Comparing Costs and Efficiencies of Different Alfalfa Irrigation Systems

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ABSTRACT

Alfalfa production is basically a linear function of plant transpiration and stomatal conductance that drives carbon dioxide uptake to build plant carbohydrates and biomass. Cutting schedules, irrigation non-uniformity and poor scheduling can result in lost yield and water use efficiency. Improved uniformity and scheduling of pivot and subsurface drip irrigation (SDI) can result in significant yield and water use efficiency (tons hay/inch of water) increases, but the additional capital and operational costs of these systems can equal as much as 2 to 3 tons per acre additional yield over the cost of border strip/flood irrigation.

Key Words: alfalfa, irrigation, distribution uniformity, flood, pivot, SDI, economics

INTRODUCTION

Declining water supply: The average allocation of surface water to most San Joaquin Valley growers has been reduced by 30 to 65% over the last ten years, depending on the watershed and irrigation district. 2011 was a welcome relief with nearly 100% supply for most areas. But the reality is that most Westside growers only have 2.5 feet of water in a 100% year. If you're growing alfalfa or almonds and need 4 to 4.5 feet to meet crop demand you have to pump or buy "surplus" or "emergency pool" water to make up the difference. In some cases this has cost as much as $700/ac-ft. In addition to the unpredictability over natural drought cycling are the continued legal issues surrounding the pumping of fresh water from the Sacramento/San Joaquin River Delta. These issues have a huge impact on both the quantity and quality of water exported for irrigation and municipal needs south of the Delta.

The drive for conservation and increased efficiency: Of course you can't grow hay with water costs of $700/ac-ft, but the squeeze is on across the southwestern states as water costs everywhere are increasing and growers are asking how to make the most *profitable* amount of crop/drop. This equation is simple – as costs go up, you either 1) go broke, 2) become more efficient and produce the same tonnage for less cost, 3) get more price for your crop, or 4) you produce more tonnage for only a slight increase in production costs. Most of the time it's a combination of (3) and (4) with new technology (chemical and/or mechanical) and varieties that drive the productivity increases. This paper will review alfalfa water requirements, the impact of irrigation uniformity on yield and then explore the potential for improving alfalfa water use efficiency and tonnage with alternative irrigation systems and the capital and operational costs of the various alternatives as they compare to traditional flood irrigation.

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ALFALFA WATER CONSUMPTION (ET) and IRRIGATION UNIFORMITY

Assuming your field fertility and pest pressure is not a problem, understanding these two concepts is the key to top alfalfa yields. The fuel of forage production is carbon dioxide (CO_2) assimilation through the stomata on the alfalfa leaves. This provides the carbon base for carbohydrate production powered by the engine of photosynthesis and root nutrient uptake. The more open the stomata, the greater the CO_2 uptake, the greater your hay tonnage and the greater your crop water use.

Evapotranspiration (ET,) "potential" ETo, Crop coefficients (Kc) and average ET: Climate determines your "potential" ETo – essentially maximum water use by unstressed pasture. Since most forage crops are planted dense and cover the ground like a pasture then it's natural to assume that their ET would be the same as ETo, and as a first guess this isn't too bad. But there are developmental differences due to initial seedling growth, physiology of the particular forage compared to pasture and cutting schedules. Basically, the crop coefficient, Kc, is the ratio of actual crop water use for a particular stage of growth compared to ETo. We have typical Kc values for the developmental stages of most crops. Crop ET is then calculated as follows:

$$ETcrop = ETo * Kc * E_f$$

ETo = <u>reference crop</u> (tall grass) ET

Kc = <u>crop coefficient</u> for a given stage of growth as a ratio of grass water use. May be 0 to 1.3, standard values are good starting point.

E_f = an "<u>environmental factor</u>" to account for immature permanent crops, salinity, etc. May be 0.1 to 1.1 depending on field. Usually 1 for good ground and water.

Figure 1 illustrates the changes in alfalfa ET over the year due to serial cutting. The real picture of actual ET, even when averaged on a weekly basis, can be much more variable and can actually have some Kc values in excess of 1.5, more than 150% of ETo. Alfalfa ET measured in a

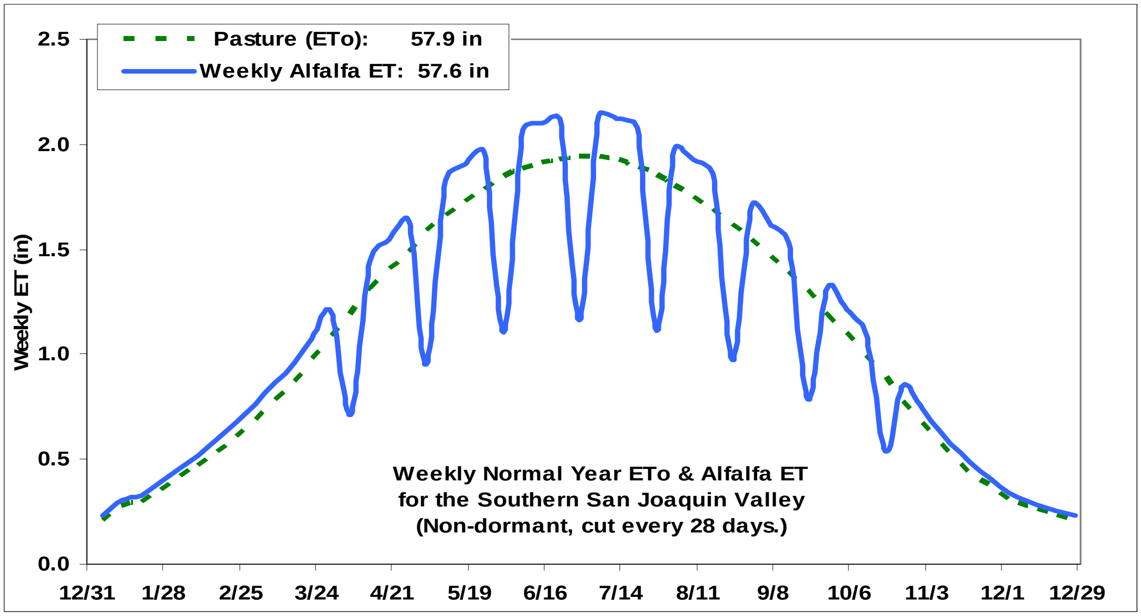


Fig. 1. Weekly ET for an established stand of non-dormant alfalfa in the SJV with 8 cuttings. Crop ET is calculated using peak crop coefficient (Kc) values of 1.1 immediately upon irrigating after bale pickup and a low of 0.6 for one week immediately after cutting as the hay cures prior to baling.

Buttonwillow field on heavy, cracking black clay irrigated once per cutting showed that mid-season Kc's occasionally ran 115 to 150% (0.33 to 0.45 inches/day) in July and August. The net result was that the average May-October Kc for this field was 1.10 instead of the 0.95 normally used. **<u>Bottom line:</u> Normal year ET tables are a good guideline for planning irrigations, BUT actual crop ET can be +/-15%. Therefore, you must check soil moisture and irrigation uniformity over the season to maximize yield and efficiency.**

Yield/ET production functions and water use efficiency (WUE): Much research over the last 30 years has examined the WUE, **crop per drop** so to speak, of most field crops. The production function for a given crop predicts the yield as a function of crop ET. The final WUE is a ratio of final yield over total applied water. Figure 2.a. shows the variety of alfalfa production functions that have been developed from many different locations and research trials throughout the West (Hanson et al., 2007). A few growers I've known over the years have obtained 12 t/ac under flood and yields of 14 to 24 t/ac have been reported for subsurface drip irrigation and pivots with intensive fertigation (Ludwick, 2000.) Figure 2.b. is a more realistic picture from my

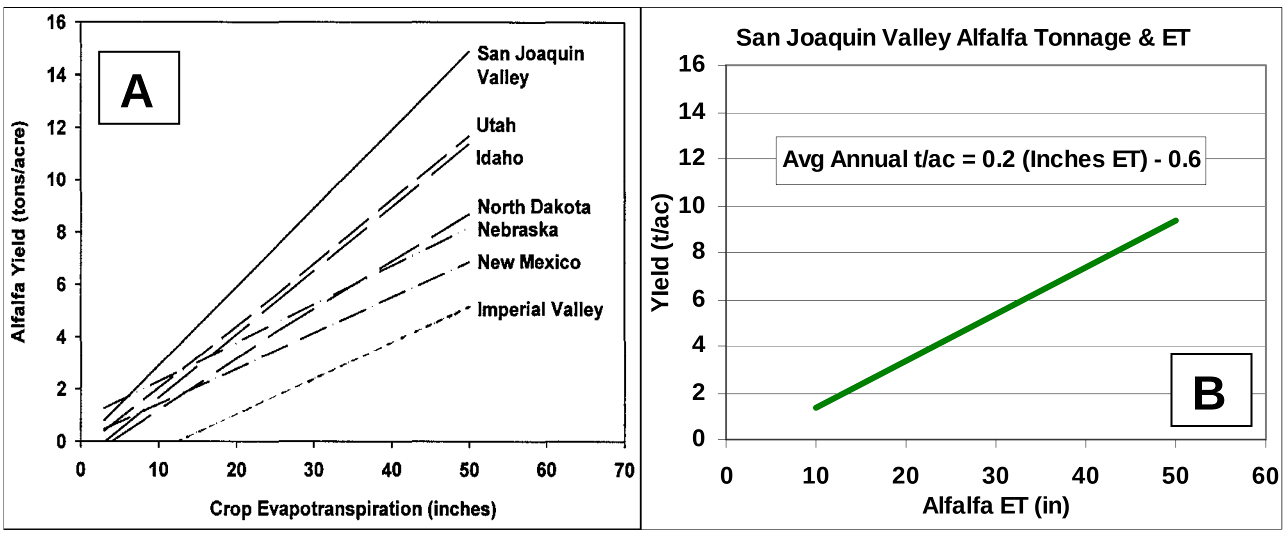


Fig. 2. Optimal alfalfa production functions for various locations in the West (left, Hanson et al., 2007). More realistic field production function for well-managed established alfalfa in the SJV (right, Sanden, personal observation, 3 year trial in Buttonwillow).

observation of production conditions (and a 3 year trial measuring ET/yield of alfalfa in Buttonwillow) where leaf loss in the field is unavoidable and top hay yields are around 10 t/ac. What this function says is that it takes about 5 inches of ET to make one ton of alfalfa hay. You'll notice that the lowest production line in Fig. 2a. is for the Imperial Valley. Excessive heat during the day and night result in high "respiration losses" in alfalfa, where the plant actually burns up some stored carbohydrates as it transpires large amounts of water to maintain cooling. CO_2 assimilation is high, but so are metabolic losses. Alfalfa is a C3 plant that prefers cooler temperatures (50-80^{o}F) for the most efficient photosynthesis. So it's not surprising that many research trials find the best WUE in the spring and fall cuttings and areas with cooler nights.

Irrigation "distribution uniformity" (DU) and the impact on yield: Stress from dry soil, disease and salinity can all add up to decrease the stomatal conductance and uptake of CO_2. So it

follows that you want to irrigate the field as uniformly as possible to avoid having some parts too dry while avoiding saturating other areas that leads to disease. That way every part of the field can produce hay at the optimum rate. The usual measure of field uniformity is the "distribution uniformity": **DU (%) = 100 * "low quarter infiltration" / average whole field infiltration**
Figure 3 illustrates how this plays out in your crop rootzone for a field DU of about 80% with some deficit irrigation on the end. To insure that no more than about 12% of the field gets less

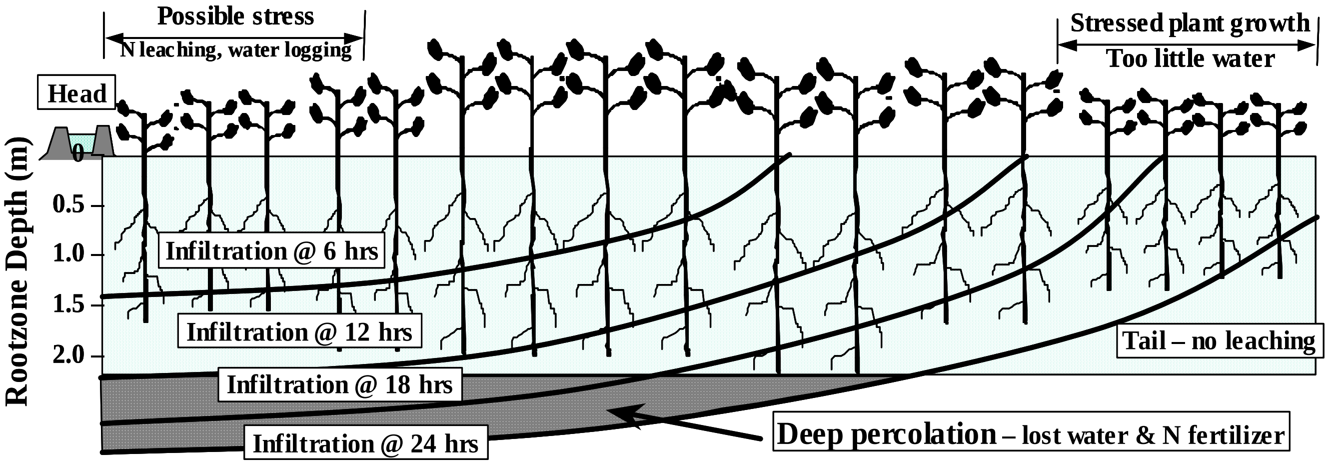
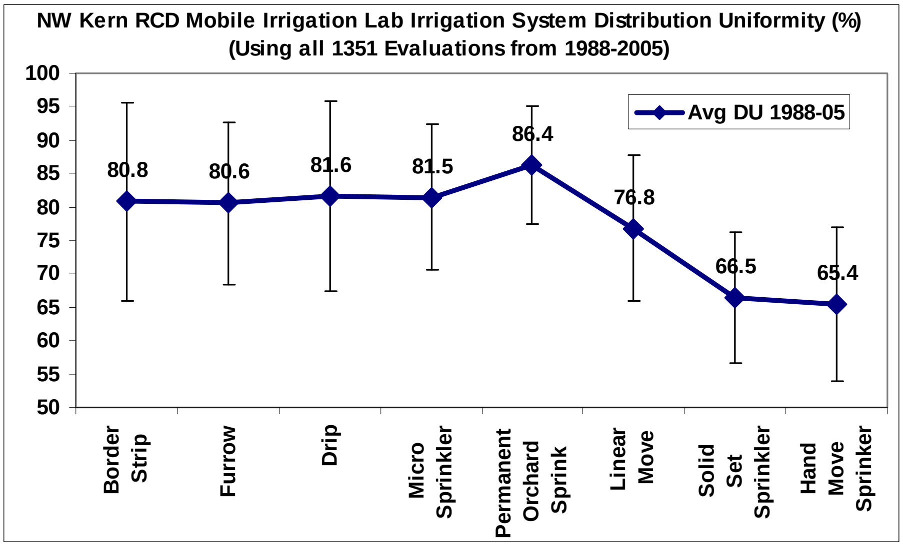


Fig. 3. Cross-section of crop rootzone during a 24 hour flood irrigation.

than full ET, you divide the expected ET of the crop by the field application DU. So if the alfalfa has a 50 inch requirement for ET and the field has an **80% DU** then the **applied water required = 50/0.8 = 62.5 inches.** That's an extra foot of water! If the **DU is 90%** (which is achievable with quarter mile runs, the right on-flow rate, a tail water return system and proper scheduling) then **applied water = 50/0.9 = 55.5 inches.** So you can save 7 inches of water by improving the uniformity and still adequately water the field.

We know irrigation uniformity is important to optimize water use efficiency and yield. So all I need to do is convert my field to pivot or drip to be more uniform, right? Sorry, but the data show that converting to pressure or micro is no guarantee of operational uniformity. Figure 4 shows the average and +/- one standard deviation distribution uniformity for a variety of flood, sprinkler and micro systems measured in Kern County from 1988-2005. The furrow, linear, solid set and hand-move sprinkler evaluations are from field and vegetable crops. Most of the border, drip and micro-sprinkler evaluations were done in orchards, but many alfalfa fields were included in the border numbers. The range of DU's listed to the right brackets about 70% of the fields tested. Wait a minute – from flood to micro systems the average DU is almost the same – about 80%, and sprinklers are even worse! Why? These are real fields managed by real people that have a wide range of ability in fine-tuning their operation. Yes, micro irrigation and pivot systems have the best engineering potential for maximum uniformity and efficiency, but to attain these levels requires a lot more maintenance than flood.

So how does this play out in a production field? Figure 5 is a hypothetical alfalfa field that can yield 12 ton for the areas in the field where the irrigation schedule is just right. But this field does not drain well and where there is too much water you lose stand and yield to scald and phytophthora (the blocked end of the border and some of the head end in this case). Obviously,



SYSTEM	Avg DU -1 S.D.	Avg DU +1 S.D.
Border Strip	66	96
Furrow	68	93
Drip	67	96
Micro Sprinkler	71	92
Orchard Sprinkler	78	95
Solid-set Sprinkler	57	76
Hand-move Sprinkler	54	77
Linear Move	66	88
Side Roll	*60*	*85*
**Center Pivot*	*75*	*95*
**Sub-surface Drip*	*75*	*95*

Fig.4. Average and +/- 1 standard deviation field distribution uniformity for 1351 various irrigation systems in Kern County from 1988-2005. (*These systems not evaluated. Low/High effiiciency numbers from Howell, 2003)

where the infiltration is too little (about 900 to 1150 feet from the head) the tonnage also decreases. Table 1 gives three yield scenarios using a theoretical production function (Fig. 5) for a potentially high producing field in Kern County for a 70, 80 or 90% DU and the field average applied water for the season is 42, 48, 54 or 60 inches. Remember that a 55 inch water application is about right for a 50 inch ET requirement and a field with 90% DU.

		Average Field Irrig (in)				Qtr Yield by Avg Depth (t/ac)			
	Field Qtr	42	48	54	60	42	48	54	60
70% DU	Wettest	55	62	70	78	11.2	10.0	6.8	1.5
	Wet	46	53	59	66	10.1	11.1	10.7	8.8
	Drier	38	43	49	54	6.6	9.1	10.6	11.2
	Dry	29	34	38	42	0.7	3.9	6.6	8.6
	Field Average Yield (t/ac):					**7.1**	**8.5**	**8.7**	**7.5**
		Average Field Irrig (in)							
		42	48	54	60	42	48	54	60
80% DU	Wettest	50	58	65	72	10.9	11.0	9.2	5.7
	Wet	45	51	58	64	9.7	11.0	11.0	9.5
	Drier	39	45	50	56	7.3	9.7	10.9	11.1
	Dry	34	38	43	48	3.9	6.9	9.1	10.5
	Field Average Yield (t/ac):					**7.9**	**9.6**	**10.0**	**9.2**
		Average Field Irrig (in)							
		42	48	54	60	42	48	54	60
90% DU	Wettest	46	53	59	66	10.1	11.1	10.7	8.8
	Wet	43	50	56	62	9.2	10.8	11.1	10.1
	Drier	41	46	52	58	8.0	10.1	11.1	10.9
	Dry	38	43	49	54	6.6	9.1	10.6	11.2
	Field Average Yield (t/ac):					**8.5**	**10.3**	**10.9**	**10.2**

Table 1. Average seasonal applied water on the wettest to driest areas of an alfalfa field and the resulting yield for those areas for for various irrigation amounts and DU.

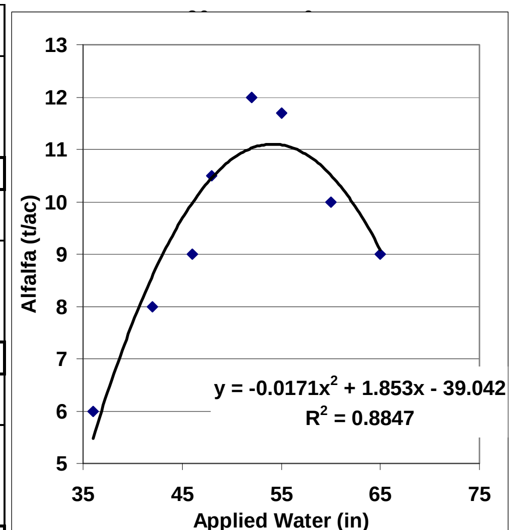


Fig. 5. Alfalfa production function for field sensitive to waterlogging.

Improving the DU to 90% with tail water return and higher on-flows to reduce infiltration and water-logging at the head and tail you bump the whole field up to 10.9 t/ac with 54 inches of water! This gets you more yield than just adding 6 inches and staying at 70 or 75% uniformity, **Bottom line: improving irrigation DU pays.**

IRRIGATION SYSTEMS: COMPONENTS, CONDITIONS, COSTS

The information in Figure 4 and Table 1, based on actual irrigation system evaluations and observations of production field in Kern County, shows that yield can be increased by improving field distribution uniformity. The example in Table 1 shows that by just increasing DU/water use efficiency from 70 to 90% you can increase yield by more than 2 ton/ac even before the potential advantages for fertigation and pest control offered by SDI and center pivots that you don't have with flood. These advantages and disadvantages of various systems are listed below. We will not include these factors in the following analyses as they tend to be area/field specific and we have no real data on cost differences. Costs have been calculated based on a 160 acre field. The total annual costs include the annualized costs of the capital investment in the system (excluding wells and pumps) plus the annual operating costs that include the water, energy cost for distributing the water, irrigator labor, and maintenance. In the case of flood irrigation, the annual operating costs also include pulling and pushing ditches.

The goal here is to get as much water going directly to crop transpiration as possible. So anything we can do to minimize evaporation, deep percolation/water-logging, runoff and drought stress potentially channels that water to the crop and boosts production efficiency and tonnage. In principal, SDI is the system that should best optimize all these factors. It is also the system which requires the most attention to maintenance and scheduling. Specific advantages and disadvantages of the various system categories are:

Flood: Advantages – gopher control is least problematic, low to no energy cost, no filtration necessary, total infiltrated water depth varies over season, tailwater return systems improve uniformity and provide better stand quality by draining check ends. Disadvantages – land must be leveled, pushing in head ditches, water-logging ends, stress between irrigations and cuttings.

Sprinkler: Advantages – better water application control for stand germination, depth of water controlled by run time, no land leveling, no borders needed, fertigation possible. Disadvantages – more gophers, significant capital cost – highest for solid-set, high energy and labor costs.

Pivot: Advantages – rapid field coverage, usually more uniform than hand-move and side-roll which makes pesticide applications as well as fertigation possible, reasonable capital cost, lower energy cost than other sprinklers, least labor cost. Disadvantages – gophers, high instantaneous application rates, potentially higher evaporation losses, lose field corners, needs filtration.

SDI: Advantages – high frequency daily irrigation possible even when cutting, maximum crop transpiration possible, potentially superior application of P and K fertilizers, uniformity unaffected by wind. Disadvantages – sprinklers needed for establishment, salinity may be a problem, GOPHERS!! Extensive damage to system possible if not controlled, root intrusion/emitter clogging, cannot "see" water – pressure and soil moisture monitoring essential for good yields, quality filtration essential.

The detailed budget sheets on the following pages present the investment costs, amortized investment cost and annual operating costs for 8 different alfalfa irrigation systems on a per acre basis. Two different budget sheets are presented using the low and high end estimates of current

COMPARISON OF IRRIGATION SYSTEM COSTS FOR ALFALFA IN THE SOUTHERN SAN JOAQUIN VALLEY

Lower System Cost

QUARTER SECTION FIELD (160 gross ac), SEASON ET @ 52 INCHES

Head ditch with siphons, 1/4 mile run, no tailwater return. District water, no energy charge.
For border, 1 alfalfa valve every 50 feet, 1/4 mile runs, 2 tail pits, 18" mainline.
Hand-move sprinkler with 45' moves, 30' pipes, 30" risers and 1/8" nozzles.
Drip with 10 mil, 0.900 tape, 1/4 mile runs, shanked in 9 to 12" below grade, 60" centers.
($/ac, Calculations appear in *italics*)

CAPITAL COSTS	Deprec (Yrs)	Head Ditch Siphon	Border (no tail return)	Border (tail return)	Hand Move Sprinkler	Solid Set Sprinkler	Side Roll Sprinkler	Center Pivot	SDI - Tape (60" beds)
Net acres:		155	155	154	155	155	155	122	155
Land leveling & borders:	4	150	150	150			10		
Reservoir / tailpit(s):	20			180					
Above ground equip:	20	250	350	350	385	1765	400	662	250
Below ground:	20		480	480	12	12		115	300
*Sprinkler rent 1st year:	4								230
Drip tape + R&R:	6								300
Annualized Capital Cost (+ 4.75% int):		*61.69*	*107.25*	*121.39*	*31.18*	*139.58*	*34.22*	*61.03*	*166.32*

RESOURCE COSTS						
ET:	52	inches				
Water Cost:	**50**	**$/ac-ft**				
Irrigation Labor:	11	$/hr		Pivot (40 psi):	40	$/ac-ft
Equipment Operator:	13	$/hr		Drip Energy Cost (20 psi):	25	$/ac-ft
Sprinkler Energy Cost (70 psi):	60	$/ac-ft		Tailpit Energy Cost (15 psi):	15	$/ac-ft

SYSTEM ASSUMPTIONS	Head Ditch Siphon	Border (no tail return)	Border (tail return)	Hand Move Sprinkler	Solid Set Sprinkler	Side Roll Sprinkler	Center Pivot	SDI - Tape (60" beds)
Distribution Uniformity	**78%**	**80%**	**85%**	**75%**	**82%**	**80%**	**90%**	**92%**
Extra Evaporation (inches)	**0.0**	**0.0**	**0.0**	**3.0**	**3.0**	**3.0**	**4.0**	**0.0**
Applied Water (inches)	***67***	***65***	***61***	***72***	***66***	***68***	***62***	***57***
Calculated Number of Irrigations	*13*	*13*	*12*	*12*	*11*	*17*	*51*	*57*
Days (sets)/irrigation cycle	10	10	10	12	12	10	1	2
Irrigation Labor Hrs/Irrig-Day	4	3	3	8	3	2	2	3
Layout/Remove Sprinklers				60	150			
Total Season Hours	*533*	*390*	*367*	*1217*	*548*	*340*	*103*	*339*
Irrig Labor Hrs/acre	***3.44***	***2.52***	***2.38***	***7.85***	***3.54***	***2.19***	***0.84***	***2.19***
Inches/day (or pass)	*5.0*	*5.0*	*5.0*	*6.0*	*6.0*	*4.0*	*1.2*	*1.0*
Required Flowrate (gpm)	*2320*	*1450*	*1441*	*1450*	*1450*	*1160*	*2739*	*1450*

ANNUAL COSTS	Head Ditch Siphon	Border (no tail return)	Border (tail return)	Hand Move Sprinkler	Solid Set Sprinkler	Side Roll Sprinkler	Center Pivot	SDI - Tape (60" beds)
Water	*277.78*	*270.83*	*254.90*	*301.39*	*276.73*	*283.33*	*257.41*	*235.51*
Energy Cost			*7.65*	*361.67*	*361.67*	*332.07*	*205.93*	*128.70*
Irrigator	*37.85*	*27.68*	*26.22*	*86.39*	*38.92*	*24.13*	*9.28*	*24.07*
Equipment Operator	*9.75*							
Ditch Pulling/Pushing, Equip	12							
Maintenance	5	10	12	12	20	12	12	75
Annualized Capital Cost	*61.69*	*107.25*	*121.39*	*31.18*	*139.58*	*34.22*	*61.03*	*166.32*
TOTAL	***404.07***	***415.76***	***422.16***	***792.63***	***836.90***	***685.76***	***545.65***	***629.60***
Additional tons/ac required @ $160/ton to achieve equal cost with Ditch/Siphon	***0***	***0.1***	***0.1***	***2.4***	***2.7***	***1.8***	***0.9***	***1.4***

COMPARISON OF IRRIGATION SYSTEM COSTS FOR ALFALFA IN THE SOUTHERN SAN JOAQUIN VALLEY

Higher System Cost

QUARTER SECTION FIELD (160 gross ac), SEASON ET @ 52 INCHES

Head ditch with siphons, 1/4 mile run, no tailwater return. District water, no energy charge.
For border, 1 alfalfa valve every 50 feet, 1/4 mile runs, 2 tail pits, 18" mainline.
Hand-move sprinkler with 45' moves, 30' pipes, 30" risers and 1/8" nozzles.
Drip with 10 mil, 0.900 tape, 1/4 mile runs, shanked in 9 to 12" below grade, 60" centers.
($/ac, Calculations appear in *italics*)

CAPITAL COSTS	Deprec (Yrs)	Head Ditch Siphon	Border (no tail return)	Border (tail return)	Hand Move Sprinkler	Solid Set Sprinkler	Side Roll Sprinkler	Center Pivot	SDI - Tape (60" beds)
	Net acres:	155	155	154	155	155	155	122	155
Land leveling & borders:	4	300	300	300	10	10	10	10	30
Reservoir / tailpit(s):	20			180					
Above ground equip:	20	250	350	585	850	2750	835	900	850
Below ground:	20		480	480			12	150	125
*Sprinkler rent 1st year:	4								230
Drip tape + R&R:	6								733
TOTAL CAPITAL COST		$550	$1,130	$1,545	$860	$2,760	$857	$1,060	$1,968
Annualized Capital Cost (+ 4.75% int):		*103.75*	*149.31*	*181.91*	*69.57*	*218.82*	*69.34*	*85.28*	*292.75*

RESOURCE COSTS					
ET:	52	inches			
Water Cost:	**50**	**$/ac-ft**			
Irrigation Labor:	11	$/hr	Pivot (40 psi):	40	$/ac-ft
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Applied Water (inches)	**67**	**65**	**61**	**72**	**66**	**68**	**62**	**57**
Calculated Number of Irrigations	13	13	12	12	11	17	51	57
Days (sets)/irrigation cycle	10	10	10	12	12	10	1	2
Irrigation Labor Hrs/Irrig-Day	10	10	9	12	8	3	7	10
Layout/Remove Sprinklers				80	180			
Total Season Hours	*1333*	*1300*	*1101*	*1816*	*1243*	*510*	*360*	*1130*
Irrig Labor Hrs/acre	*8.60*	*8.39*	*7.15*	*11.72*	*8.02*	*3.29*	*2.95*	*7.29*
Inches/day (or pass)	*5.0*	*5.0*	*5.0*	*6.0*	*6.0*	*4.0*	*1.2*	*1.0*
Required Flowrate (gpm)	*2320*	*1450*	*1441*	*1450*	*1450*	*1160*	*2739*	*1450*

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Energy Cost			*7.65*	*361.67*	*361.67*	*332.07*	*205.93*	*128.70*
Irrigator	*94.62*	*92.26*	*78.66*	*128.88*	*88.19*	*36.19*	*32.49*	*80.22*
Equipment Operator	*9.75*							
Ditch Pulling/Pushing, Equip	12							
Maintenance	19	20	21	19	25	12	12	75
Annualized Capital Cost	*103.75*	*149.31*	*181.91*	*69.57*	*218.82*	*69.34*	*85.28*	*292.75*
TOTAL Annual Irrigation Cost	***$517***	***$532***	***$544***	***$881***	***$970***	***$733***	***$593***	***$812***
Additional tons/ac required @ $160/ton to achieve equal cost with Ditch/Siphon	***0***	***0.1***	***0.2***	***2.3***	***2.8***	***1.4***	***0.5***	***1.8***

system costs we obtained as of Fall 2011. (Irrigation system costs courtesy of Valley Irrigation, Sacramento Valley and US Irrigation, Kern County.) Water cost is fixed at $50/ac-ft, energy costs at $15 to $60/ac-ft depending on low or high pressure and irrigation labor at $11/hr. The DU for a given system is held constant between the two example budget comparisons and has been set at a "good" (siphon/border) to "very good" (pivot, SDI) level consistent with a grower who has decided to invest in irrigation improvements. ET is assumed to be 52 inches.

SUMMARY

Between these low-high analyses the least expensive annualized system capital cost was for hand-move sprinkler lines @ $31/ac while the most expensive annualized capital outlay was for the high-end SDI system @ $293/ac. A 20 year depreciation life was used for everything except drip tape (6 years) and land leveling for flood (4 years). (Due to this short depreciation time for land-leveling costs the head ditch/siphon system was $62/ac.)

By contrast, the total annual cost including the annualized capital cost plus the annual operating cost was the most expensive for solid-set hand-move sprinklers @ $970/ac with hand-move lines coming in second @ $880/ac due to considerable labor and power requirements and poor uniformity. Total annual cost for the head ditch/siphon system was $404/ac at the low end and $517/ac at the high end. The standard border strip system with concrete mainline and alfalfa valves was $422 and $508/ac at the low and high estimates, respectively. SDI yearly cost was $630 and $812/ac on the low and high ends. Center pivot annual costs were $546 and $593/ac on the low and high ends, but this does not include the extra property tax you have to pay on the unused corners. **Bottom line: At $160/ton, it took an average of 0.7 t/ac increased yield to offset the cost of a center pivot over basic flood irrigation and an average 1.6 t/ac increase to offset the additional cost of SDI. When you add back in the additional cost for harvest you really need 2 t/ac to break even. Changes in this differential are not very sensitive to water cost UNLESS flood uniformity decreases while SDI uniformity remains high.**

This is almost the same differential yield achieved by Hutmacher et al (2001) in an early study in Imperial Valley that compared SDI and flood irrigation from 1994-1996, where they achieved an average annual increase of 1.8 t/ac. Alfalfa ET was virtually the same for both treatments. Economic analysis of 20 years of center pivot vs. SDI in corn in Kansas showed that center pivot was always more profitable than SDI for fields larger than 40 acres (Lamm, 2009). I have heard anecdotal comments by growers and irrigation companies saying they get 2 to 3 t/ac increases in yield with SDI. An alfalfa grower in the Imperial Valley near Seeley has reported growing 15 t/ac with SDI, nearly 4 t/ac more than his flood acreage, and also saved water. His final water use efficiency (WUE, as ton/ac-ft applied water) for the SDI alfalfa was double that of his flood alfalfa. This type of increase in real WUE seems more the exception than the rule, however. A study of 15 years of SDI in row crops by Ayars et al. (1999) concluded that water use efficiency as "crop per drop" was increased mainly due to increased yield, not less water applied per acre.

WEB RESOURCES

Excel Comparison and calculator spreadsheet for alfalfa irrigation system costs in this paper: http://cekern.ucdavis.edu/Irrigation_Management, click COMPARISON OF ALFALFA IRRIGATION SYSTEM COSTS

Excel spreadsheet for comparing center pivot and SDI economics and is available for free downloading at: http://www.oznet.ksu.edu/sdi/Software/SDISoftware.htm

Excellent website explaining soil moisture sensors: http://www.sowacs.com/sensors/index.html

UC cost of production budgets for alfalfa and other major CA crops: http://coststudies.ucdavis.edu/current.php

2011 field crop cost studies for Imperial Valley: http://ceimperial.ucdavis.edu

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Hanson, B.R., K.M. Bali, B.L. Sanden. 2007. *Irrigated Alfalfa Production in Mediterranean and Desert Climates.* Technical manual companion to *Arid Land Alfalfa Manual.* Univ. California, Davis, Dept. Land, Air and Water Resources, UC ANR Publication to be announced. 36 pp.

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Lamm, F. R., D. H. Rogers, M. Alam, D. M. O'Brien, and T. P. Trooien. 2009. Twenty years of progress with SDI in Kansas. ASABE paper no. 095923. Available from ASABE, St. Joseph, MI. 23 pp.

Ludwick, A.E. 2000. High Yield Alfalfa 24 tons Irrigated...12 tons Non-Irrigated. Better Crops Vol. 84 No. 1. pp.18-19

Additional Irrigation Management Resources

Determining Daily Reference Evapotranspiration (ETo). UC Publication 21426.

Irrigation Scheduling: A Guide for Efficient On-Farm Water Management. UC Publication 21454.

Jones, D.W., R.L. Snyder, S. Eching and H. Gomez-McPherson. 1999. California Irrigation Management Information System (CIMIS) Reference Evapotranspiration. Climate zone map, Dept. of Water Resources, Sacramento, CA. http://wwwcimis.water.ca.gov/cimis/images/etomap.jpg

Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Agronomic Crops, Grasses, and Vegetable Crops. UC Publication 21427.