arrannged in semi-circular six row (0.76 m rows) segments around the pivot. The LEPA heads were in the non-wheel traffic furrows. The wheel rows were not diked but were chiseled. The treatments were based on fractions of soil water replenishment (like the drip studies) as follows: T-100 full replenishment; T-80 80% of T-100; T-60 60% of T-100; T-40 40% of T-100; T-20 20% of T-100; and T-0 0% of T-100 (dryland following emergence). The plot flow rates were based on the distance of the center of the plot from the pivot, nozzle flow rates, and system irrigation capacity. Approximately 25 mm of water could be applied to the area in 12 hours. The weekly irrigation amount was determined from the soil water content of the three T-100 plots over their 1.5 m profile, like the drip study. The weekly irrigation amount for T-100 was determined and 25 mm incremental irrigations (a few 12 mm irrigations were used) were applied to match the irrigation need. The plot area was uniformly fertilized with 7 g(N)/m^2 of anhydrous ammonia. Corn (Pioneer 3245) was planted on 20 April, emerged on 3 May, and was harvested on 22 September. The final plant density was approximately 8.4 plants/m^2. Three germination and emergence irrigations were applied on DOY 111, 112, and 118 of 25 mm, 38 mm, and 15 mm, respectively. Treatment irrigations were initiated on 17 June (DOY 168). Neutron tubes were installed on 6 May and first read on 7 May. Urea nitrogen was proportionally injected into the irrigation water and continued until 26 July just after silking. T-100 received 21 g(N)/m^2 of fertilizer with the irrigation and the other treatments received proportionally less.

Corn yields are shown in Table 3. Corn yields varied from 0.338 kg/m^2 for T-0 to 1.310 kg/m^2 for T-100. Like the drip study, grain yields were affected by both kernel mass and kernel numbers. Harvest index (ratio of grain yield to biomass yield) was affected only by the drier treatments (T-20 and T-0). Interestingly the T-0 treatment yields were much better for the LEPA experiment due to the earlier planting and more timely rains

Table 3. 1993 LEPA EXPERIMENT YIELD AND YIELD COMPONENTS.

TREATMENT	GRAIN YIELD [1/] kg m^{-2}	HARVEST INDEX [2/] kg kg^{-1}	BIOMASS YIELD [2/] kg m^{-2}	KERNEL MASS mg kernel^{-1}	KERNEL NUMBER # m^{-2}	KERNELS per EAR # ear^{-1}
T-100	1.310a [3/]	0.572a	2.232a	315a	4165a	512b
T-80	1.252a	0.573a	2.228a	325a	3857a	491b
T-60	1.086b	0.578a	2.017a	291b	3740ab	478b
T-40	.918c	0.511ab	1.671b	268c	3429b	592[illegible]
T-20	.654d	0.459b	1.273c	220d	2986c	461b
T-0	.338e	0.337c	0.830d	193e	1756d	296c
LSD$_{0.05}$	.084	0.077	0.278	23	427	61

[1/] Harvest area 10 m^2.

[2/] Harvest sample 8 plants.

[3/] Numbers followed by different letters are statistically different ($P<0.05$) based on the least significant difference (LSD). Shaded cells are the maximum parameter values.

Table 4. 1993 LEPA EXPERIMENT IRRIGATION AND WATER USE.

TREATMENT	GRAIN YIELD $kg\ m^{-2}$	SEASONAL IRRIGATION mm	WATER USE[1] mm	WATER USE EFFICIENCY[2] $kg\ m^{-3}$	SOIL WATER DEPLETION[3] mm
T-100	1.310a[4]	644	973a	1.35c	88c
T-80	1.252a	515	848b	1.48ab	92bc
T-60	1.086b	386	731c	1.48ab	95bc
T-40	0.918c	258	593d	1.55a	104bc
T-20	0.654d	129	483d	1.36bc	113b
T-0	0.338e	0	383e	0.89d	142a
$LSD_{0.05}$	0.084		23	0.13	23

[1] Sum of seasonal irrigation, seasonal rainfall (241 mm), and growing season 2.5-m profile soil water depletion. Assumes deep percolation and runoff were negligible. Plots were diked to minimize field runoff.

[2] Ratio of grain yield to water use.

[3] Measured soil water depletion over the 2.5-m profile from DOY 127 to DOY 265 by neutron attenuation.

[4] Numbers followed by different letters are statistically different ($P<0.05$) based on the least significant difference (LSD). Shaded cells are the maximum parameter values.

at specific crop development periods. Table 4 shows the irrigation, water use, and water use efficiency data for the LEPA experiment. Seasonal irrigations varied from 0 mm for T-0 to 644 mm for T-100. Water use efficiency was mainly affected only by the severe water deficit of T-0. Soil water depletion increased from 88 mm for T-100 to 142 mm for T-0. Water use varied from 383 mm for T-0 to 973 mm for T-100, somewhat comparable to the drip study even though this study was planted nearly a month earlier.

Grain yield was related to seasonal irrigation amount as shown in Figure 4. The grain yield, like the drip study, was linearly related to ET until ET exceeded about 900 mm (data not shown). The LEPA management was good with over 90% of the applied water for T-100 being consumed in ET as shown in Figure 5. The partitioning of applied water into ET actually improved with the higher irrigation amounts due to the effect on root development and their ability to explore and utilize deeper soil water.

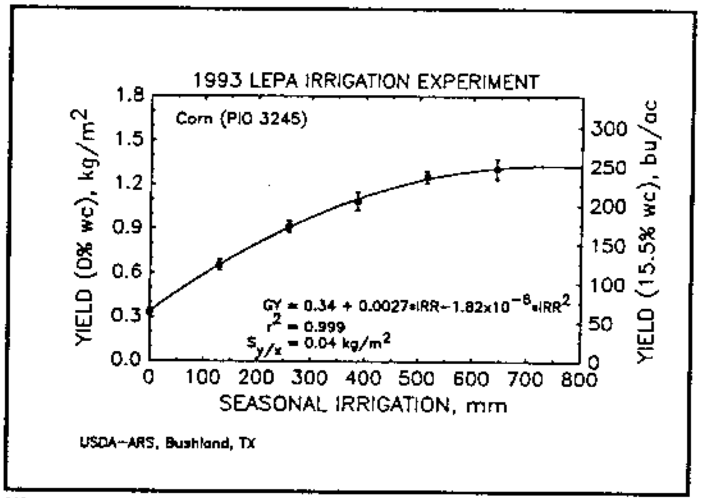


Figure 4. Corn yield response to LEPA irrigation amount in 1993 at Bushland, TX.

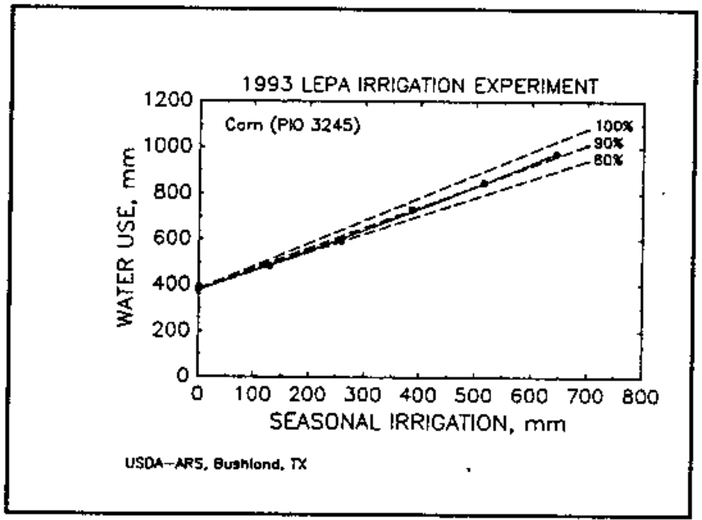


Figure 5. Water use by corn in relation to water applications by LEPA irrigation in 1993. Dashed lines represent constant partitioning fractions of 100, 90, and 80%.

1993 SPRINKLER IRRIGATION RESULTS

Two LEPA methods (Fangemier sock and bubble) and two spray methods (above-canopy and in-canopy) were evaluated at four irrigation levels -- T-100, T-75, T-50, and T-25 -- similar to the LEPA and drip experiments. The T-100 treatment had full soil water replenishment based on the 1.5-m profile soil water content as measured by neutron attenuation, like the drip and LEPA experiments. The application methods were replicated three times on a three-span lateral move sprinkler system. The application devices were spaced 1.52 m apart. The LEPA bubble mode used Senninger Quad IV LEPA heads about 0.3 m above the ground. The LEPA sock mode used Fangemeier socks attached to the Quad IV heads like the LEPA center pivot experiment. These socks dragged over the soil and were designed to minimize dike washing. The above-canopy spray heads were about 1.5 m above the ground while the in-canopy sprays were Quad IV heads in the flat spray mode about 0.3 m above the ground. The application rates were achieved by system speed changes across the particular treatment area. Sorghum (DeKalb 41y) was grown in 0.76 m spaced rows parallel to the system travel path. LEPA and in-canopy spray heads were in alternate rows. All furrows were diked with a trip-roll diker at a spacing of about 1.5 m.

Grain yields (Figure 6) averaged 707 g/m^2 for the LEPA sock and 690 g/m^2 for the LEPA bubble modes. The average yield for the in-canopy spray treatments was 665 g/m^2 and 669 g/m^2 for the above-canopy treatments. T-100 yields averaged 835 g/m^2, while average yields declined to 802 g/m^2 for T-75, 675 g/m^2 for T-50, and to 420 g/m^2 for T-25. With full ET replacement, only small differences were evident for different sprinkler methods; however, with increasing soil water deficits, LEPA became more efficient. The improved efficiency is due to alternate row irrigation (less soil water evaporation and deeper soil infiltration) and less evaporation from wetted foliage or soil surfaces.

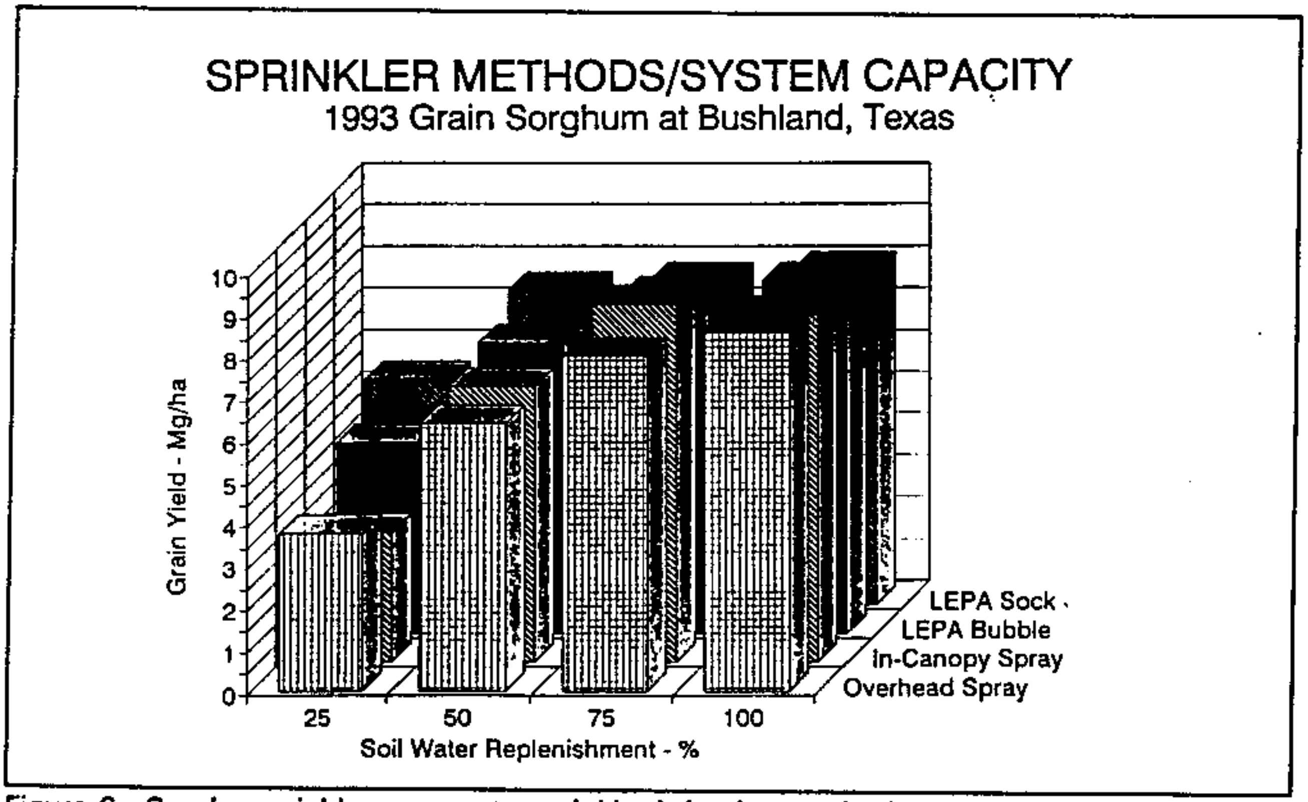


Figure 6. Sorghum yield response to sprinkler irrigation methods at Bushland, TX in 1993

1993 SORGHUM EVAPOTRANSPIRATION RESULTS

Sorghum (DeKalb 56) was planted on the east lysimeter fields on 28 May (DOY 148). The two fields are designated NE (north east) and SE (south east) as are the two weighing lysimeters. Each lysimeter is in the center of a square, 5 ha field. Due to unavoidable differences in field condition the plant density after emergence was 24.5 plants m^{-2} on the south field but only 20.4 plants m^{-2} on the north. The lysimeters were hand planted and thinned after emergence resulting in a final plant density of 21.6 plants m^{-2} on both lysimeters. On DOY 159 granular urea was applied at a rate of 11.2 $g(N)/m^2$.

One field was directly north of the other and both were irrigated by a single lateral move sprinkler. The low pressure spray nozzles on the sprinkler were the same for the first two irrigations but were sized thereafter to deliver twice as much water to the north field as to the south. There was 217 mm of rainfall over the growing season contributing to totals of water applied of 402 mm for the south and 564 mm for the north field (Figure 7). Initial profile water contents were essentially the same for the north and south fields. Water contents were also comparable between the north and south lysimeters but both lysimeters were somewhat wetter in the A horizon and below 130 cm than was the field (Figure 8). By the end of the season, the lower irrigation rate on the south field had depleted the profile more than the higher irrigation rate on the north field (Figure 8). The south lysimeter also was drier than the north at season's end (Figure 10). The crop extracted considerable water to 130 cm and some water below that in the south field and lysimeter. On the north side there was no water content change at 130 cm and deeper. This is to be expected since the higher irrigation amounts and resulting higher water contents at shallower depths in the north would result in most root activity being in the upper soil layers.

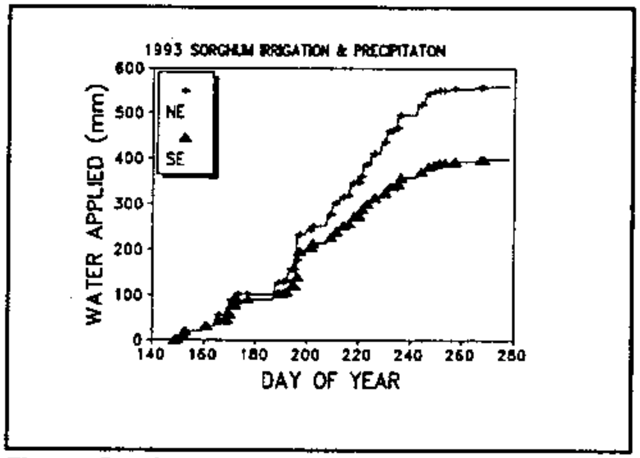


Figure 7. Cumulative irrigation plus precipitation.

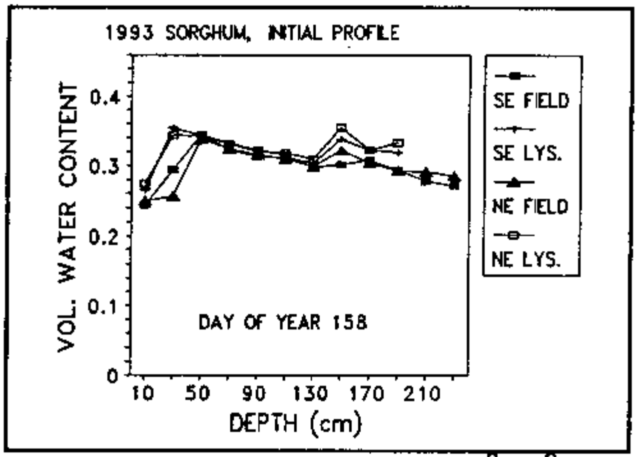


Figure 8. Initial water contents ($m^3\ m^{-3}$).

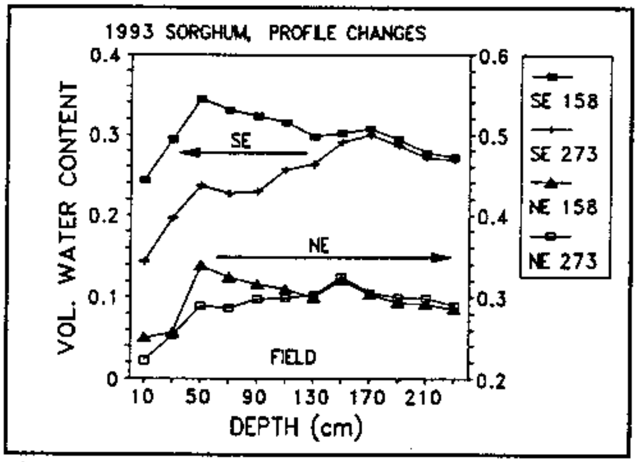


Figure 9. Field soil water profiles at season start and end.

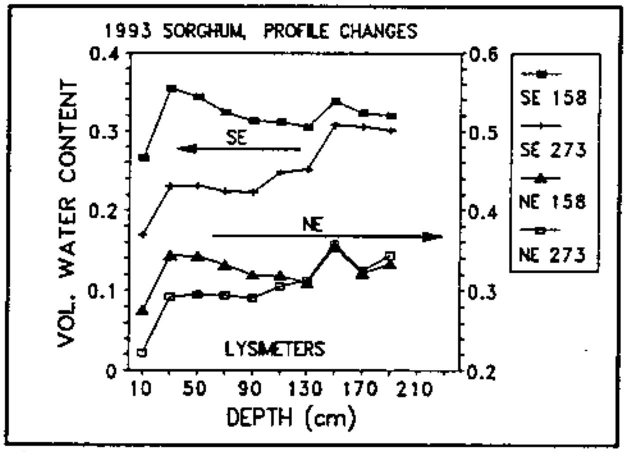


Figure 10. Lysimeter soil water profiles at season start and end.

Daily evapotranspiration (ET) was higher on the north lysimeter throughout much of the season. Higher ET occurring on the north side before LAI attained 3.5 was probably due to higher rates of evaporation from soil rather than higher transpiration rates since water contents were still similar on the two lysimeters. Differences in ET narrowed to less than 0.1 mm d^{-1} from about DOY 200 to 220 when LAI peaked (data not shown). After DOY 220 daily ET on both lysimeters declined but that on the south lysimeter declined more rapidly as the crop was increasingly stressed and some senescence occurred after DOY 245. Cumulative ET was 660 and 581 mm on the north and south lysimeters, respectively (Figure 11).

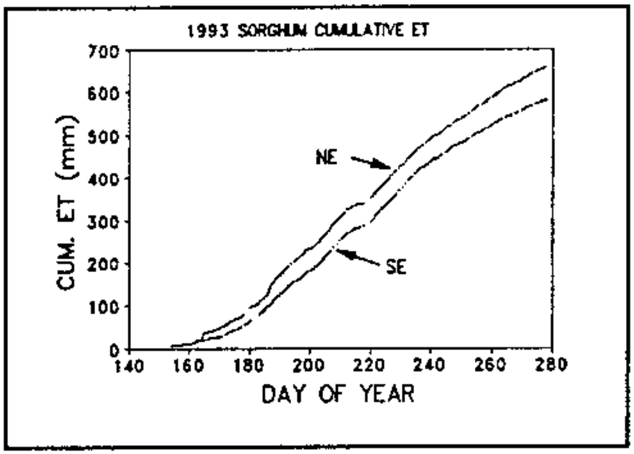


Figure 11. Cumulative evapotranspiration for NE and SE lysimeters.

Although irrigation and ET differences were large, plant growth on the north and south fields was remarkably similar. Plant heights throughout the season were virtually identical. Leaf area index (LAI) was higher on the south field, due to higher plant densities, until about DOY 240. Late in the season LAI for the south field was significantly lower than that in the north, indicating the effect of water deficit stress (Figure 12). Due to the higher plant densities on the south field the sorghum stalks were noticeably thinner there. This,

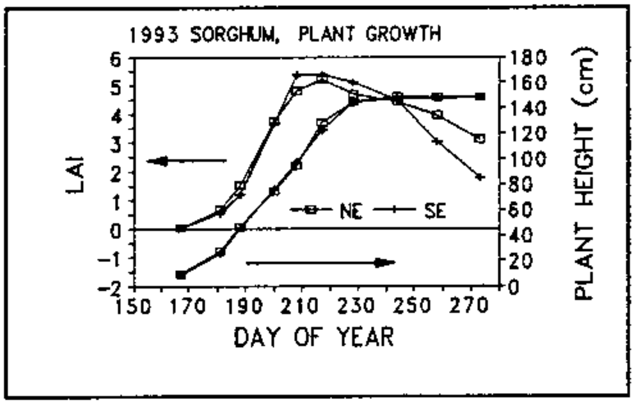


Figure 12. Plant height and LAI for NE and SE fields.

in addition to the plant stress from reduced irrigation, caused the south crop to be more susceptible to charcoal rot resulting in lodging as the crop matured. There was little lodging on the north field. Combine samples were taken by combining across the field from east to west end and weighing the resulting load. Five samples were taken from each field. Because of lodging the south field yielded 826 g m^{-2} compared to 868 g m^{-2} on the north (significant at 5% level). However, hand samples in the fields were not significantly different at 980 and 984 g m^{-2} on the south and north fields, respectively, even at the 10% level (mean of 3, 3 m^2 samples). Likewise the yields from the lysimeters were not significantly different, at 919 and 898 g m^{-2}, for the south and north, respectively (mean of 4 rows on 9 m^2 lysimeter).

SOIL WATER MEASUREMENT DEVICES

For some 40 years soil moisture gages based on neutron scattering have been a valuable tool for soil water investigations, including water balance measurements of evapotranspiration. However, in the US licensing, training and safety regulations pertaining to the radioactive source in these devices makes their use expensive and restrains use in some situations such as unattended monitoring. This is apparently also a problem for our Egyptian colleagues. An ideal replacement for neutron scattering gages would allow use in access tubes, would be non-nuclear (unregulated), capable of stand alone operation and provide measurement precision comparable to that of neutron scattering devices. A recently introduced moisture gage based on measurements of the capacitance of the soil - access tube system has many of the desired capabilities. The manufacturer states that the new gage is especially suited for sandy soils as are found at the research sites in Egypt. We measured the precision of two brands of neutron scattering gages and the capacitance gage in a field calibration exercise on a sandy loam soil to determine the relative measurement precision of these devices. Both brands of neutron scattering gages were calibrated vs. volummetric soil water content with coefficients of determination ranging from 0.98 to 0.99 and standard errors of estimate less than 0.01 $m^3\ m^{-3}$ water content (3 gages of each brand) (Figure 13). Calibrations for the four capacitance gages resulted in coefficients of determination ranging from 0.59 to 0.65 and standard errors of estimate of from 0.037 to 0.040 $m^3\ m^{-3}$ water content (Figure 14). Readings were highly reproducible among the capacitance gages but the measurements were not well correlated with volummetric soil water content, probably due to sensitivity to soil bulk density variations. We conclude that the neutron scattering type gages provide acceptable precision but that the low precision of the capacitance type gage makes it unacceptable for soil water content measurements under our conditions.

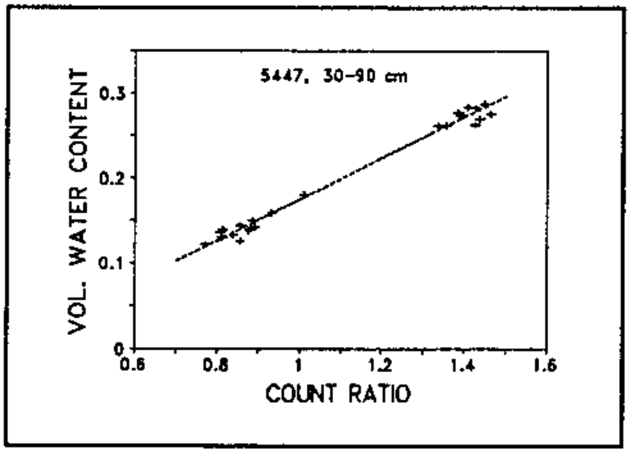


Figure 13. Typical volumetric water content vs. count ratio relationship in B horizon. Solid line is regression line.

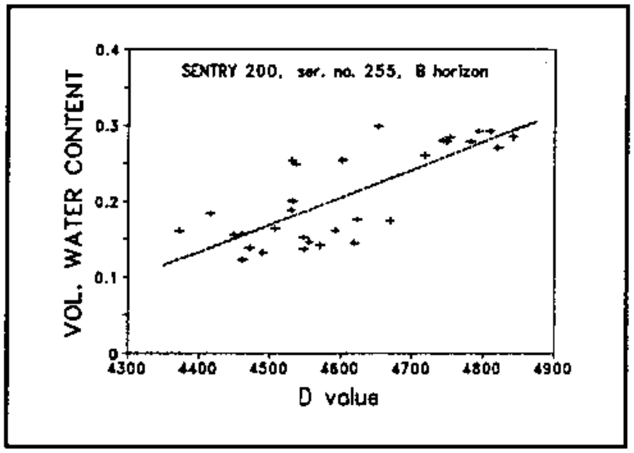


Figure 14. Typical relationship between volumetric water content and D value from SENTRY 200. Solid line is regression line.

ET MODELING

Evapotranspiration (ET) modeling has not progressed to the results stage at this point. Dr. Evett was hired on 1 October 1993, partly due to the hiring freeze imposed by USDA-ARS. Currently, weather data sets for the 1993 seasons have been compiled and organized along with soil physical property data. These data are essential to the Bushland modeling phase and will need to be coordinated with the Egyptian projects. The following outline presents our modeling approach, goals, and expected outcomes.

Goal:

Compare energy and water balances in the soil-plant-atmosphere continuum for different irrigation systems including surface and subsurface drip in order to explain and predict differences in evapotranspiration (ET) and water use efficiency.

Applications:

1. Better irrigation system design based on complex physical principles, i.e. investigation of emitter depth effect on water use for different soils.
2. Irrigation scheduling with and without crop coefficients.

Objectives:

1. Investigate emitter depth effect on partitioning of ET between evaporation from soil and transpiration. Use hydraulic properties representative of clay and sandy soils.
2. Investigate crop yield effects of differing transpiration amounts.
3. Examine use of physically based models for irrigation scheduling as a possible replacement for crop coefficient based models.

Types of models:

1. Mechanistic, physically based energy and water balance research model

(ENWATBAL)

2. Fast, more empirical plant growth, yield, ET model (CERES-Maize)
3. Irrigation scheduling software which is tailored for easy use (SCS-Scheduler ver. 3.00)

Input requirements:

1. ENWATBAL -

Weather:	Daily or half-hourly wind speed, solar radiation, dew point temperature, air temperature and precipitation. Surface roughness length, reference elevation for weather measurements.
Soils:	For each soil horizon: Tables of water content vs. potential; and, of hydraulic conductivity vs. potential over the range of zero to -30,000 m soil water potential. Limited to 9 horizons. For each soil layer: Horizon to which layer belongs, layer thickness, initial water content and temperature. Number of layers limited by computer memory. For entire profile: table of heat conductivity by vapor vs. soil temperature. For top soil horizon: table of soil albedo vs. water content over range of zero to saturation, ponded water detention depth (m).
Crop:	Daily LAI and depth of maximum rooting. Table of epidermal conductance vs. leaf water potential, table of epidermal conductance vs. solar radiation. Maximum crop water potential and specific hydraulic resistance of crop.

2. CERES-Maize -

Weather: Daily solar radiation, air temperature and precipitation.

Soils: For each soil layer: Layer thickness, lower limit of plant extractable water, drained upper limit, saturated water content, rooting weighting factor, initial soil water content. Limited to ten layers.

For top soil layer: soil albedo, stage 1 evaporation coefficient (mm), whole-profile drainage rate coefficient, runoff curve number.

Crop: Sowing date (DOY) and depth (m), population (plants m^{-2}), growing degree days (GDD) from seedling emergence to end of juvenile phase (°C), GDD from silking to maturity (°C), photoperiod sensitivity (h^{-1}), potential kernel number (kernels/plant), potential kernel growth rate (mg/(kernel d).

3. SCS-Scheduler -

Weather: Air temperature, relative humidity, solar radiation, wind speed and rainfall. May be downloaded over telephone from weather station.

Soils: Available water holding capacity and initial water content by layer.

Crop: Crop type (crop coefficient vs. GDD), emergence date, and growing season length.

Capabilities:

ENWATBAL -

Separates evaporation from soil surface and transpiration from plant on a physical basis. Can be modified to include source term in the soil water flux equations at any depth for simulation of buried drip irrigation. Because soil water flux is based on Darcy's law (physically based) and soil hydraulic characteristics, upward movement of water can be realistically simulated.

Ceres-Maize -

Can predict plant growth and yield. Much faster than ENWATBAL. Evaporation from soil and transpiration more empirically based. Soil water flux divided into saturated flow which is handled using a cascading bucket approach and unsaturated flow which is calculated by Darcy's law but does not allow soil hydraulic characteristics to be input.

SCS -

Uses modified Penman equation (Doorenbos and Pruitt) to calculate potential ET which is converted to actual ET using crop coefficients. Can provide irrigation amount needed for several different scenarios and scheduling criteria. Can use historical data and predictions of weather if real data are unavailable. Provides more accurate estimates if actual measurements of weather and soil water content are provided.

EGYPT DRIP EXPERIMENTS

Drip irrigation experiments were conducted at New Boustan (Noubaria) in Egypt in 1993 on corn and potato. The potato experiment is currently in progress. The soil at this site is a deep coarse sand with limited residual nutrients. Corn (Giza 103) was planted on 5 June in 0.80 m wide rows and harvested on 20 September. An Egyptian drip tube with in-line turbulent flow emitters called GR (these are similar to the Netafim old-style emitters) were used. Emitters were spaced at 0.5 m down the lateral and a lateral was placed at each row of corn. Both subsurface and surface drip lines were used. The nutrient requirements for the corn were supplied by chemical injection into the irrigation water. The water source was the River Nile. The irrigation treatments were T-80 20% less than the recommended corn irrigation requirement (785 mm; 3296 m^3 per feddan) or 628 mm, T-100 the full recommended amount of 785 mm, and T-120 20% more than the recommended amount or 942 mm. Yield data are shown below for the 1993 corn crop.

Table 5. CORN YIELD RESULTS FOR EGYPT STUDY AT NEW BOUSTAN (Noubaria) IN 1993.

TREATMENT		IRRIGATION AMOUNT mm	GRAIN YIELD $g\ m^{-2}$	BIOMASS YIELD $g\ m^{-2}$
SURFACE	T-80	628	1,000	1,198
SURFACE	T-100	785	890	1,110
SURFACE	T-120	942	529	790
SUBSURFACE	T-80	628	357	650
SUBSURFACE	T-100	785	474	855
SUBSURFACE	T-120	942	342	805

Note, these data were transmitted from our Egyptian colleagues and some values don't seem correct (or our intrepretation is incorrect). They reported the yields in tons/feddan as grain and biomass. A feddan was converted as 4,200 m^2 and a ton as 1 Mg. The biomass yield values were added to the grain yield to obtain the total biomass values shown in Table 5. The grain values seem reasonable to us, but the biomass values must be incorrect or we have miss computed them.

The subsurface lines had noticeable plugging from root intrusion that affected the yields substantially. Yields of corn were depressed by the excess irrigation treatment T-120. Daily irrigation amounts were determined by using the T-100 water requirement and dividing by the number of days in the season (100 days). The resulting application amounts were 6.3 mm/d to T-80, 7.9 mm/d to T-100, and 9.4 mm/d to T-120. The reason that the T-1 treatment seemed to perform so well is likely that this irrigation rate is more reflective of the actual crop needs of corn. Both the T-2 and T-3 treatments may be excessive. In 1994, variable irrigation rates to more closely match actual irrigation needs may be attempted if agreeable with our cooperators.

The corn plots looked very healthy when Drs. Stewart, Howell, and Schneider visited in September. The corn looked comparable to our plots in the U.S., except the corn in Egypt was much taller.

EGYPT AND BUSHLAND LYSIMETER DESIGN

Ismailia. The field sites at New Boustan in Noubaria in Egypt were small and bordered by trees. For this reason, an open field was selected at the SWRI research station at Ismailia for the weighing lysimeters and ET research. The new field is adjacent to existing SWRI sprinkler irrigation plots and not bordered by large trees. The field was subdivided into two square plots each 1 ha in size (about 2.5 feddans) for the lysimeters. The lysimeters were installed in the center of each field. The soil is a deep coarse sand, so the lysimeter could be repacked and a monolith would be of little value. The lysimeter area was selected as 2.0 m by 1.5 m to accommodate 0.75 m rows. The depth was limited to only 1.5 m since no water table or deep water extraction was expected. The lysimeters were designed with vacuum extractors to provide a similar lower boundary to that in the field. The lysimeters were patterned after several in use by the Department of Energy near Richland, WA. The scales were commercial 9.1 Mg (20,000 lbs.) load-beam platforms and should provide ET resolution between 0.05 mm to 0.10 mm. The lysimeters were designed at Bushland and built at Ismailia by the Arab Contractors company. This company also provided the construction and installation labor. The lysimeter scales and associated micro-meteorological sensors will be measured by a Campbell Scientific CR-7 data logger located in the field with the lysimeters and powered by a 12 Vdc battery and solar charger. A Campbell Scientific 012 weather station was located near by one lysimeter (in the alfalfa field) to measure hourly solar radiation, air temperature, relative humidity, wind speed, wind direction, and precipitation data all recorded automatically by a CR-10.

These two fields will contain alfalfa and corn in 1994. The alfalfa crop should remain in place for several years as data on reference ET is collected. The other lysimeter can be used for water requirement studies for various crops.

Bushland. A similar lysimeter was designed for Bushland to measure reference ET from irrigated grass. Alfalfa is not a major irrigated crop in the immediate area, and its cultivation and harvesting is difficult with the USDA-ARS farm equipment. Grass reference ET is also of interest to urban water users in this region. The Bushland grass ET lysimeter is 1.5 m by 1.5 m in surface area and 2.3 m deep. Since it will contain a Pullman clay loam soil, a monolith will be used. The scale and data logger will be identical to the ones used in Egypt. The lysimeter design is complete and construction contracts are pending. The field area adjacent to the Bushland ET weather station site was selected for this lysimeter location. The plot area has been laser leveled, and following installation the grass will be maintained like the weather station grass site. The Bushland lysimeter should be operational by late April in time for the corn irrigation season. The lysimeter layout is shown in Figure 14. Reference ET equations for grass ET will be tested with weather data from the adjacent weather station.

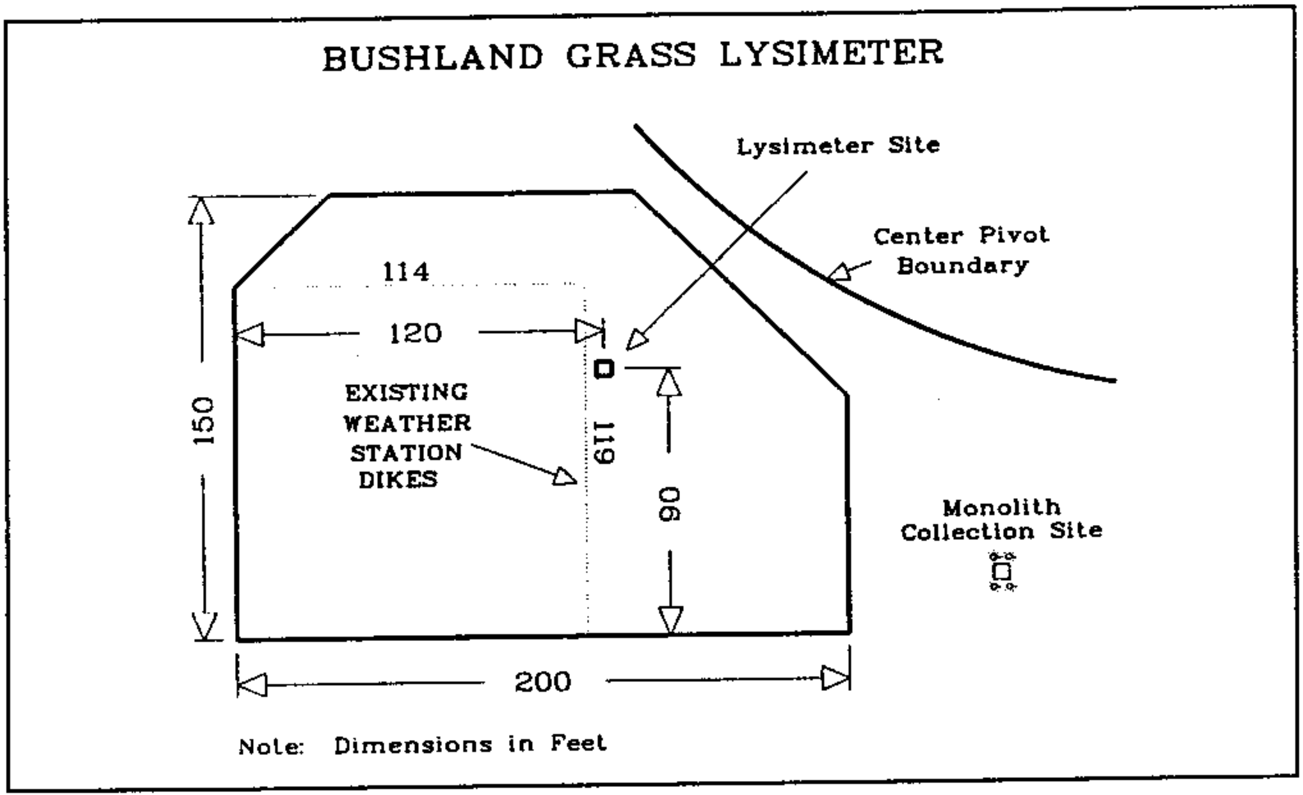


Figure 14. Bushland lysimeter field layout.

SUMMARY

Significant progress has been made on the project objectives. System installation at Bushland delayed 1993 corn planting, but the data and yields were very good. Good results have been obtained from the research in Egypt as well. The aspects of lysimeter construction and installation are certainly not trivial, and they take careful planning and execution for good results. Dr. Evett is planning to travel to Egypt in March to finish lysimeter calibrations and data acquisition system training. We expect several Egyptian colleagues to travel to the U.S. in late March of 1994 for training on lysimeter operation and joint data exchanges.

The project plans included the purchase of a neutron probe for the Egypt studies. The Egyptian scientists did not want to use the nuclear probe and suggested that we investigate the non-nuclear soil water probe marketed by Troxler in the U.S. A complete study was conducted with cooperation from USDA-SCS in Texas to evaluate the non-nuclear soil water meter on a sandy soil similar to those in Egypt. The results reported here were definitely not encouraging, and this avoided the needless purchase of the equipment. Other soil water measurement devices are being studied for application to the irrigation management in Egypt.

Both research teams (U.S. and Egypt) have learned much in this first year. We sincerely believe that the third year's funding is critical to completing this project as scheduled. ARS is excited about our cooperation with SWRI on this project and expect this to be the beginning of a long and close relationship. We certainly appreciate the support from NARP in Egypt and from USDA-OICD in Washington, DC.