SDI FOR CONSERVING WATER IN CORN PRODUCTION

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ABSTRACT

On-farm water savings of 20-25% can be obtained with subsurface drip irrigation (SDI) for corn production on the deep silt loam soils of the semi-arid Great Plains (United States) through a combination of reducing non-beneficial water balance components and better usage of precipitation. The conjunctive use of SDI with appropriate nitrogen fertigation strategies resulted in optimization of corn yield, nitrogen uptake and water use efficiency at an irrigation level of approximately 75% of normal. A field study indicated a differential response in corn yield and water use for SDI and low energy precision application (LEPA) sprinkler irrigation as affected by weather conditions. SDI had approximately 6% yield advantage (0.9 Mg/ha) over LEPA in three normal to wet years while reducing crop water use by 4% (30 mm). Conversely, LEPA had approximately 7% yield advantage (1.0 Mg/ha) over SDI in four extreme drought years but with increased crop water use of 4% (27 mm). More research is needed to explain the differential response of the two system types.

INTRODUCTION

Water conservation, irrigation efficiency, and water use efficiency have long been recognized as confusing terms with individuals often bringing their own experiences and perceptions into their own definitions (CAST, 1998; CAST 1996; Howell, 2001; Howell and Evett, 2005; and Lamm, 2002a). Howell and Evett (2005) correctly point out that difficulties can arise if incompatible temporal and spatial scales are used in statements about effective water use. For example, water savings from a reduction in deep percolation may be inconsequential if the temporal scale is large enough to allow return to the aquifer. Similarly, reduction of runoff is not a water savings on a large spatial scale when the runoff can be reused at a downstream location in the basin. The debate over the proper use of water conservation terms has and will continue to be the topic of many publications and presentations. Rather than go into this debate any further, discussion here will be limited to improvements in water usage at the farm level that can be obtained on a real-time basis. This temporal and spatial scale is highly relevant to the farmer in an economic sense, but is also relevant to society through stabilization of farm income and through its multiplying effect in the overall economy. Obtaining higher crop production with efficient use of production inputs has long been a road for profitability in American agriculture. A significant portion of this report will center on methods of reducing non-beneficial water balance components and also on improving water use efficiency. Water use efficiency will be defined here as the crop economic yield divided by the crop evapotranspiration. In the case of corn production, the grain is typically the economic yield, whereas for some horticultural crops, both the product and quality can contribute to the economic yield.

CONCEPTUAL DISCUSSION OF WATER CONSERVATION WITH SDI

In a thorough review of crop yield response to water, Howell et al. (1990) enumerated four methods of increasing water use efficiency: 1) increasing the harvest index (ratio of crop economic yield to total dry matter production); 2) reducing the transpiration ratio (ratio of transpiration to dry matter production); 3) reducing the root dry matter amount and/or the dry matter threshold required to initiate the first increment of economic yield; or 4) increasing the crop transpiration component relative to the other water balance components, for example, through reductions of evaporation, drainage, and runoff. Attempts to increase water use efficiency through irrigation systems and technologies and their associated management strategies almost exclusively use Method 4 (Howell, 2001). Potential advantages of SDI in terms of improvements in irrigation water use efficiency have been discussed by Lamm (2002b) and Phene (2002) and can be summarized into these broad categories:

- Reduction or elimination of non-beneficial water balance components
- Avoidance of unnecessary irrigation events
- Improved in-field uniformities and targeting of plant root zone
- Improved infiltration, storage, and use of precipitation
- Substitution of lower quality water for higher quality water
- Improved conjunctive use of water and agrochemicals
- Improved crop health, growth, yield, and quality

Reductions in non-beneficial water balance components depend on what type of irrigation system, SDI is being compared to. For the purposes of this discussion, the alternative system is center pivot sprinkler irrigation. In the semi-arid Great Plains region of the United States, the principal use of irrigation systems is to provide for crop transpiration, though additional important uses occur in some parts of the country (e.g., salinity management, frost protection, crop cooling). The primary non-beneficial components are deep percolation (P), evaporation (E), and runoff (R) or the "Big Three" losses as characterized by Howell and Evett (2005).

Percolation losses (P)

Deep percolation can be minimized on well managed center pivot sprinkler (CP) and SDI systems with most P losses in the Great Plains occurring in the spring and early summer before the irrigation season begins. The management exceptions would be cases where runoff and runon results in ponding in low areas of CP systems and in SDI applications that are not matched to rootzone/dripline depth and soil characteristics. SDI might also have a slight advantage in reducing P losses by applying smaller irrigation amounts in a more uniform and timely as-needed manner.

Evaporation losses (E)

There can be appreciable differences in evaporation losses between SDI and CP systems. The E losses under CP systems are droplet evaporation in the air, canopy losses which include canopy evaporation and interception storage, and finally soil and surface water evaporation losses resulting from irrigation. These losses can vary with duration of canopy wetting, sprinkler nozzle type, and the nozzle height with respect to the crop canopy. These E losses have been estimated to be 15%, 8% and 2% for impact nozzles on the truss, spray heads at truss rod height and LEPA nozzles near the ground, respectively, for a typical 25 mm irrigation event (Schneider and Howell, 1993). All of these E losses are eliminated or greatly reduced with SDI, provided the dripline depth, soil characteristics and irrigation management prevents migration of water to the soil surface. When surface wetting by the SDI system is not needed for germination or for salinity management, deeper systems can reduce soil evaporation and weed growth. Decreases in evaporation losses of 51 and 81 cm were predicted for 15 and 30 cm dripline depths, respectively, compared with DI in a field and modeling study for corn (Zea mays L.) on a Pullman clay loam soil in Texas (Evett et al., 1995). Evett et al., (2005) suggests that by eliminating surface wetting with SDI, crop evapotranspiration may be reduced by as much as 10% primarily through reductions early in the season before canopy closure.

Irrigation runoff (R)

Irrigation runoff from CP systems can be a problem when the wetted radius of the nozzle, application rate, cropping system, topography, and soil characteristics are not properly matched. It should be noted that some of techniques that decrease E losses with CP systems increase the potential for R losses. Buchleiter (1991) reported that LEPA on 1% sloping silt loam soils had no runoff while runoff exceeded 30% on a slope of 3%. LEPA systems must be carefully managed using the guiding principles outlined by Lyle (1992) to prevent R losses from grossly exceeding the E reductions LEPA provides. SDI systems do not typically experience irrigation runoff.

Effect of smaller irrigation events

Pressurized irrigation systems such as CP and SDI have a distinct advantage over surface irrigation systems (i.e., furrow, basin, border strip, corrugations, etc.) by minimizing or eliminating the use of the soil surface as a water transport medium. Removing this water transport phenomenon from soils with their inherent spatial variability can result in greater application uniformity and also allow smaller irrigation events. SDI systems can use smaller irrigation events than are typically used on CP systems. Some of the evaporation losses on CP systems, such as interception storage on a corn plant, are closer to being a fixed amount rather than a percentage of total application. Thus, a corn interception storage loss of 2 mm (Lamm, 2003a) is more acceptable on a smaller number of irrigation events with larger amounts than for smaller more frequent irrigation events. Smaller irrigation events that are possible with SDI allow for the avoidance of irrigation events by scheduling closer to the time of actual crop water needs. This can be of particular benefit in day-to-day irrigation management and micromanagement decisions (e.g. initiation and termination of irrigation season. See also Lamm et al., 1996). For example compare the decision of conducting an additional SDI event of 6 mm as needed at season's end to typical sprinkler or furrow irrigation events of 25 and 100 mm, respectively.

Improved uniformity and targeting of crop rootzone

In theory, it seems reasonable to assume that SDI could have higher in-field uniformities than CP and surface irrigation systems. The reasons include the sheer number of points of water dispersal in the field and many of the earlier discussion issues, such as reduced percolation, evaporation, and runoff losses along with the complete removal of the soil surface as a water transport mechanism. Of course, this higher potential in-field uniformity is only possible with a properly designed and maintained system. Ayars et al. (1999) reported UC higher than 95 for SDI after 9 years of use provided that clogging and root intrusion were kept under control with acid water treatment. In another study, system uniformity was determined for both surface drip (DI) and SDI driplines used for 8 years in South Carolina (Camp et al., 1997). System uniformity was greatly reduced for SDI primarily because of the presence of a few completely clogged emitters in the three tubes that were examined. Clogging was attributed to entry of soil particles into the system during construction and/or repair operations. This emphasizes the importance of careful installation and maintenance of SDI systems. There is no direct mathematical relationship between uniformity and irrigation efficiency but it is very difficult to achieve a high efficiency if in-field uniformity is low (Hanson, 1995). SDI also targets irrigation application to the crop root zone rather than totally relying on soil water redistribution forces that CP and surface irrigation systems must use. Results of Ben-Asher and Phene (1993), and Phene & Phene (1987) indicate that for a given irrigation amount the wetted volume is approximately 46% larger for the SDI system than for a DI system on a of a wetted clay loam soil and the wetted radius is also shorter in the SDI system. Consistent and steady delivery of water and nutrients to the center of the rootzone is considered to be one of the principle advantages that SDI has over other irrigation systems (Bar-Yosef, 1999). The ability to deliver phosphorus, which is relatively immobile compared to nitrogen, is considered of especial benefit.

Improve infiltration, storage and use of precipitation

There are opportunities in some regions and climates to make better use of precipitation with SDI. Drier soil surfaces allow greater infiltration of higher intensity rainfall events and thus reduce irrigation requirements. Similarly, there is evidence that SDI may be better able to "mine" the soil water during the growing season without yield reduction. The soil water "mining" aspect will be discussed later in this report. Drier soil profiles at harvest allow greater opportunities to store precipitation during the dormant season (Lamm and Rogers, 1985). The improved storage and use of in-season precipitation may be very dependent on the frequency and intensity of rainfall events. The usefulness of small infrequent events in semi-arid regions may be diminished because of less root proliferation in the drier soil layers above the dripline (Lascano, 2005). More research is needed to describe the partitioning of rainfall and SDI into the overall crop water balance.

Improved use of degraded waters

SDI can utilize degraded water in some circumstances which can save higher quality waters for other uses (Trooien et al., 2002). Wastewater is a significant source of irrigation water in the Middle East and is projected to be 36% of the total agricultural water supply in Israel by 2010 (Shelef and Azov, 1996). Smaller and more frequent irrigation applications with SDI can maintain a more consistent and lower soil matric potential helping to reduce salinity hazards. Subsurface wastewater application can reduce pathogen drift and reduce human and animal contact with such waters.

Improved conjunctive use of water and agrochemicals

SDI provides excellent opportunities for conjunctive management of water and agrochemicals which primarily affect water use efficiency through increasing crop yield. Precise and timely application of fertilizer and pesticides through the SDI system can result in greater efficacy and, in some cases, reduction in their use (Nakayama and Bucks, 1986). This topic will be discussed in more detail for corn (Zea mays L.) production later in this report.

Improved crop health, growth, yield, and quality

In a review of SDI research, Camp (1998) found that yields for crops grown with SDI were equal to or greater than yields from other methods of irrigation. He also found that the water requirement for SDI systems was generally similar to or slightly less than for any efficient, well-managed irrigation systems. Some researchers reported irrigation water requirements as much as 40% less than for other irrigation methods. Crop diseases and pest infestations can be lower using SDI and associated technologies in some crops such as cantaloupe (C. melo). Similarly, weed infestations can be lowered in alfalfa (Medicago sativa) and almond (Prunus dulcis) production by keeping the soil surface drier (Lamm, 2002b).

Overall improvements in water conservation with SDI

In a given setting some or possibly all of these water conservation aspects may express themselves. However, in cases where an individual aspect can be quantified with some degree of accuracy, it is wrong to assume that all the aspects combine through direct addition into a cumulative total water savings and/or crop yield improvement. Many of the water conservation aspects are either directly or indirectly related and it is likely some interactions will occur. For example, an improvement in field uniformity could actually increase overall transpiration as more plants would be experiencing a consistent and desired soil water condition. However, as stated earlier, increasing crop transpiration is a primary purpose of irrigation systems. Crop yields are positively related to transpiration. On-farm economics often dictate that higher crop yields must be obtained to maintain economic viability.

RESEARCH RESULTS WITH CORN

A number of SDI research studies with field corn (Zea mays L.) have been conducted at Kansas State University since 1989. The brief nature of this report will not allow a thorough listing of all the methods and materials used in the research studies. A summary of several of these studies up until through the year 1999 was provided by Lamm and Trooien, 2003a. Further updates were provided by Lamm (2003b). The research studies discussed here were conducted at the Kansas State University Northwest Research-Extension Center at Colby, Kansas, USA during the period, 1989 to 2004. The deep silt loam soil can supply about 445 mm of available soil water for a 2.4 m soil profile. The climate can be described as semi-arid with a summer precipitation pattern and with a long term average annual rainfall of approximately 480 mm. Average precipitation is approximately 300 mm during the 120-day corn growing season. Irrigation was scheduled only according to need as determined from a corn water budget using an alfalfa-based Penman equation (Lamm et al., 1987) for reference evapotranspiration (ETr). Empirical crop coefficients suitable for local conditions were used to modify ETr to the actual crop water use, ETc. The range of limited irrigation treatments was provided by either only replacing a fraction of calculated ETc in the irrigation schedule (e.g., 0.00 0.25, 0.50, 0.75, 1.00 or 1.25 ETc) or by limiting the irrigation capacity to a fixed value (e.g., 0.0, 2.5, 3.3, 4.3, 5.1, 6.4 mm/d). In some of the comparisons to be discussed, the irrigation levels are converted to the fraction of full irrigation. This allows for several studies to be compared simultaneously across the years. Full irrigation in these cases was considered to be a ETc replacement value of 100% and an irrigation capacity of 6.4 mm/d. Similarly, corn grain yield and water use efficiency (WUE were also sometimes normalized to their maximum observed value for the given year to allow simultaneous comparisons across studies and years.

General effect of irrigation level on corn yields and water use efficiency

The results from four studies conducted from 1989 through 2004 were combined to examine the general effect of SDI amounts on corn yield and water use efficiency. Relative corn yield reached a plateau region at about 80% of full irrigation and continued to remain at that level to about 130% of full irrigation (Fig.1). Yield variation as calculated from the regression equation for this plateau region is less than 5% and would not be considered significantly different. These results are similar to earlier conclusions drawn for one of included studies (SDI Water Requirement Study, 1989-1991) where Lamm et al., (1995) indicated water savings of approximately 25% were possible with SDI by reducing non-beneficial water balance components. The similarity of results for all four studies is encouraging because the later studies included the effect of the four extreme drought years of 2000 through 2003.

An examination of water use efficiency for the same four studies indicates that water use efficiency plateaus for levels of full irrigation ranging from 61% to 109% with less than 5% variation in WUE (Fig. 2). The highest WUE occurs at an irrigation level of approximately 82% of full irrigation. This value agrees with results summarized by Howell, (2001) for multiple types of irrigation systems. The highest WUE (82% of full irrigation) also occurred in the plateau region of highest corn yield (80 to 130% of full irrigation). This suggests that both water- and economically-efficient production can be obtained with SDI levels of approximately 80% of full irrigation across a wide range of weather conditions on these soils in this region. Some of the stability in corn yield and water use efficiency across this range of irrigation levels may be explained by how deep percolation is managed and by how soil water is “mined” with SDI on this soil type and in this climatic region. These aspects are discussed in the next two sections.

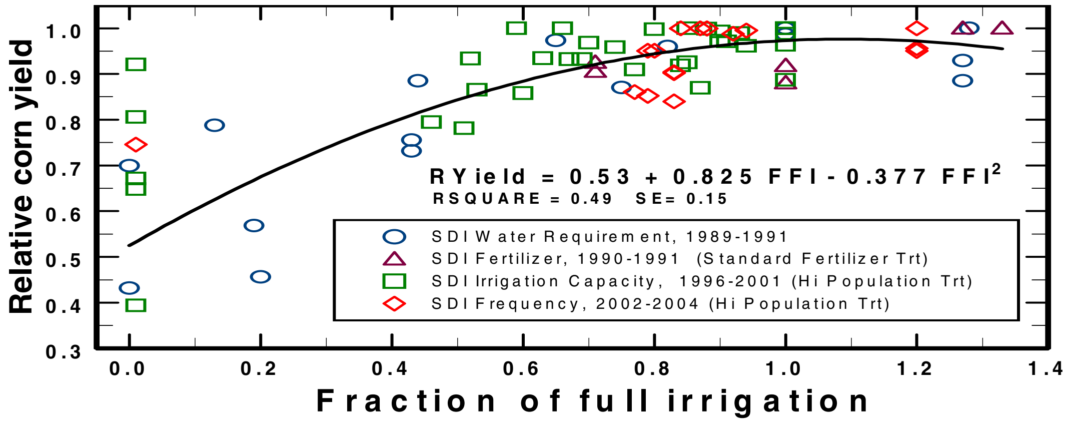

Figure 1. Relative corn grain yield for a given SDI research study and year as related to the fraction of full irrigation, KSU Northwest Research-Extension Center, Colby, Kansas.

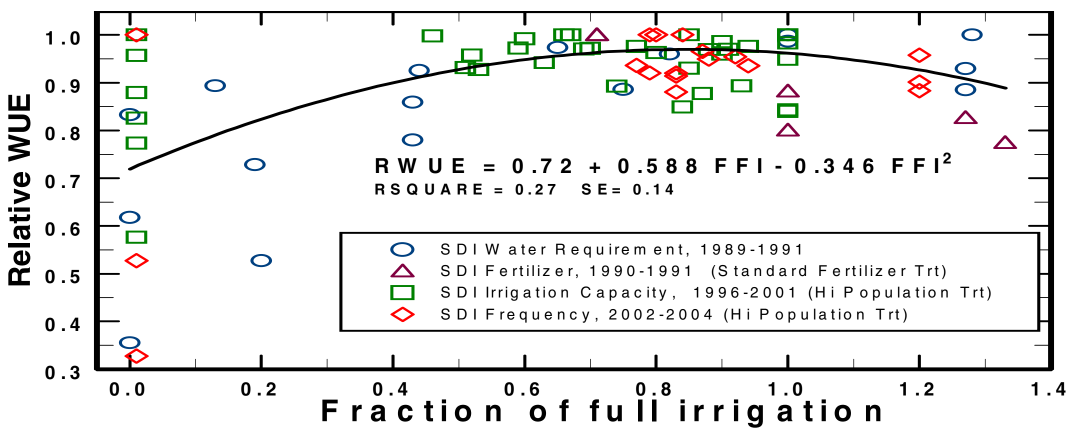

Figure 2. Relative water use efficiency of corn for a given SDI research study and year as related to the fraction of full irrigation, KSU Northwest Research-Extension Center, Colby, Kansas.

Minimization of deep percolation with SDI

Deep percolation can occur with SDI if design and management considerations such as soil characteristics, dripline spacing, dripline depth, and irrigation levels are not taken into account in operational strategies (Darusman et al., 1997 a and b; Lamm and Trooien, 2003b; and Lamm et. al., 2003). However, with proper management deep percolation can be minimized with SDI. Appreciable reductions in deep percolation (7% of full irrigation amount) were obtained by Lamm et al., (1995) when the corn irrigation level was reduced to approximately 74% of full irrigation with SDI without affecting actual corn water use (Fig. 3).

Mining of soil water with SDI

The examination of soil water profiles under SDI shows some distinctive grouping of adequately and inadequately irrigated treatments (Fig. 4) in a SDI capacity study for corn production.

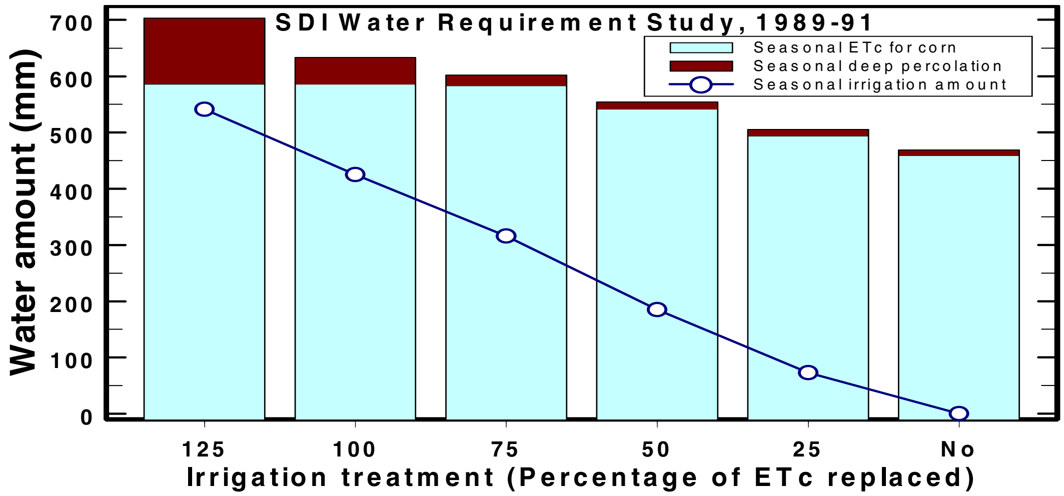

Figure 3. Cumulative calculated evapotranspiration and seasonal deep percolation as related to irrigation amount in an SDI water requirement study, KSU Northwest Research-Extension Center, Colby, Kansas. Data from Lamm et al., 1995).

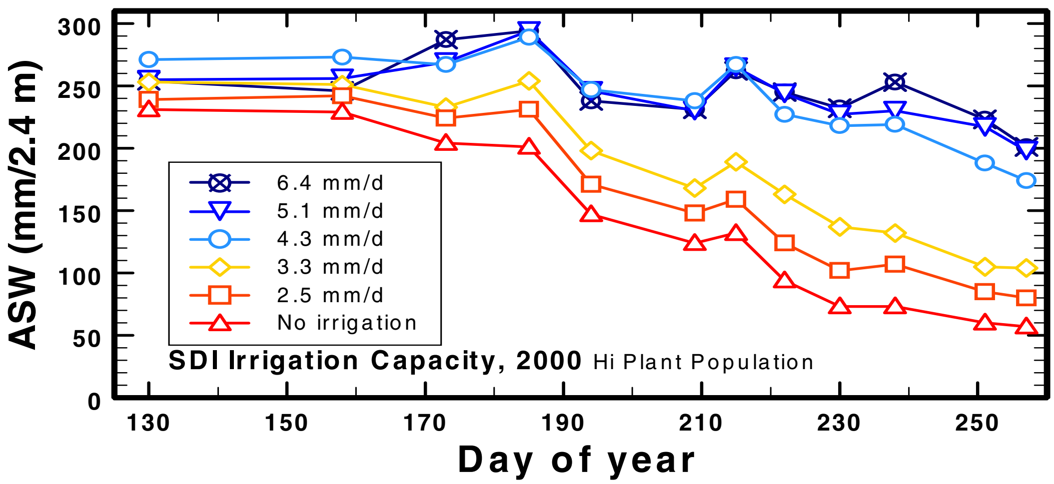

Figure 4. Progression of the available soil water in a 2.4 m soil profile as affected by daily SDI capacity for the highest corn plant population in an SDI capacity study, 2000, KSU Northwest Research-Extension Center, Colby, Kansas. (Data from Lamm and Trooien, 2002).

There is some possible rationale to explain the grouping (Fig.4). The upper three treatments may group together because the range of 4.3 to 6.4 mm/d is sufficient to provide a large enough portion of the daily crop water needs. Even in the drier years, there are a few opportunities to shut off irrigation for the 5.1 and 6.4 mm/d treatments when the irrigation deficit is low. This would allow these treatments to be closer to the effective value of 4.3 mm/d. The 6.4 mm/d irrigation capacity is approximately the long term full irrigation requirement for corn in northwest Kansas using other irrigation methods. The higher efficiency, daily irrigation may allow the SDI to be more effective than other irrigation methods. The lower three treatments may group together for almost the opposite reason. Available soil water reserves become depleted to a large extent and the corn crop begins to shut down plant processes that use water. This shutting down tends to reduce grain yields depending on the severity and length of the water stress period. The fact that the 2.5 and 3.3 mm/d treatments obtain respectable corn yield increases over the nonirrigated control may be a good indication of how well this balancing of water use/water conservation is being handled by the daily infusion of at least some irrigation water. The grouping of the upper three treatments suggests that an irrigation capacity of 4.3 mm/d might be an adequate irrigation capacity if the producer has the desire to allocate water to an optimum land area. Somewhat similar grouping of treatments was observed in all five years (1997-2001) of this study (Lamm and Trooien, 2001) and also in three years of study where irrigation replacement was based on a fraction of ETc (Lamm et al., 1995).

BMP for combined SDI and fertigation of corn

A four-year field study was used to develop a Best Management Practice (BMP) for nitrogen (N) fertigation for corn using subsurface drip irrigation (SDI) with irrigation scheduled to replace approximately 75% of ETc. Corn yield, nitrogen uptake by the crop, and WUE all plateaued at the same level of total applied N that corresponded to the 180-kg/ha N fertigation rate (Fig. 5) Average yield for the 180 kg/ha N fertigation rate was 13.4 Mg/ha. Results emphasize that high -yielding corn production also can be efficient in nutrient and water use.

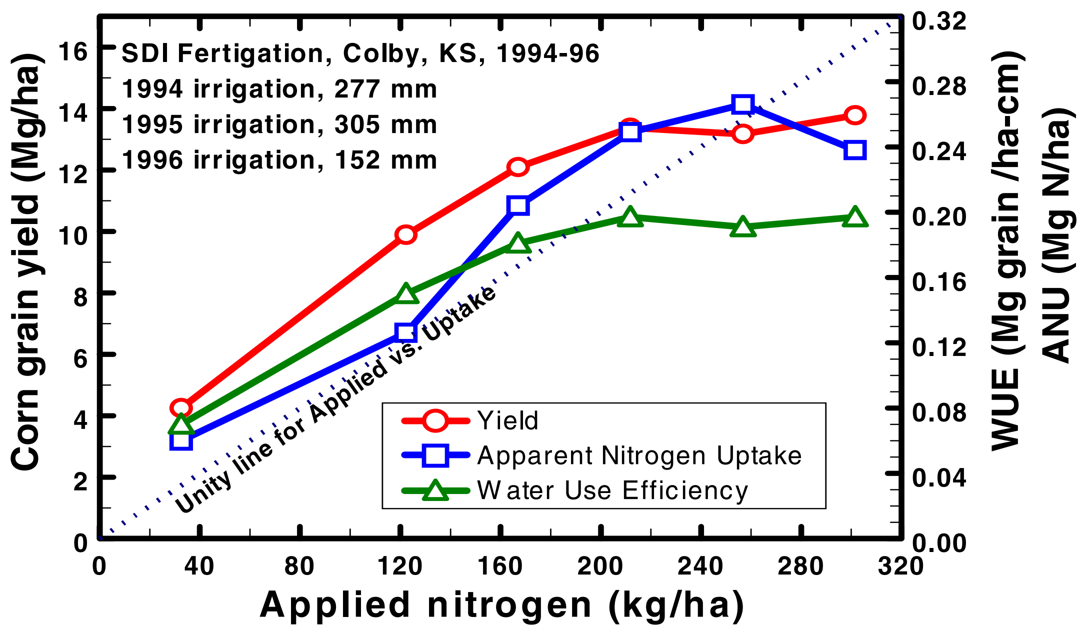

Figure 5. Average (1994-1996) corn yield, apparent nitrogen uptake in the above ground biomass and water use efficiency as related to the total applied N (preseason amount, starter fertilizer, fertigation and naturally occurring N in the irrigation water). Total applied N exceeded the fertigation applied N by 35 kg/ha. KSU Northwest Research-Extension Center, Colby, Kansas. (After Lamm et al, 2004).

Comparison of SDI and simulated LEPA sprinkler irrigation for corn production

A seven-year field study (1998-2004) was conducted to compare simulated low energy precision application (LEPA) sprinkler irrigation to subsurface drip irrigation (SDI) for field corn production. Averaged over the seven-year period there was very little difference in corn grain yields between system type (14.8 and 14.6 Mg/ha for LEPA and SDI, respectively) across all comparable irrigation capacities. However, LEPA had higher grain yields for 4 extreme drought years (approximately 1 Mg/ha) and SDI had higher yields in 3 normal to wetter years (approximately 0.9 Mg/ha).

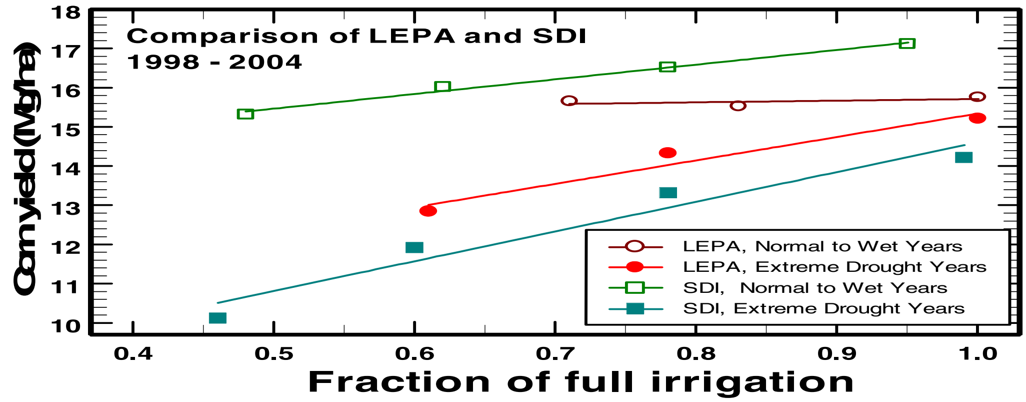

Figure 6. Corn grain yield as affected by weather conditions and irrigation level for SDI and LEPA sprinkler irrigation, KSU Northwest Research-Extension Center, Colby, Kansas. (Data from Lamm, 2004).

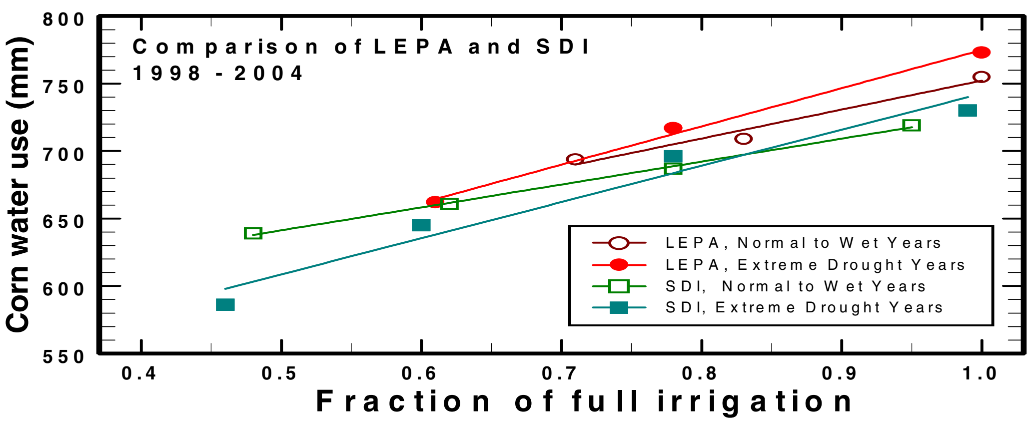

Figure 7. Cumulative corn water use as affected by weather conditions and irrigation level for SDI and LEPA sprinkler irrigation, KSU Northwest Research-Extension Center, Colby, Kansas. (Data from Lamm, 2004).

Higher LEPA yields were associated with higher kernels/ear as compared to SDI (534 vs. 493 kernels/ear in dry years). Higher SDI yields were associated with higher kernel weight at harvest as compared to LEPA (34.7 vs. 33.2 grams/100 kernels in normal to wetter years). Seasonal water use was approximately 4% higher with LEPA than SDI and was associated with the period from anthesis to physiological maturity. More research is needed to discover the causes in the shifting of yield components between the two systems.

ACKNOWLEDGEMENTS

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