Subsurface Drip Irrigation of Alfalfa – Climbing the Learning Curve

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INTRODUCTION

Long-term strategies for improvement of water-efficient alfalfa production systems are necessary to meet the needs of a growing population, to mitigate drought events, and to lessen demands on water resources (Putnam, 2012). Of these strategies, one of the most important is to improve the technology of water application and control. Management strategies which improve the ability of growers to apply water at rates closely matching true crop demand are important, regardless of crop and the irrigation technology utilized. Drip irrigation is one such technology – the advantages and disadvantages of this technique are discussed.

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WHAT'S THE IDEAL IRRIGATION SYSTEM FOR ALFALFA?

The ideal irrigation system for alfalfa is one that:

- Maximizes Distribution Uniformity (DU), approaching 85-95%
- Allows operators to very closely match applied water with real-time crop demand and use
- Can quickly irrigate an entire field within a day or two
- Allows for small increments of water when needed
- Can completely fill the root zone to field capacity
- Minimizes water losses below the root zone, off-site surface runoff, and evaporation.
- Minimizes energy requirements
- Requires little labor
- Maintains sufficient oxygen in root zone (not excessive saturation)
- Prevents salinity accumulation
- Is flexible and able to adjust for the requirements of frequent harvests (drying periods)
- Does not worsen pest problems (particularly rodents, weeds, nematodes and diseases)
- Minimizes cost

It should be immediately obvious that no system (surface, sprinkler or drip) will fully meet all of these conditions, but each has advantages and disadvantages and strengths for each criterion. Choice of the best irrigation system for a farm must be carefully analyzed considering the available water supply, soil features, and economic criteria. Here we review SDI as applied to alfalfa, as per its major advantages and disadvantages, and suggest methods to improve success with SDI for alfalfa.

DESCRIPTION OF SUBSURFACE DRIP IRRIGATION (SDI) SYSTEMS

We have been observing installation of drip systems on >16 farms in California during 2013-2015. Subsurface drip irrigation is defined as the application of water below the soil surface though emitters with discharge rates generally in the same range as surface drip irrigation (ASAE Standards 2005). Although SDI has been a part of irrigated agriculture in the USA for over 50 years, its nationwide use of SDI in the USA has increased of 59% between 2003 and 2008, which reached 260,000 hectare acres in 2008 (USDA-NASS 2009). Surface drip irrigation (DI) has increased with a more modest rate of 23% during the same period.

In alfalfa, drip lines with a lifetime of 6 to 12 years are typically buried 8 to 18" below the soil surface on 30'-80" centers between lateral drip lines, depending upon soil type. The most common spacing on farms has been 40" spacing, with 10-12" depth, with regular spacing between emitters at 12-16" (note that ideal spacing parameters are dictated by soil type and other factors). A pressurized system (pumps) as well as a filtering and filter maintenance system are necessary for SDI in all crops – as are water treatment capabilities and the ability to apply fertilizers through the system. Most of the systems we have observed source water from wells, whereas some have surface water sources, and in those cases settling ponds or small reservoirs may be necessary to improve reliability of water supply.

KEY POTENTIAL ADVANTAGES AND DISADVANTAGES OF SDI IN ALFALFA

Yield. Both from a theoretical basis, and from observations, water management in alfalfa under SDI has the potential to significantly improve yields in alfalfa. Yield advantages have been widely seen with tomato (Hartz and Hanson, 2009) and in experimental and observational evidence with alfalfa (Hutmacher, 2001) and with growers (Michael, 2009), across many types of soils.

Why is this? There are several key mechanisms which may lead to improved yield in alfalfa, as compared especially with surface irrigation systems (the dominant system in California), but also with some sprinkler systems. We should be careful in our analysis here, since all three systems (flood, sprinkler, and drip) in alfalfa have the capability to be improved so as to improve yields. With SDI, however, there is likely a <u>requirement</u> to increase yields in alfalfa, due to the differences in costs compared with less-expensive surface and sprinkler systems (Figure 1)

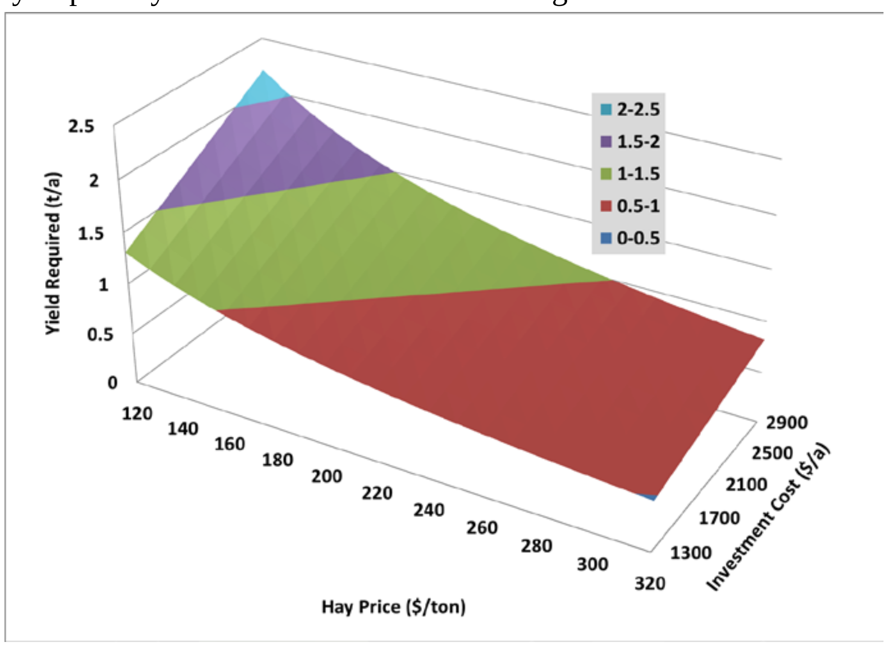

Figure 1. Yield required to justify SDI at various investment costs and hay prices. This considers a 15 year infrastructure depreciation and 6 year tape life, not other differences in operating costs.

Distribution Uniformity over Space. One of the key advantages of SDI systems, when properly spaced, is to improve distribution uniformity (DU) over a field. Check flood systems, especially, may have built-in problems with uniformity due to greater times available for water infiltration at the top vs. middle vs. bottom of the field, especially with long 'runs', sandy soils, or highly variable soils. This is typically not much of a problem in SDI systems, which can apply very close to the same application rate throughout the entire field (although SDI systems must be designed for high DU).

Improvement in Yields in Alfalfa due to SDI may be due to

- Better Distribution Uniformity over the Field
- More Rapid Application of Water over time
- Prevention of wetting-drying patterns in the field, continual supply of water to the plant
- Irrigating closer to harvests
- Irrigating small amounts when needed
- Maintaining oxygen levels in the soil
- Greater yield uniformity
- No surface water evaporation
- Stand longevity – lower weed pressure

Distribution Uniformity over time. One of the key advantages of SDI in alfalfa is the ability to quickly apply a uniform irrigation to an entire field. Depending upon flow rates, many surface systems require from 2-12 days to irrigate a 80-100 acre field. Similarly wheel-line sprinklers require many days to irrigate a field (note that center pivots can also apply water very quickly to a field). This may not seem important, but in a 26-30 day growth period, this can have a huge effect on average yields over the field due to delays in supplying water to certain sections. Timing limitations means that many parts of a field are not irrigated for many days after water is required, causing a built-in drought period for sections of the field that may last for weeks. This appears to be a major advantage of SDI systems.

Costs/Benefits. The cost of SDI installations in alfalfa fields is clearly been an important disadvantage of SDI systems in alfalfa, and has been the key limiting factor to adaptation of the technique historically. However, these costs can be justified if yields are improved and/or price of the product is sufficient to cover costs (Sanden et al., 2011). During the past 20 years, the industry has seen dramatic increases in the value of alfalfa hay, which exceeded $200/ton for the first time in 2007, and has been most frequently priced from $180 to over $300/ton during the past 8 years (Figure 3). This has fundamentally changed the cost/value equation for growers for SDI and other improvements. In our review of grower investment costs, these have ranged from a low of $800-$1,000/acre to nearly $3000/acre, with typical

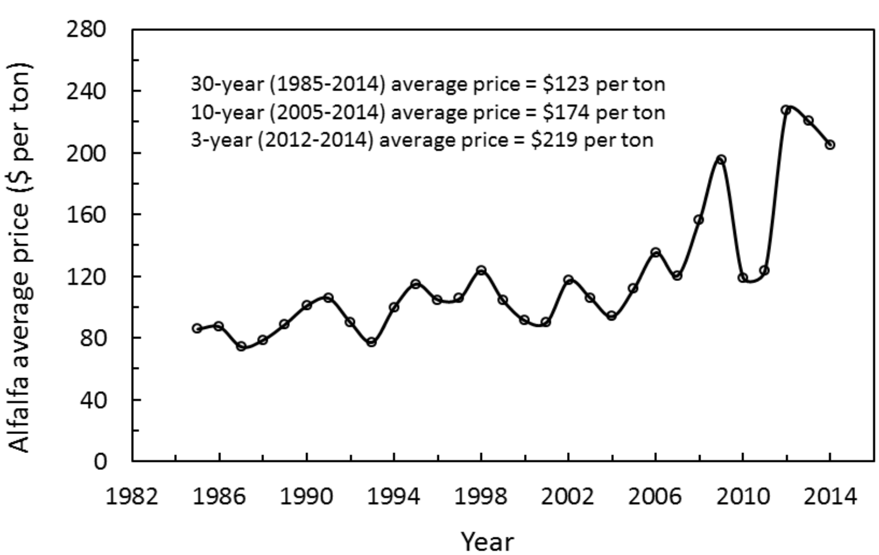

Figure 3. Price of alfalfa hay, California, 1984 through 2014 (USDA-NASS and Hay Market News).

costs ranging between $1600-$2200/acre.

The yield required to justify the cost of SDI in alfalfa can be seen in Figure 2 – modelled with hay prices between approximately $160 to $280/ton and investment costs in the $2,000 range, typically from less than ½ ton to 1 ½ ton is required to justify the system (utilizing a 15 year infrastructure lifespan and a 6 year drip lifetime). Growers have reported about 2.5 tons/acre improvements in yield.

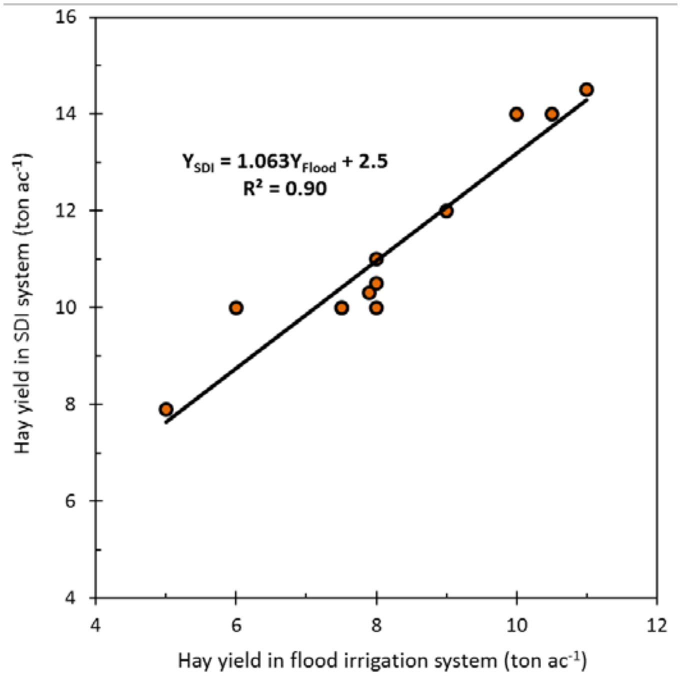

Figure 4. Estimation of yields in SDI systems by growers, compared with their check flood systems on 11 California ranches (survey data).

Labor. SDI systems have the promise of reduced labor requirements, and this has been demonstrated on several farms. Certainly, a well-designed system can be nearly fully automated, compared with many surface systems which require full time irrigators.   However, additional labor is likely to be required for scouting for rodent infestations and fixing leaks in the system, and fine-tuning irrigation strategies. Additionally, finer management skills are likely to be required in SDI systems to monitor irrigation schedules, water quality, and system performance.

'Corrugation' Yield Patterns in SDI Fields. One problem with SDI systems we have observed is less-than-optimum distribution uniformity on some soil types, depending upon the spacing of lateral SDI lines and water management (Figure 5). This results in a 'corrugation' yield pattern, with alternating higher-and lower-yielding strips, with higher yielding crops immediately over the drip lines – in many cases we have estimated yield losses due to this pattern to be in the 10-20% range, in spite of over-all excellent yield levels in the SDI system over the whole field. While this should be listed as a disadvantage currently (depending upon soil types), this can be addressed through spacing changes (reducing spacing to less than 40", depending upon soil type), or perhaps timely flood irrigation events.   The corrugations are mostly observed during the first year of the stand and become less apparent afterwards.

Rodent Damage. Rodent damage, particularly the potential for gopher, vole, or squirrel damage, is probably <u>the</u> key practical disadvantage and main barrier of adaptation of SDI currently.   Some environments and locations appear to have far greater rodent pressure than others. Gophers in particular, due to the ideal habitat represented by alfalfa (plenty of food, cover, and undisturbed soil) can be devastating to SDI in alfalfa, and several SDI installations have been abandoned due to rodent damage, so its importance should not be underestimated. While rodent damage to alfalfa stands is likely no different in SDI compared with sprinklers (where it is also a significant problem), at least in sprinkler-irrigated fields it does not ruin the irrigation system. Rodent burrows are flooded with surface irrigation methods, reducing the populations of gophers with flood irrigation. However, only SDI is under threat due to chewing on the drip lines and leaks resulting from rodent activity.

A range of techniques can be used to manage rodents. Rodent damage can be reduced by initial soil preparation (deep ripping), and a combination of frequent monitoring, scouting for sources of invasion, use of many techniques including trapping, poisoning, the use of predators (owl boxes), the use of repellents such as Protec-T. Many of these techniques require further evaluation as to their effectiveness, but a high level of management and vigilance should be considered a requirement for effective management of SDI in alfalfa.

Figure 5. SDI generally results in excellent Distribution Uniformity throughout the field, as in this Imperial Valley field (left). However, a 'corrugation' effect can be seen on some soil types and some lateral spacing, resulting in poorer growth between lateral drip lines, as per this field in Fresno County (right). This may be especially seen during early root development, but can be mitigated by occasional flood irrigations or closer lateral spacing.

Crop Rotation. Alfalfa SDI fields would likely be rotated with another crop such as corn, wheat, cotton or tomato over a 6-12 year period, leaving the system in place, so the return on investment can be optimized. Crop rotation may prove to be an important aspect of profitability and viability of the system as a whole. Many of the growers we spoke with plan their systems to accommodate several crops – either starting with alfalfa or starting with another crop. Systems which install SDI for crops such as tomato have rotated to alfalfa, having paid most or all of the costs of the system with the tomato crop. However, the spacing may not be optimized for both crops. Further research on optimum crop rotations with SDI may be necessary.

Stand Persistence. Some growers have theorized that stand persistence can be improved with SDI. Although we do not have clear long-term evidence, there is some preliminary evidence to support this. Stand persistence may be improved due to 1) lack of standing water on the surface, 2) less traffic influence due to traffic on dry surfaces, 3) better 'tail end' stands due to better drainage at the ends of fields compared with surface systems, 4) lack of soil cracking on cracking clay soils. Several SDI alfalfa fields have now been in place for over 4-8 years with good success, and an experiment comparing SDI with check flood at El Centro, we have already observed significant tail-end alfalfa stand damage due to flood irrigation, whereas stands are excellent in the SDI field after 2 years of production.

Water Quality, Evaporative Losses. The low evaporative losses (due to the low evaporation off of relatively dry soils) is a key advantage of SDI vs. surface or sprinkler systems, when properly designed and operated. Additionally, SDI systems result in zero runoff – water moving off of check flood irrigation fields, which has been a major issue for water quality, since pesticides or particulates can move off of fields (Prichard, 2010). Growers are under tremendous pressure to minimize these sources of pollution, and SDI offers a key advantage for water quality environmental impacts.

Water Savings. We will not comment extensively here on the potential for water savings with SDI . However, depending upon the efficiencies of the system to which it is compared, water savings can be substantial, especially on sandy soils. Hutmacher et al. (2001) and others have noted that SDI systems may result in increased yield, which may actually increase water demand, although he reported a modest savings in water (7%). However, since application efficiencies are greater and yields increase, the Water Use Efficiencies of alfalfa under SDI are likely to be greater. Since ET is directly related to yield in alfalfa, no change in actual utilization of water is expected – the major changes would be in the efficiency of application (reduction in runoff, reduction in evaporation). On sandy soils especially, the savings in water application is likely to be significant compared with surface systems.

Irrigation Scheduling. SDI offers a key advantage in designing and implementing irrigation schedules with a higher level of control. Growers can choose virtually any irrigation schedule (e.g. 4 hrs/day, 12 hrs/day, every other day, etc.), or 'spoon feeding' water and fertilizers to the crop to precisely meet demand. There is significant evidence for increased yields with SDI, which is likely due to the avoidance of periodic drought and ability to continually provide sufficient moisture for alfalfa crops under unsaturated conditions, which in turn results in improving oxygen circulation in the root zone. The capacity to provide water directly to the root zone exactly as needed is a key advantage of SDI.

Influence of Harvests on Irrigation. Alfalfa is unique among crops in that harvest scheduling must be considered when designing irrigation methods and management practices. SDI has some key advantages in this regard. In check flood fields (and in many sprinkler irrigated fields), growers must dry down the crop for 7-20 days before, during, and after harvest. Growers have discovered that they can irrigate much more closely to a harvest period with SDI, reducing drought stress effects that result from harvest schedules. Although theoretically, one could irrigated during harvest, growers have found that to be impractical, and utilize the harvest period to repair SDI systems and control gophers.

Salinity. Salinity may be a key limitation for SDI systems. Buildup of soil saline conditions could occur between drip lines, or at different levels of the soil if steps are not taken to control salinity. This can be a major issue in some regions which have high salinity in their irrigation sources, such as the Imperial Valley. Irrigation scheduling in combination with introducing non-SDI methods (sprinklers or flood irrigation) in combination with SDI are important strategies for controlling salinity in saline affected areas. Design and drip line spacing should also account for salinity, in such a way to achieve a certain degree of overlap among the wetted areas, as salts tend to accumulate along the wetted fronts (or fringes). Overlaps among wetted areas are thus intended to keep salt well diluted, thus preventing harmful salt concentrations.

Need to Retain Diverse Water Application methods. Our observations have led us to believe that growers should try to retain other methods of water applications in their SDI installations, including the ability to flood irrigate, and/or sprinkle irrigate. Why is his necessary? Sprinkler irrigation is nearly universally recommended for stand establishment of alfalfa, including with surface-irrigation systems, due to the need for small amounts of water applied to the surface and the need to prevent crusting. Drip lines buried 8-12" deep are not likely to supply moisture uniformly to the soil surface for seedling growth. After establishment, an occasional flood (or sprinkler) irrigation is likely to be beneficial on some soil types. Its purposes would be 1) to provide an initial full uniform soil water profile before significant growth to promote deep rooting patterns, 2) Improve crop growth between laterals (see Figure 5), 3) suppress gopher habitat, and 4) to control salinity through leaching

Key Opportunities for Future Research and Improvement. Since this method has not been widely adapted in alfalfa, there are a range of opportunities for improvement of this system as applied to alfalfa. Important areas for further research include;

- Innovative techniques for rodent management in alfalfa
- Prediction of optimum spacing and depth of driplines for alfalfa under different soil types
- Better irrigation scheduling under SDI systems to maximize yield
- Influence of SDI on quality, longevity of stands.
- Interactions of SDI with controlled traffic
- Ability of SDI to conserve water and perform under deficit (drought) conditions
- Interactions with varieties.
- The performance of SDI under different crop rotations
- Economic returns of SDI under different economic and soil conditions

CONCLUSIONS

Subsurface Drip Irrigation, although currently practiced by a minority of farmers, has the capacity to improve yields and improve water use efficiency. The key mechanisms for improvement in crop performance are likely the ability to 1) maintain continuous water supply and better soil moisture conditions ('spoon feeding') to the crop, 2) Better distribution uniformity over space and time for both water and nutrient applications, 3) prevention of wetting-drying cycles which may result in lack of water during sensitive growth periods as well as lack of oxygen to root systems. Key limitations of SDI methods include cost of installation, which must be justified by higher yields, and management of rodent damage and water quality. Although one must be cautious about its limitations, the ability of SDI to achieve higher yields in practice should be viewed as an important strategy for increasing water use efficiency of irrigated alfalfa production systems. UC web resources for SDI can be found at: http://alfalfa.ucdavis.edu