SUBSURFACE DRIP IRRIGATION AND POSSIBILITIES IN ALFALFA

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SUMMARY

Alfalfa has crop water needs greater than most crops and, thus, can benefit from very efficient irrigation systems such as subsurface drip irrigation (SDI). Yield and quality can be improved when using SDI as compared to alternative irrigation systems. Rodent control continues to be a challenge with SDI systems for alfalfa. On some soils with some SDI designs, irrigation with SDI may need to be reduced during the harvest interval to avoid wet spots and compaction by heavy harvesting equipment. Results from a field study at Kansas State University indicates that yields were not greatly affected by irrigation levels ranging from replacement of 70 to 100% of crop evapotranspiration minus precipitation, and that improvements in alfalfa quality partially compensates for lower yields when deficit irrigated. In the Central Great Plains region, an SDI regime of 85% ET minus precipitation appears reasonable on deep silt loam soils.

POTENTIAL ADVANTAGES OF SDI FOR ALFALFA

Increased Yield, Increased Water Productivity, and Reduced Irrigation Requirements

Alfalfa (Medicago sativa L.), a forage crop, has relatively large crop water needs and, thus, highly efficient irrigation systems such as subsurface drip irrigation (SDI) might substantially reduce total irrigation water demand. In some regions, the water allocation for irrigation is limited by hydrogeological or institutional constraints, so SDI can effectively increase alfalfa production by increasing the crop transpiration while reducing or eliminating irrigation runoff, deep percolation and soil water evaporation. Annual alfalfa dry matter yields are typically linearly related to crop evapotranspiration (ET), and within season yields often decrease with successive harvests as the crop experiences more stressful drier and hotter climatic conditions (Bauder et al., 1978; Metochis, 1980; Grimes et al., 1992; Saeed and El-Nadi 1997). Since alfalfa is such a large water user and has a very long growing season, irrigation labor requirements can be reduced with SDI relative to less efficient alternative irrigation systems that would require more irrigation and thus more irrigation events (Hengeller, 1995).

A major advantage of SDI on alfalfa is the ability to continue irrigating immediately prior, during and immediately after the multiple seasonal harvests. Continuation of irrigation reduces the amount of water stress on the alfalfa and thus can increase forage production which is generally linearly related to transpiration. Transpiration on SDI plots that did not require cessation of irrigation was 36% higher during this period than plots where irrigation was stopped for the normal harvest interval (Hutmacher et al., 1992). Yields with SDI were approximately 22% higher than surface flood-irrigated fields while still reducing irrigation amounts by approximately 6%. In a later summary of this same research study, Ayars et al. (1999) indicated water productivity (WP), the alfalfa yield divided by the crop water use, was increased mainly

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due to increased yield, not due to less crop water use. When irrigation can continue, less physiological stress on the crown of the plants occurs, and weed competition can be reduced.

Avoidance of Ponding and Foliar Leaf Damage with SDI

Alfalfa can be very sensitive to foliar leaf burn from sprinkler irrigation of low-quality water. Yields can also be reduced by temporary ponding of irrigation water on the soil surface during periods of hot weather. SDI can avoid both of these issues entirely (Hengeller, 1995).

Improved Weed Control

In drier regions, annual weed competition can also be reduced with SDI compared to surface and sprinkler irrigation since the soil surface is not wetted by irrigation. The weed control advantage is difficult to quantify in alfalfa but has been noted by numerous investigators (Bui and Osgood, 1990; Hengeller, 1995; Alam et al., 2002b). Fewer weeds can result in better quality hay which then can receive a premium price in some regions.

CHALLENGES FOR SDI WHEN GROWING ALFALFA

Rodent Control and Dripline Depth

Burrowing mammals, principally of the rodent family, can cause extensive leaks in alfalfa fields when using SDI. Most rodents avoid digging into wet soil, so dripline leaks presumably are not caused by the animals looking for water. Rather, rodents must gnaw on hard materials, such as plastic, to wear down their continuously growing teeth. The difficulty in determining the actual location of a dripline leak caused by rodents is compounded by the fact that the leaking water may follow the burrow path for a considerable distance before surfacing. Anecdotal reports from the U. S. Great Plains can be used to describe some of the typical habitat scenarios that tend to increase rodent problems. These scenarios include the close proximity of permanent pastures and alfalfa fields, railroad and highway easements, irrigation canals, sandy soils, crop and grain residues during an extended winter dormant period, or absence of tillage. Some growers have tried deep subsoiling and/or applying poison bait around the SDI system field perimeters as a means of reducing rodent subsurface entry into the field. Caustic, odoriferous, pungent, and unpalatable chemical materials have been applied through SDI systems in attempts to reduce rodent damage, but most of these trials have not obtained adequate control. Periodic wetting of the soil during the dormant period has been suggested as a possible means of reducing rodent damage. Deeper SDI depths (18 inches or greater) may avoid some rodent damage (Van der Gulik, 1999). Many of the burrowing mammals of concern in the United States have a typical depth range of activity that is less than 18 inches (Cline et. al. 1982). Since alfalfa is a deep-rooted crop, deeper installation of driplines may be beneficial in reducing damage as we have observed anecdotally in our studies at Kansas State University where we installed driplines at a 20 inch depth. However, on the negative side, deeper driplines require more labor to make the repair when a leak does occur. Industry is experimenting with products that may help with the rodent management issue.

Soil Wetting Problems

On some soils with some SDI designs, irrigation with SDI may need to be reduced during the harvest interval to avoid wet spots and compaction by heavy harvesting equipment. Possible solutions to these problems might be deeper SDI installations or closer dripline and emitter spacings, thus resulting in more uniform water distribution (McGill, 1993; Hengeller, 1995).

The choice of emitter discharge rate must also account for the soil hydraulic properties in order to avoid backpressure on the emitters and surfacing of water. Surfacing is an SDI phenomenon in which excessive emitter flowrate, coupled with insufficient soil water redistribution, creates or uses an existing preferential flow path to allow free water to reach the soil surface. Surfacing can be a significant problem on some soil types and is particularly troublesome when it occurs in alfalfa fields resulting in wet spots at harvest (Hutmacher et al., 1992; McGill, 1993). Surfacing can sometimes be avoided with deeply-placed driplines, but this is only an acceptable solution when the mismatch of emitter flowrate and soil properties is small and the added soil depth provides a larger soil volume for water redistribution. This "surfacing" phenomenon also may be directly associated with a "chimney effect" in which small, fine soil particles are carried to the surface in the preferential flow path or macropore. The sorting of soil particles and deposition into the walls of the chimney will further reinforce the preferential flow path and surfacing may become worse. The chimney can be disrupted by tillage, but will often reappear because the flow channel still exists in the region around the emitter which was undisturbed by tillage. The surfacing and chimney effects are somewhat analogous to volcanic activity (Zimmer et al., 1988), and the point where free water exits the soil has even been called a caldera (Fig. 1).

Figure 1. Caldera resulting from surfacing of water from an SDI emitter in California. Photo courtesy of F. R. Lamm, Kansas State University.

Appropriate Dripline Spacings

On some soils under good irrigation management, it may be possible to use relatively wide dripline spacing for alfalfa because of its extensive and deep root system. In arid California on a silty clay loam, yields from driplines spaced at 6.6 ft were nearly equal to that obtained by a narrower, 3.3 ft spacing after the first year of operation (Ayars et al., 1999). Alfalfa yield for the wider spacing was reduced approximately 17% during the first year of that study when the root system was not well established. In semi-arid Kansas on a sandy loam soil, yields were 18% lower for 5 ft spacing as compared to the narrower 3.3 ft spacing for the second and third years of production (Alam et al., 2002b). It was concluded in this study that it was more economical to use the 3.3 ft spacing. However, it is possible that irrigation applications with SDI on this soil type were too marginal to allow the alfalfa to fully develop under the wider 5 ft spacing. Irrigation applications were only approximately 50% of the average reference evapotranspiration due to study constraints imposed on this producer-owned field. In Mexico, subsurface dripline spacings of 2.6 and 3.3 ft were compared under three irrigation regimes (100, 80 and 60% of ET replacement) in a two year study (Avila, et al., 2003). Annual alfalfa forage yields for the 3.3 ft dripline spacing were 94, 97 and 92% of those obtained with the 2.6 ft dripline spacing for the

100, 80 and 60% ET irrigation regimes, respectively. They also found irrigation amounts were reduced 15 to 49% and yields were increased 14 to 25% when comparing SDI to surface gravity irrigation. They recommended a dripline spacing of 3.3 ft with irrigation regime scheduled to replace 80% of ET.

ALFALFA STUDY WITH SDI AT KSU-NWREC, 2005-2007

Brief Discussion of Methodology and Procedures

This experiment was conducted at the Kansas State University Northwest Research-Extension Center at Colby, Kansas, USA, during the period 2005 through 2007. The deep silt loam soil can supply about 17.5 inches of plant available soil water from an 8-ft. soil profile. The climate can be described as semi-arid with a summer precipitation pattern and a long term average annual rainfall of approximately 19 inches. Average precipitation is approximately 15.75 inches during April through October, the typical alfalfa active-growing period. The latitude is 39.39 degrees north and the longitude is 101.07 degrees west with an elevation of 3159 ft above sea level. The study area was planted in the fall of 2003 and interseeded again in the spring of 2004 to help establish a sufficient stand. Although the crop was harvested 3 times during the summer of 2004, no research data was collected until the summer of 2005.

The subsurface drip irrigation (SDI) system was installed in the fall of 2003 before planting of the alfalfa. Low-flow (0.16 gal/h-emitter) dripline with a 12-inch emitter spacing and 0.875 inch inside diameter (Roberts Ro-Drip XL 12-15) was installed with a 5 ft dripline spacing using a shank-type injector at a depth of 20 inches. There were six driplines in each plot running from east to west for a length of approximately 80 ft. Each plot was instrumented with a municipal-type flowmeter to record accumulated flow. The water source for the study was fresh groundwater pumped from the Ogallala aquifer.

No fertilizer was applied to the field site during the course of the study, but small amounts of nitrogen and sulfur were applied through the dripline in the form of Urea-Sulfuric Acid (N-pHuric 15/49, 15% nitrogen and 49% sulfuric acid by weight). The Urea-Sulfuric Acid was injected annually in the late fall at an approximate rate of 3.75 gal/a to help maintain emitter performance and to help prevent alfalfa root intrusion. The amounts of N and S provided annually in this maintenance treatment were approximately 7 lbs/a and 7.5 lbs/a, respectively. Sodium hypochlorite (7.5% concentration) was also applied as a dripline maintenance treatment twice a year (early spring and late fall) at an approximate rate of 2.5 gal/a.

Five harvests occurred each year with the first harvest occurring near the end of May, approximately 54 days from the beginning of spring green-up which typically began around April 1. Typically harvests occurred approximately every 28 to 30 days with the exception of the last harvest which was delayed until a killing frost occurred. This delayed harvest allowed the crop to store up reserves in the root zone to limit winter kill. During each harvest, plot samples were obtained from each replicated treatment plot at three horizontal distances from the dripline (0, 15 and 30 inches) to examine the effect of the 5 ft dripline spacing on alfalfa yield. Harvested wet forage yields were corrected to dry matter yield for each horizontal distance from the dripline. A composite plot yield was also calculated.

The summer irrigation treatments were three levels of irrigation (replicated three times in a randomized complete block design) that were designed to apply 100, 85 or 70% of the calculated evapotranspiration that was not replaced by precipitation. In the late fall of each year following the dormancy of the alfalfa top growth, an irrigation amount of 5 inches was applied with the SDI system. This large irrigation event was conducted to reduce the chance for root intrusion and/or rodent damage during the long overwinter period. This large irrigation amount would affect the year-to-year sustainability of the alfalfa under the more deficit-irrigated treatments, but should not greatly affect the in-season differential responses of the various irrigation treatments.

Volumetric soil water content was measured weekly or biweekly with a neutron attenuation moisture meter in 12-inch increments to a depth of 10 ft at a distance of 30 inches horizontally from the dripline. Crop water use was calculated as the sum of soil water depletion between the initial and final soil water measurements, and precipitation and irrigation between the initial and final soil water measurements. Calculating crop water use in this manner would inadvertently include any deep percolation and rainfall runoff and is sometimes termed as the field water supply. Water productivity (WP) was calculated as dry matter alfalfa yield divided by the total crop water use.

Results and Discussion

Weather conditions during the three years of the study were generally favorable for alfalfa production. There was very little difference in seasonal calculated ETc for the three years of the study, but a difference of nearly 5 inches occurred in seasonal precipitation between the wettest year (2005) and the driest year (2006). Irrigation requirements were somewhat similar among the three years, with the seasonal amount for the fully irrigated treatment being 22.6, 25.0 and 21.7 inches for 2005, 2006 and 2007, respectively. Overall, the years provided a relatively good variety of seasonal weather conditions and the varying conditions were typical of the Central Great Plains.

Alfalfa yields were excellent compared to regional norms (Rogers, 2012) of approximately 6.5 tons/a for all 3 years (Table 1 and Figure 2). There were no statistically significant differences in dry matter yields attributable to irrigation level, but yields differed by year with the greatest dry matter yield the first year of the study in 2005 and the smallest yield in 2006. Yields for the second harvest in 2006 were reduced by a hail storm on June 16, and an early final harvest on September 13 contributed further to lower total 2006 yield. The first-harvest yields in 2007 may have been suppressed by a hard freeze on April 12 with a temperature of 20°F. The average dry matter yields from this study were approximately 10% greater than those reported by Alam et al. (2002a) for alfalfa grown on a sandy loam in southwest Kansas. The annual yields also compare well with the maximum yields from several western U.S. states summarized by Grismer (2001) which ranged from approximately 7.5 to 9.8 tons/a.

The lack of significant differences in total seasonal alfalfa dry matter yield as affected by irrigation level is probably related to the extensive root system of the alfalfa being able to sufficiently and effectively mine the plant available soil water from the deep silt loam soil without experiencing severe water stress. Although available soil water decreased throughout the season and more so as the irrigation level became more deficit (data not shown), the decreasing late summer crop growth and less crop water use during the latter part of the season (fall) would tend to buffer yield differences between the treatments. Plant available soil water started each year at a relatively high level because of overwinter precipitation and because of the 5 inches of late fall irrigation applied to minimize overwinter root intrusion and rodent damage of the SDI system. Seasonal water use within a given year was significantly different and increased with increasing irrigation level (Table 1), averaging approximately 11% greater for the fully irrigated (100% of ETc) compared to the most deficit irrigation level (70% of ETc). Seasonal water use was also significantly different between years with greater water use in 2005 and the smallest water use in 2006.

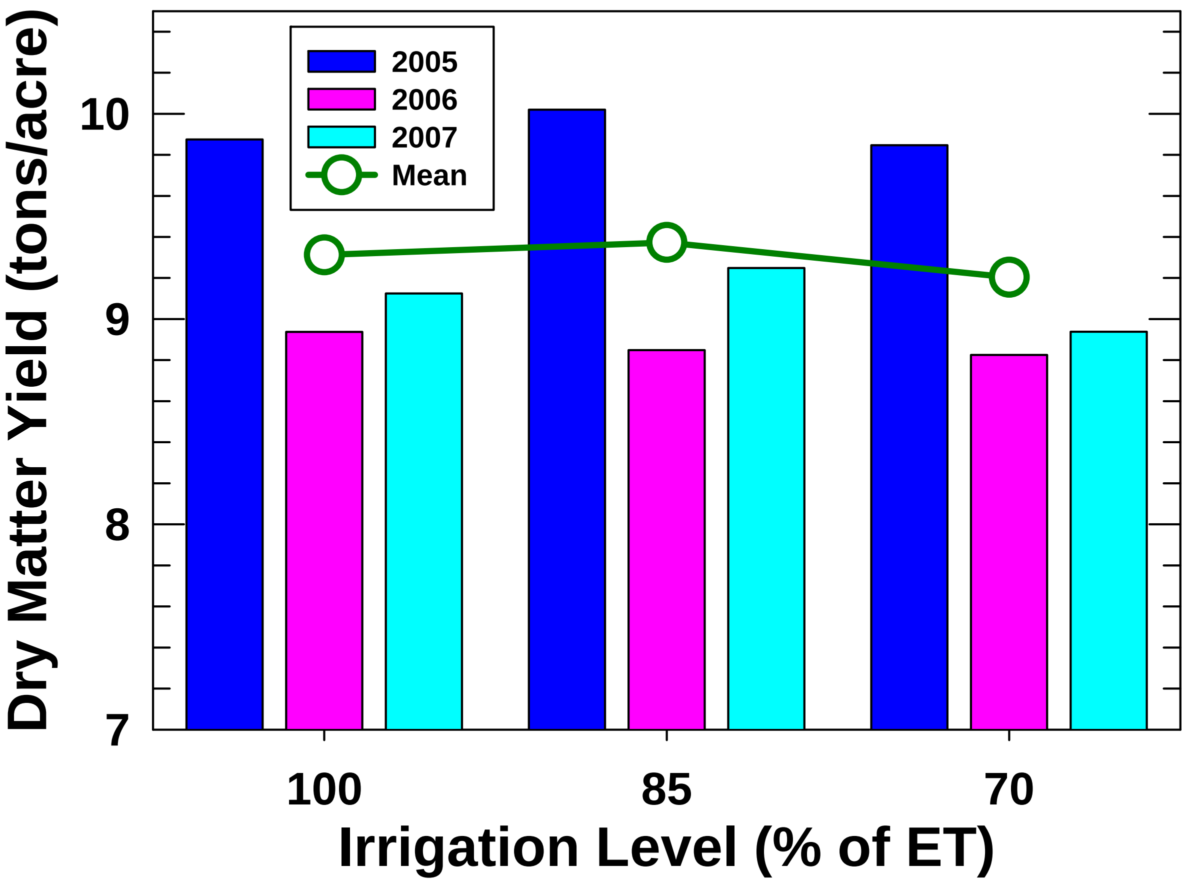

Figure 2. Annual dry matter yields for alfalfa as affected by irrigation level for 2005 through 2007 in a subsurface drip irrigation study, KSU Northwest Research-Extension Center, Colby, Kansas.

Table 1. Annual alfalfa dry matter yield, seasonal water use, and water productivity as affected by irrigation levels in a subsurface drip irrigation study, 2005 through 2007, KSU Northwest Research-Extension Center, Colby, Kansas.

Irrigation level (% of ET)	2005	2006	2007	Mean
	Dry matter yield (tons/a)			
100	9.87	8.94	9.12	9.31
85	10.02	8.85	9.25	9.37
70	9.85	8.83	8.94	9.20
Mean	9.91 A	8.87 C	9.10 B	9.30
	Seasonal water use (inches)			
100	42.1 a	37.1 c	41.8 a	40.3 ψ
85	39.9 b	33.5 d	39.8 b	37.7 Θ
70	38.9 b	29.2 e	36.6 c	34.9 λ
Mean	40.3 A	33.3 C	39.4 B	37.7 Θ
	Water productivity (ton/acre-in)			
100	0.2347 bc	0.2407 bc	0.2184 d	0.2313
85	0.2510 bc	0.2641 ab	0.2327 cd	0.2493
70	0.2530 bc	0.3021 a	0.2442 bc	0.2664
Mean	0.2462 B	0.2690 A	0.2317 C	0.2490

Table values for a given parameter (dry matter yield, seasonal water use, or water productivity) for the various years and irrigation levels followed by a different lowercase letter are significantly different at $P<0.05$.

Column values for the parameters for the various years followed by a different uppercase letter are significantly different at $P<0.05$.

Row values for the parameters for the various irrigation levels followed by a different Greek symbol are significantly different at $P<0.05$.

Water productivity tended to be greater for the deficit-irrigated treatments and was significantly greater in both 2006 and 2007 for the 70% of ETc treatment as compared to the fully-irrigated treatment (Table 1). Although the greatest dry matter yield occurred in 2005, that year had a significantly lower WP and the greatest WP occurred in 2006 which had the smallest annual dry matter yield. Water productivities in this study were somewhat greater than values of 0.18 to 0.19 tons/acre-inch that was reported by Grismer (2001) and also greater than the 0.20 tons/acre-inch value by Hengeller (1995). These greater WP values are probably indicative of reduced soil water evaporation, the E component of ETc, when alfalfa is grown with SDI.

There were generally, no appreciable difference (<0.1 ton/acre) in annual alfalfa drymatter yield as affected by distance from dripline when averaged over all the years (Table 2 and Figure 3), but there were differences between years. Although no statistically significant differences in alfalfa yield as affected by distance from the dripline occurred in 2005 and 2007, yield gradually and significantly decreased as distance from dripline increased in the drier and warmer year of 2006. The small yield differences in 2006 that were related to increased distance from the dripline tended to increase slowly with successive harvests (data not shown). This would be as anticipated as the plant available soil water decreases throughout the season and alfalfa plants further from the dripline would be having increased difficulty scavenging for the limited soil water resources. The general results of no appreciable differences in alfalfa drymatter yield as affected by distance from dripline for this 60-inch dripline spacing would appear to conflict with the results obtained by Alam et al. (2002a) that found an approximately 19% yield increase for driplines spaced at 40 inches as compared to driplines spaced at 60 inches. The sandy loam soil texture of that demonstration study in southwest Kansas may have increased in-season water stress for alfalfa plants in the wider 60-inch spacing, and plant stands were also negatively affected by the wider dripline spacing (Alam et al., 2002a). Additionally, in the current study, 5 inches of dormant-season subsurface drip irrigation was applied to help prevent root intrusion and rodent damage, and this may have increased profile soil water at the further distances from the dripline as compared to the Alam et al. (2002a) study. However, the results of the current study are somewhat similar to the results of Hutmacher et al. (1992) from the arid Imperial Valley of California on a silty clay loam that found that yields from driplines spaced at 80-inches were nearly equal to that obtained by a narrower 40-inch spacing after the first year of operation.

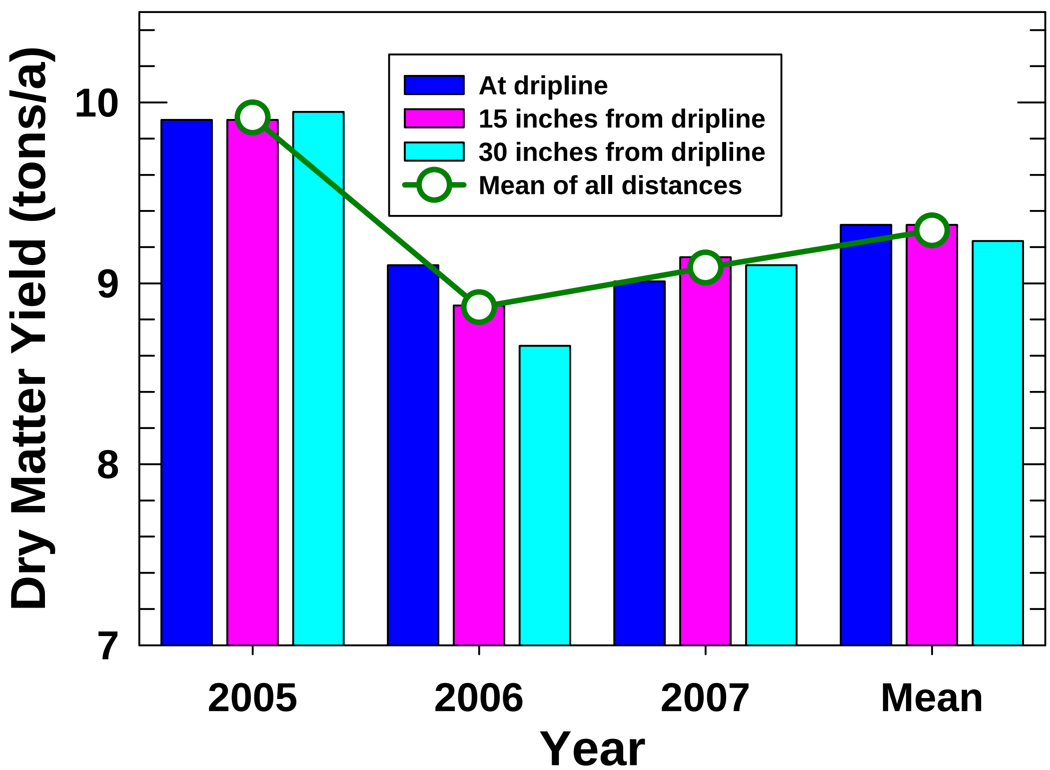

Figure 3. Annual dry matter yields for alfalfa as affected by perpendicular distance from the dripline for 2005 through 2007 in a subsurface drip irrigation study, KSU Northwest Research-Extension Center, Colby, Kansas.

Table 2 Annual alfalfa dry matter yields, tons/acre, as affected by distance from dripline and irrigation level, 2005 through 2007, KSU Northwest Research-Extension Center, Colby, Kansas.

Year	Irrigation level (% of ET)	Distance from dripline		
		0 inches	15 inches	30 inches
2005	100	9.86	9.81	9.95
	85	9.81	10.13	9.99
	70	10.08	9.72	9.81
	Mean	9.90 a	9.90 a	9.95 a
2006	100	9.01	9.06	8.65
	85	8.92	8.79	8.88
	70	9.37	8.79	8.39
	Mean	9.10 b	8.88 bc	8.65 c
2007	100	9.14	9.14	9.10
	85	9.06	9.32	9.28
	70	8.83	9.01	8.92
	Mean	9.01 b	9.14 b	9.10 b
All years	100	9.32	9.32	9.23
	85	9.28	9.41	9.41
	70	9.41	9.19	9.06
	Mean	9.32	9.32	9.23

Alfalfa drymatter yields for the various years and distances from the dripline followed by a different lowercase letter are significantly different at $P<0.05$. No significant differences in drymatter yields for the various distances from the dripline were attributable to irrigation level.

Alfalfa crop water productivity was significantly greater for the first harvest and generally decreased with successive harvests (data not shown). This is because the reduction in alfalfa yield was greater than the reduction in crop water use that occurred with successive harvests. This suggest that when irrigation water is limited it may be best to concentrate scheduled amounts (i.e., irrigation requirements as indicated by irrigation scheduling procedures) towards the earlier growth periods and then just apply amounts necessary to maintain plant stands during the later parts of the season. Similarly, many publications in semi-arid and arid regions often suggest such a strategy when water is limited (Orloff et al., 1999; Guitjens (1993); Hanson and Putnam, 2000; McWilliams, 2002). Crop water productivity was not significantly affected by irrigation level within a given harvest but a slight numerical trend existed towards greater water productivity with less irrigation. The absence of a strong difference in water productivity suggests that applied irrigation was used efficiently by this crop with the SDI system. In a study of furrow- and subsurface drip- irrigated alfalfa in Brawley, California it was concluded that SDI water productivity increases were more related to yield increases than to changes in crop water use (Ayars, et al., 1999).

Summarizing the results of this field study, there were not large differences in annual yield between irrigation levels but over the course of each season there would tend to be a slight reduction in alfalfa yield with increasing distance from the dripline. This reduction was greater for the 70% ET treatment and resulted in reduced overall annual yields (Figure 4). However, crude protein (a measure of alfalfa quality) and digestibility was greater at the greater distances and reduced ET. This helped compensate for the yield reduction. When considering long term viability of the alfalfa, it is concluded that the 85% ET replacement would be better than the 70% ET replacement if drought conditions continue for multiple seasons.

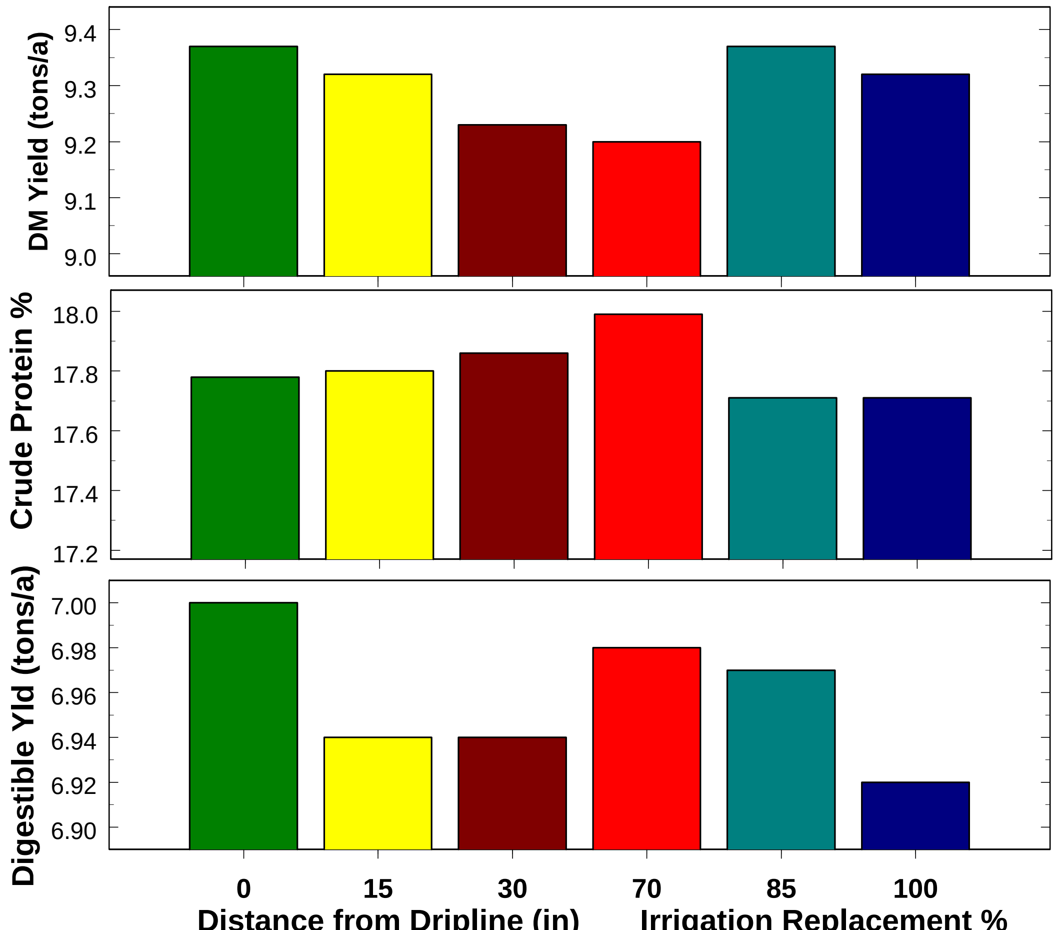

Figure 4. Dry matter yield, percentage crude protein and digestible dry matter yield as affected by perpendicular horizontal distance from dripline and irrigation level, KSU Northwest Research-Extension Center, Colby Kansas. Data is averaged over the years, 2005 through 2007.

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Considerable portions of this paper are repeated here from earlier papers by the author for the purpose of summarizing this information for the larger general audience at this symposium.

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