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Subsurface Drip Irrigation of Alfalfa

Freddie R. Lamm, Professor and Research Irrigation Engineer

Kansas State University, Colby, Kansas, flamm@ksu.edu

Keith R. Harmoney, Professor and Research Range Scientist

Kansas State University, Hays, Kansas, kharmone@ksu.edu

Abdrabbo A. Aboukheira, Associate Research Scientist,

Columbia University, New York, New York,aas2243@columbia.edu

Sandy K. Johnson, Associate Professor and Extension Livestock Specialist

Kansas State University, Colby, Kansas, sandyj@ksu.edu

***Abstract*.** Alfalfa, a forage crop, has relatively large crop water needs and, thus, can benefit from highly efficient irrigation systems such as subsurface drip irrigation (SDI). A field study was conducted from 2005 through 2007 at the KSU Northwest Research-Extension Center, Colby, Kansas to examine alfalfa production at three perpendicular distances from the dripline (0, 15 and 30 inches) for 60-inch spaced driplines under three irrigation regimes (treatments designed to replace 100, 85 or 70% of ETc minus precipitation). No statistically significant differences in dry matter yields were attributable to irrigation level, but a tendency for slightly reduced yields was observed with less irrigation as the season progressed through the 4 to 5 harvests annually. Also, yields tended to decrease with distance from the dripline during a dry season.

Keywords. microirrigation, alfalfa, forage, irrigation management, drip irrigation, Great Plains.

Introduction

Alfalfa (*Medicago sativa* L.), a forage crop, has relatively large crop water needs and, thus, can benefit from highly efficient irrigation systems such as subsurface drip irrigation (SDI). In some regions, the water allocation for irrigation is limited by geohydrological 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. Since alfalfa is such a large water user and has a very long growing season, irrigation labor requirements with SDI can be reduced relative to less-efficient, alternative irrigation systems that would require 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 requirements by approximately 6%. Water productivity (WP), the alfalfa yield divided by the water use, was increased mainly due to increased yield, not due to less water use (Ayars et al. 1999). When irrigation can continue, plant crowns have less physiological stress, and this can help suppress weed competition. 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).

On some soils under good irrigation management, it may be possible to use a 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 80 inches were nearly equal to that obtained by a narrower, 40-inch spacing after the first year of operation. Yield for the wider spacing was reduced approximately 17% during the first year when the root system was not well established. In semi-arid Kansas on a sandy loam soil, yields were 18% lower for a 60-inch spacing as compared to the narrower 40-inch spacing for the second and third years of production (Alam et al., 2002 a and b). It was concluded in this study that it was more economical to use the 40-inch spacing. However, it may be possible that irrigation applications with SDI on this soil type were too marginal to allow the alfalfa to fully develop under the wider 60-inch spacing. SDI applications were only approximately 50% of the average reference evapotranspiration due to study constraints imposed on this producer-owned field.

A field study was conducted from 2005 through 2007 at the KSU Northwest Research-Extension Center, Colby, Kansas to examine alfalfa production at three perpendicular distances from the dripline (0, 15 and 30 inches) for 60-inch spaced driplines under three irrigation regimes (treatments designed to replace 100, 85 or 70% of crop evapotranspiration (ETc) minus precipitation).

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 as described in more detail by Bidwell et al. (1980), 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 field site was approximately 390 ft wide and 80 ft long, consisting of 13 field plots approximately 30 x 80 ft in dimension. The two most northern and southern plots were not used in the field study and served as crop buffers. The area was thoroughly disked with a tandem disk and firmed with a spring tooth cultivator prior to planting of the inoculated alfalfa seed. The alfalfa (Pioneer HiBred brand 54Q25) at the field site was planted on September 12, 2003 with a disk drill at an approximate seeding rate of 12 lbs/a. Stand establishment was insufficient with the fall 2003 planting, so on April 20, 2004, the established alfalfa stand was interseeded at an approximate seeding rate of 12 lbs/a using the same disk drill at an approximately 15 degree angle to the original drill rows. Hand-set sprinkler lines were used to apply approximately 1 inch of irrigation after both seeding attempts to improve germination. Stand establishment after this second seeding was sufficient for good alfalfa production. The SDI system was not used for stand establishment for either planting due to the deep SDI installation depth of 20 inches. Although the crop was harvested three times during the summer and irrigated using the SDI system, no irrigation treatments were imposed or harvest data was collected during 2004 while the alfalfa was becoming more fully established. During 2004, the crop was irrigated as needed with a water-budget irrigation schedule designed to apply approximating 100% of the alfalfa evapotranspiration not replaced by precipitation for a total seasonal irrigation amount of approximately 14.75 inches.

The subsurface drip irrigation (SDI) system was installed in the fall of 2003 before planting of the alfalfa. Low-flow (0.6 L/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 60-inch dripline spacing using a shank-type injector at a depth of 20 inches. The emitter exponent for this dripline as measured in the laboratory was 0.59 which was slightly greater than the manufacturer's specified value of 0.57. 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 with a water temperature of approximately 57° F.

Cultural Practices and Harvest Procedures

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. 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 60-inch dripline spacing on alfalfa yield. This self-propelled plot harvester utilized a flail chopper 36 inches in width to cut and blow the harvested material into a container mounted on load cells on the harvester for mass determination. Samples centered at the fixed horizontal distances (0, 15 and 30 inches) from the dripline were obtained from the second, third, and fourth driplines of the 6-dripline plots, respectively, to avoid overlap of the harvester which had width greater than the sampling distance interval. The plot area and wet mass were recorded and a grab-sample of approximately 2.5 lb of the wet mass was used for water content determination. Harvested wet forage yields were corrected to dry matter yield for each horizontal distance from the dripline. A composite plot yield was calculated as the average of the combined sum of the measured yield at horizontal distance 0 and at 30 inches and twice the measured yield at 15 inches (i.e., 4 yield terms divided by 4 to accurately mirror samples around the distance 0 sample and to fully represent the 60-inch dripline spacing).

Irrigation Water Management

The 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.

Irrigation was scheduled using a weather-based water budget constructed using data collected from a NOAA weather station located approximately 1500 ft northeast of the study site. The schedules were started each year on April 1 and continued thorough the end of October or the first killing frost, whichever came first. The reference evapotranspiration (ETr) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heermann (1974). The specifics of the ETr calculations used in this study are fully described by Lamm et al. (1987). Daily crop coefficients (single Kc) were generated using FAO-56 (Allen et al., 1998) as a guide with periods adjusted to northwest Kansas growing period lengths. Specifically, Kc values for the initial 40-d period beginning April 1 were allowed to increase linearly from 0.2 to a maximum of 1.0 and remain at 1.0 until harvest. For subsequent harvests in a given year, Kc values were allowed to increase linearly from 0.2 to a maximum of 1.0 in a 17-d period. Crop evapotranspiration (ETc) was calculated as the product of Kc and ETr. In constructing the irrigation schedules, no attempt was made to modify ETc with respect to soil evaporation losses or soil water availability as outlined by Kincaid and Heermann (1974). Typically, weekly or twice-weekly irrigations were scheduled whenever the calculated soil water depletion in the profile exceeded approximately 2 inches. The few exceptions to this scheduling frequency were related to the unavailability of the pumping water source due to its concurrent use on another study site. Irrigation amounts ranged from approximately 0.25 to 1 inch for each event, depending on availability of pumping system for the given event.

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.

Weather and Water-related Experimental Data and Calculated Parameters

Additional study data collected during the growing season included irrigation and precipitation amounts, weather data, and soil water data. 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. Calculated values from the collected data included water use and water productivity. 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.

Statistical Treatment

The experimental data were analyzed as mixed models using the PROC MIXED procedure with repeated measures of the SAS statistical package (SAS Institute, 1996. SAS systems for mixed models. SAS Institute, Inc. Cary, NC, USA. 633 pp.). Year, harvests, irrigation level, distance from the dripline, and their interactions were considered fixed effects while replication was the random effect. Year and harvests were used as the repeated measures in the models. Main effects and their interactions were considered to be significant at the $P<0.05$ level. Mean separations at the $P<0.05$ level were conducted within significant effects using the LSMEANS and PDIFF options of the MIXED procedure.

Results and Discussion

Weather Conditions and Irrigation Requirements

Weather conditions during the three years of the study were generally favorable for alfalfa production. Two weather events that were less than favorable to production were a hail storm that occurred midway (June 16) between the first and second harvest in 2006 and a hard freeze (April 12) that occurred approximately two weeks after the initiation of spring green-up in 2007. 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). Weather patterns differed between the years with greater calculated ETr and greater average air temperature during May and June of 2006 as compared to the other two years, while the latter part of the 2006 season generally had less ETr and milder air temperatures. Precipitation was above the long-term average in three of the five months in 2005 (May, June and August) and for only June and September in 2006. Although May through mid-July of 2007 was very dry, precipitation during the latter part of the season was well above normal. 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.

Effect of Irrigation Level on Annual Alfalfa Yields, Water Use and Water Productivity

Alfalfa yields were excellent compared to regional norms of approximately 6.5 tons/a for all 3 years (Table 1 and Figure 1). 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.

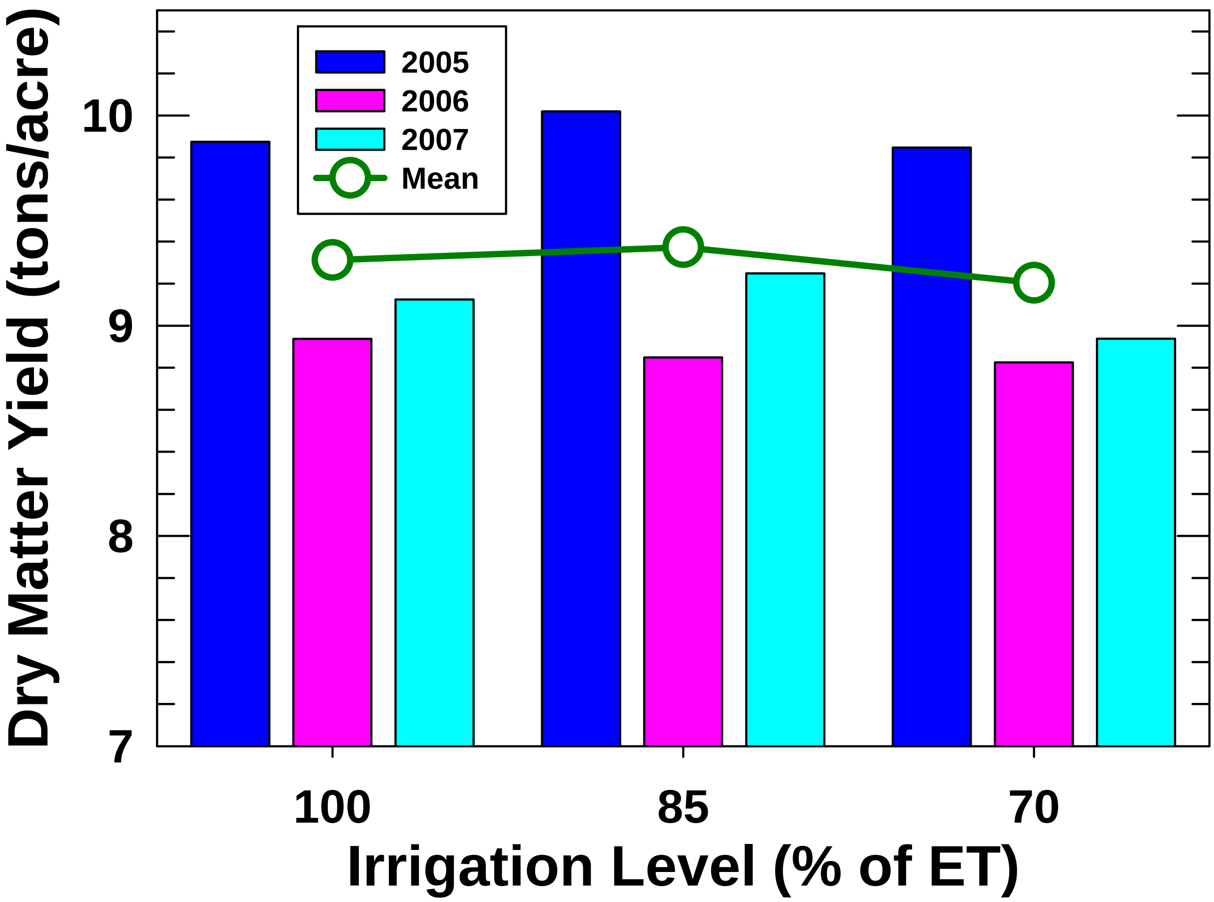

Figure 1 Annual dry matter yields for alfalfa as affected by irrigation level for 2005 through 2007 in a subsurface drip irrigation study, KSU Northwest Research-Extension Center, Colby, Kansas.

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.

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.

	Dry matter yield (tons/a)			
Irrigation level (% of ET)	2005	2006	2007	Mean
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)			
Irrigation level (% of ET)	2005	2006	2007	Mean
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)			
Irrigation level (% of ET)	2005	2006	2007	Mean
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.

Effect of Distance from Dripline on Annual Alfalfa Drymatter Yields

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 2), 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.

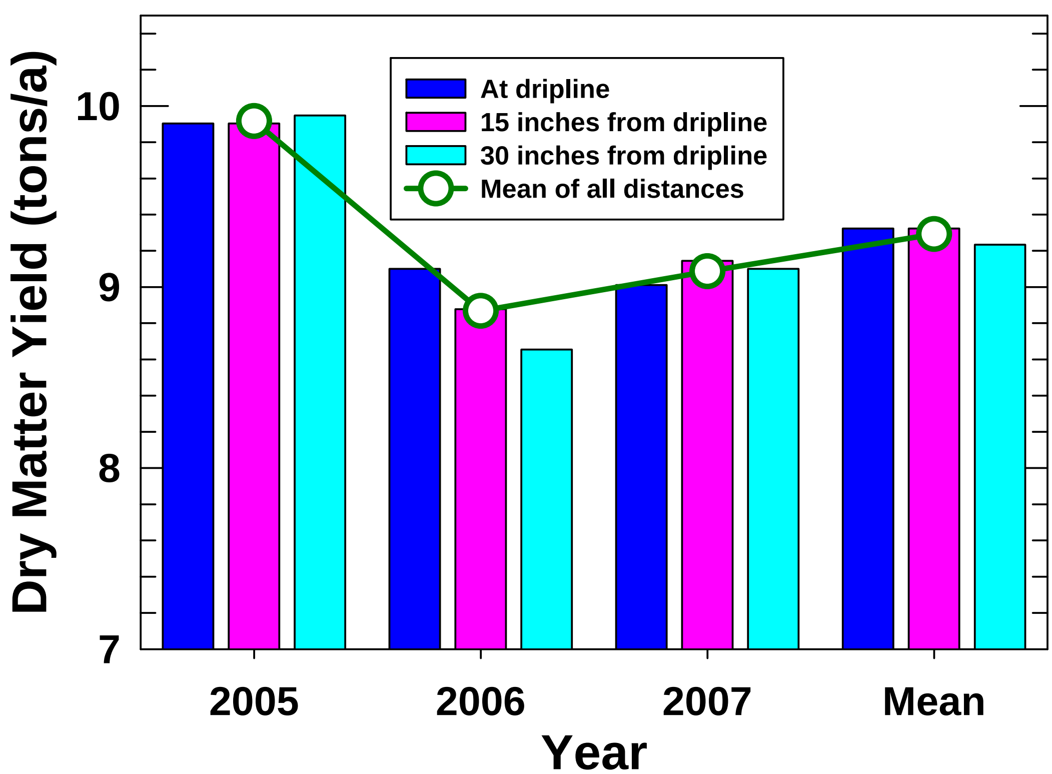

Figure 2 Annual dry matter yields for alfalfa as affected by perpendicular distance from the dripline for 2005 through 2007 in a subsurface drip irrigation study, KSU Northwest Research-Extension Center, Colby, Kansas.

Table 2 Annual alfalfa dry matter yields 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.

Concluding Statements

Irrigation levels designed to replace between 70 and 100% of the calculated ETc minus precipitation had no appreciable effect on annual alfalfa yields grown using SDI in northwest Kansas on a deep silt loam soil under typical weather conditions. These results may need to be tempered with the fact that 5 inches of irrigation was applied late fall each year to help prevent root intrusion and rodent damage. Also, no large effects of perpendicular distance from the dripline occurred on alfalfa yield. Water productivity tended to be greater for the 70% ET irrigation treatment and was significantly so in some cases. A follow-up study currently underway is examining deficit SDI of alfalfa during specific periods between harvests.

Acknowledgements

[1] Mention of tradenames is for informational purposes only and does not constitute endorsement by the authors or by the institutions they serve.

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