

# AGRONOMIC PRACTICES FOR SUBSURFACE DRIP IRRIGATION IN ALFALFA

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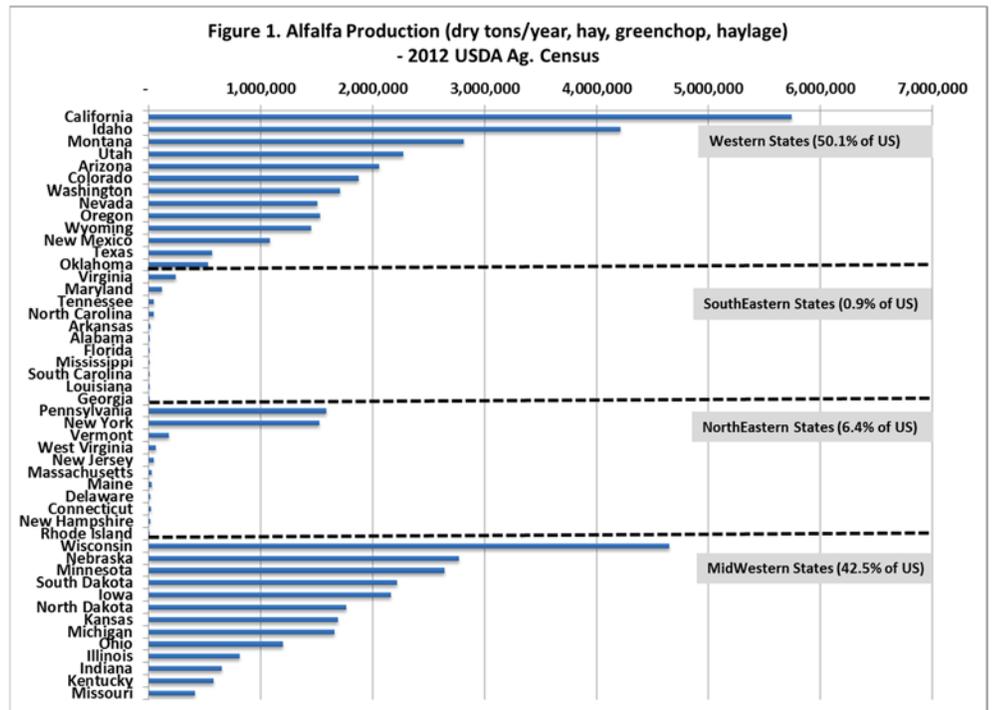
## ABSTRACT

Subsurface drip irrigation (SDI) has the potential to improve water use efficiency in alfalfa production systems. The major advantages include ability to carefully follow the water needs of the crop and match Evapotranspiration (ET) needs, to automate the system, prevent surface runoff, reduce weed germination, and most importantly to improve yields and increase water use efficiency. The major disadvantages are initial cost and maintenance of the system, particularly rodent management. While some growers have managed SDI with a high degree of success, others have been unable to manage the system maintenance due to the excessive rodent damage in some regions in California.

## INTRODUCTION

Approximately 50% of US alfalfa forage (hay, greenchop, haylage) is produced in the western US, mostly under irrigation (Figure 1). Irrigation also contributes significantly to alfalfa production in transition states such as Kansas and Nebraska. Alfalfa is the fourth largest crop in economic value in the US, and dominates many irrigated cropping systems in the western US.

Water (supply, efficiency, management) is typically the largest challenge facing western growers, and is the factor most frequently impacting yields. Long-term strategies for improvement of irrigated alfalfa production systems are necessary to improve



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yields, to mitigate drought events, and to reduce demands on water resources. Of these strategies, one of the most important is to improve the technology of water application and control. Towards this aim, subsurface Drip Irrigation (SDI) has been implemented by a number of alfalfa producers. In this paper, we outline several of the key values of SDI in alfalfa irrigation systems, recommend important management practices, and several of the important impediments to success with SDI in an alfalfa cropping system.

## WHAT'S DIFFERENT ABOUT ALFALFA?

Alfalfa has several fundamental differences from other irrigated crops, including:

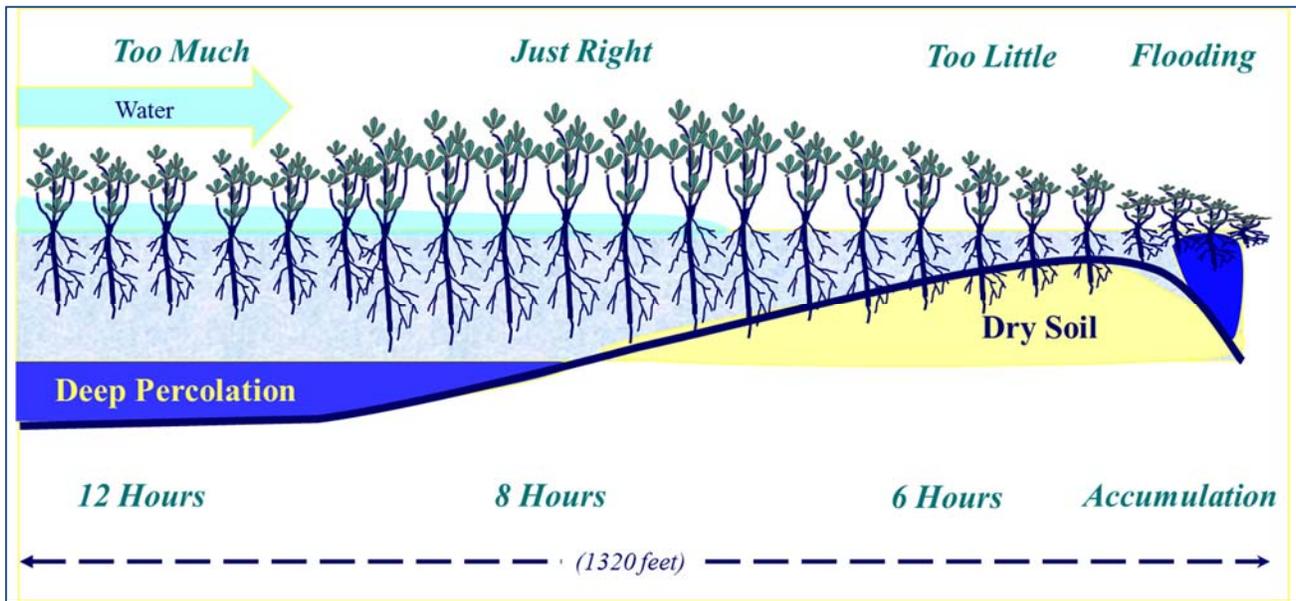
- **It is a broadcast crop** not a row crop – requiring full spatial soil wetting patterns.
- **Alfalfa is a small-seeded perennial** – therefore irrigation is in two phases – stand establishment for several months, and production for 3-10 years.
- **Deep-Rooted Crop**– Once established, alfalfa can tap into subsurface soil water and explore the full soil profile to at least 4-5 feet.
- **Herbaceous Biomass crop.** Since it is not a seed or fruit crop, biomass yield is directly related to the continuous supply of water which maximizes foliar growth.
- **Alfalfa has built-in droughts**–It is harvested 3 to 10 times/year, requiring periodic dry periods each harvest. This causes 9-18 day droughts each month, limiting management.
- **ET of alfalfa changes significantly** over 25-35 day periods, dropping to approximately ~0.3 of reference ET during a cutting, rising to ~1.1 at full canopy many times per year.
- **Alfalfa is sensitive to flooding.** Although alfalfa is often flood irrigated, standing water frequently harms alfalfa with surface irrigation.
- **Suitable for Deficit Irrigation**—alfalfa can be successfully deficit irrigated due to deep roots and ability to dry down selected harvests, producing a high percentage of full yield.
- **Alfalfa creates significant year-long wildlife habitat and cover**– therefore control of vertebrate pests (gophers, voles) is particularly problematic.

The fact that alfalfa is not a row crop or spaced orchard or vineyard crop is a fundamental difference from other drip-irrigated crops due to differing geometry and growth patterns and the need for the crop to obtain water from the entire soil profile. Most drip systems were developed for spaced or row crops. However, SDI holds promise for alfalfa production, particularly in long-season environments, and has been successfully implemented by growers in some environments.

## KEY POTENTIAL AND OBSERVED ADVANTAGES OF SDI IN ALFALFA

Use of SDI in alfalfa has several key advantages over some other types of irrigation systems. There are disadvantages as well, which will be discussed.

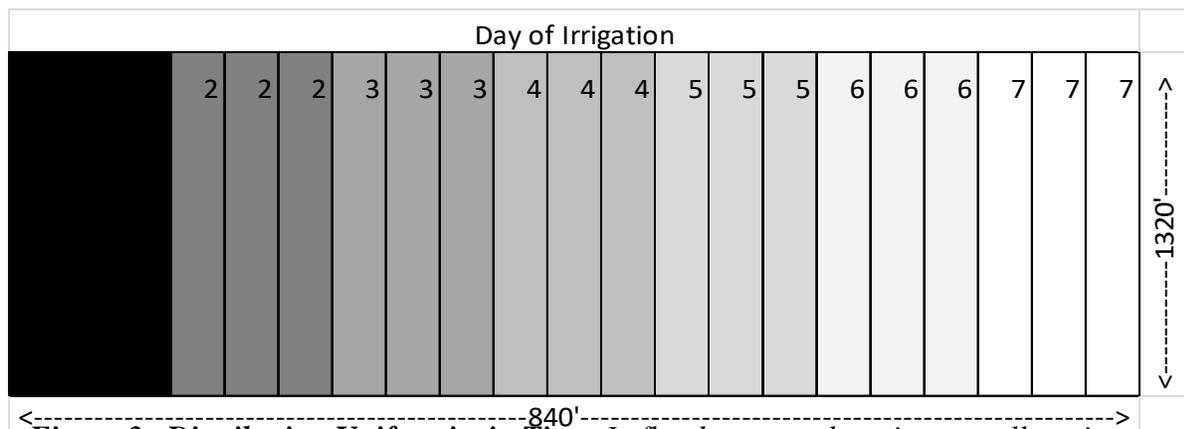
**Distribution uniformity in space.** One of the key advantages of SDI systems, when properly designed, is to improve distribution uniformity (DU) over the field. Check flood systems, especially, may have built-in problems with spatial uniformity due to greater times available for water infiltration at the top vs. middle vs. bottom of the field (Figure 2), especially with long 'runs', sandy soils, low flow water supplies, 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. Well-tuned overhead sprinkler systems also have this advantage over surface



**Figure 2. Spatial Uniformity.** Check flood systems on large fields have built-in poor distribution uniformity from the top to the bottom of irrigation runs. Since water takes some time to be pushed down the field, some areas receive less and other areas more water. Accumulation of water at tail ends (right) in surface systems often results in death of stands over time. SDI provides generally a more uniform Distribution Uniformity in space compared with check flood irrigation.

systems, but some sprinkler systems may have distribution problems depending upon the influence of wind, nozzling, and the design of the system. SDI systems particularly have an advantage over check-flood systems at the tail-ends of fields, where stand (and yield) losses are common due to standing water and other irrigation problems associated with flood systems.

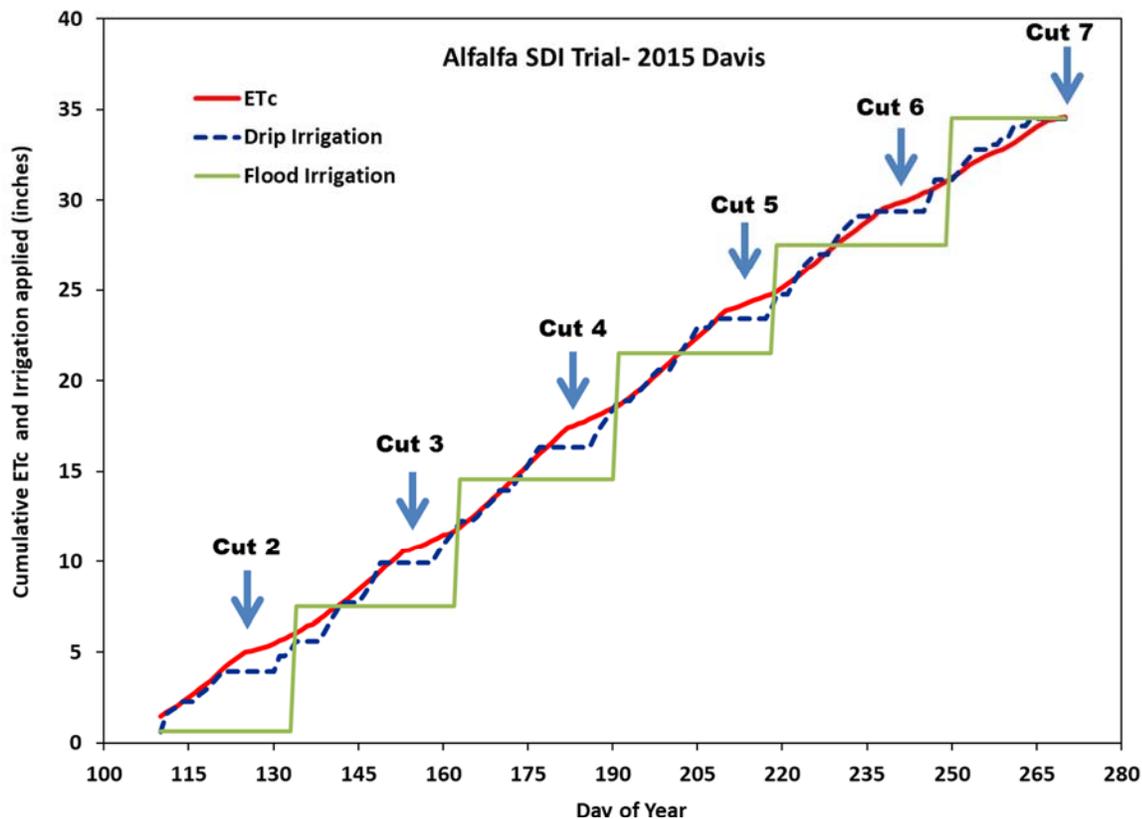
**Distribution uniformity in time.** One of the key advantages of SDI in alfalfa is the ability to quickly apply a uniform irrigation to an entire field, and to continuously irrigate a field when the



**Figure 3. Distribution Uniformity in Time.** In flood systems there is generally a time-constraint for water application. In this example, each 'set' of 3 checks might take 8-12 hrs., therefore 7 days to irrigate the field. Therefore different parts of the field are watered differently at different stages of growth. SDI, in contrast, could wet a field within a day.

crop needs water. Depending upon flow rates, many surface systems require from 1-12 days to irrigate a 80-100 acre field (a 7-day irrigation schedule is illustrated in Figure 3). Similarly wheel-line sprinklers require many days to irrigate a field. This causes irrigation timing limitations in some sections of a field may receive water a week later. On the other hand, the easy of automation and ability to make high frequency low volume applications with SDI leads to improved irrigation application efficiency and water productivity

**The importance of logistics in supplying water to alfalfa.** Alfalfa harvests are typically from 24-35 days, up to 10 times per year. The crop must be dried down each time (usually 3-8 days before and 4-9 days after a cut) to accommodate machinery, this results in a ‘built-in drought’ of 8 to 18 days each cut! Therefore, there is a window of only about 10-17 days each cut where irrigations can occur. This is particularly a problem for check flood systems and wheel lines, since essentially only one or two irrigations can occur during a growth period. Surface irrigation systems can only supply a fixed amount of water (the amount of water it takes to move the flood across the field), typically 4-6”. Thus the soil can go from saturation to near bone-dry and back again. This can have a huge effect on yields due to delays in supplying water in time. This appears to be a major advantage of SDI systems vs. surface systems and some sprinkler systems. Note: well-tuned overhead sprinkler systems also have this advantage.



**Figure 4.** The Evapotranspiration needs of the crop (ETc, solid continuous line) can be met either by SDI (broken line), or by a flood irrigation events (stair step solid line). A single flood irrigation per cutting results in over-irrigation followed by excess drying, while SDI can more closely follow the ET water needs of the crop. The total seasonally-applied water is the same, but SDI more closely follows water needs of the crop. This is ET data and SDI data from Davis, CA.

**Ability to apply water directly to root systems.** Evapotranspiration needs of a crop (ET<sub>c</sub>) is an estimate of the amount of water that the crop actually uses in a day, week, or year. Ideally, all irrigation techniques should follow the ET<sub>c</sub> demand of a crop and approximately match ET<sub>c</sub>, allowing for inefficiencies of each system. Thus if a crop requires 0.25 inches a day (typical in June for alfalfa), ¼ inch can be supplied that day, or at least supplied in 1-2 inches after a few days, with the soil acting as a reservoir. SDI has the ability of quickly supplying small amounts of water continuously to meet water needs, avoiding excessive wetting and drying cycles. Since water is supplied directly to roots, limitations of evaporation and water infiltration are less. Herbaceous plant growth is directly related to the column of water which creates turgor pressure, prevents stress, and leads to high yields.

**Ability to apply nutrients.** Availability of fertilizers is often limiting to crop growth – this is thought to be a major advantage of SDI in tomato (Hartz and Hanson, 2009). While N is likely to be the major nutrient of interest for non-legumes, phosphorus, potassium and perhaps other nutrients are of interest for alfalfa. Some growers have claimed benefits from N applications in alfalfa, but this has not been demonstrated in controlled studies. Since P is often subject to soil fixation, this may be a significant benefit of subsurface applications, creating regions of high P availability, especially on desert soils. Further work is needed in this area.

**Labor Savings?** 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 to move pipe, open and close gates, etc. However, additional labor is likely to be required for scouting for rodent infestations and fixing leaks in the system, and fine-tuning irrigation strategies. Higher management skills are likely to be required in SDI systems to monitor irrigation schedules, water quality, and system performance.

**Stand persistence.** SDI has the potential to improve stand persistence. 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.

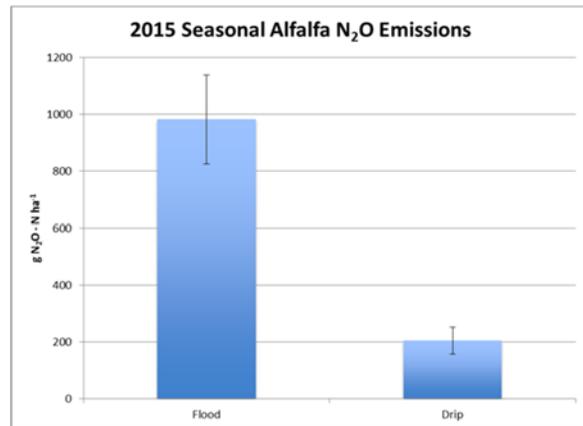
**Weeds.** We have observed, and growers have observed improvements in weed infestation in SDI alfalfa fields. This is a function of both lack of moisture for weed seed germination on soil surfaces, and of better stand persistence. In alfalfa, weed infestation are primarily a function of deteriorating stands (open areas).

**Yield.** Yield benefits are the primary promise of SDI. 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. This is likely due to the superiority of SDI in Distribution Uniformity and following ET as outlined above. 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 (e.g. re-designing and automating surface systems, or site-specific sprinkler systems, or improved scheduling and soil moisture monitoring-e.g. Neibling et al., 2009). But there are some innate qualities of water management with SDI discussed above which are likely to improve yields if implemented successfully. On the other hand, improvement in yield may be a requirement of SDI in alfalfa, due to the differences in costs compared with less-expensive surface and sprinkler systems. The yield range in long-seasoned environments ranges from 5 t/a to about 17 t/a and many of these differences on farm can be traced to irrigation management.

| Figure 1. Comparisons of Water Productivity (year 1) for alfalfa produced with flood irrigation, SDI with various deficit treatments and SDI under full irrigation, Kearney Research and Extension Center, Fresno County, CA, 2017. |       |
|---|-------|
|   | Kg/mm |
| Flood Irrigation (Full)   | 20.62 |
| SDI with July Cutoff  | 29.40 |
| SDI with August Cutoff  | 26.24 |
| SDI with July-Oct Partial Irrigation  | 24.72 |
| SDI (full irrigation)   | 22.60 |

**Water Savings/reduction of runoff.** Depending upon the efficiencies of the system to which it is compared, water savings can be substantial, especially on sandy soils. However, the opposite may be true if 1) SDI does a better job of supplying water needs of the crop, and 2) either sprinkler or flood irrigation is commonly deficit irrigated. Hutmacher et al. (2001) and others have noted that SDI systems may result in increased yield, which may actually increase water demand. However, since application efficiencies are greater and yields increase, the Water Productivity (WP, tons of hay per unit water) of alfalfa under SDI are likely to be greater. In 2017, water productivities of alfalfa was improved over flood irrigation, but particularly under deficit irrigation treatments (Table 1). 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), and in some comparisons, these savings may be substantial. An important benefit of SDI is the complete elimination of 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



**Figure 5.** Nitrous Oxide emissions measured in SDI alfalfa fields compare with flood, Davis, CA. Periodic flooding creates spikes of N<sub>2</sub>O emissions which does not occur with drip. (unpublished data from Byrnes, Burger and Horwath)

tremendous pressure to minimize these sources of pollution, and SDI offers a key advantage for water quality environmental impacts

**Greenhouse Gasses.** SDI in alfalfa, since it wets soils below the surface, results in less seasonal N<sub>2</sub>O emissions than flood irrigation (Figure 6), according to work done by UC Davis scientists Byrnes, Burger and Horwath.

### MAJOR DISADVANTAGES OF SDI IN ALFALFA

**Costs.** 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 nearly \$300/ton during the past 8 years. 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 costs ranging between \$1600-\$2200/acre.

The yield required to justify the cost of SDI in alfalfa depends upon both initial cost and the value of hay. Typically these may be from less than ½ ton to 1 ½ ton required to justify the system (utilizing a 15 year infrastructure lifespan and a 6 year drip lifetime). SDI would be more attractive if systems were reliably able to last longer- there are systems in place for alfalfa and corn that have exceeded 15-20 years in lifetime. This does not include other potential differences in costs between the system, such as labor, maintenance, gophers, etc., or subsidies offered to install systems. In our survey of growers, they estimate that yields have been improved an average of 2.5-3.0 tons/acre compared with their check flood systems. However, we have found this only to be the case in long-seasoned environments.

**‘Corrugation’ Yield Patterns in SDI Fields/Filling Soil Profiles.** While Distribution Uniformity in SDI is frequently better than most other systems, we have observed is less-than-optimum distribution uniformity (DU) 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.

**Salinity.** Salinity may be a key limitation for SDI systems in some regions, but can generally be managed with an integrated system. 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.

**Rodent Damage.** Rodent damage, particularly the potential for gopher, vole, or squirrel damage, is probably the 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.

### **KEY RECOMMENDATIONS FOR IMPLEMENTATION OF SDI IN ALFALFA**

**Proper Design:** Although complete design recommendations are specific for each farm, and beyond the scope of this article, here are a few key points: Continuous water sources are typically required, which may entail well sources, reliable surface supplies, or local reservoirs. The source and quality of the water, soil type, crop rotation and other factors will determine designs. Typical depths for alfalfa have been 8-12", depending upon soil type, with some installations deeper. Shallower depths enable quicker repairs. Spacing between laterals have ranged from 30" to 60", with 40" being most typical. Spacing is determined by soil type and crop rotation. The life of the installation (e.g. 4-6 years of alfalfa followed by row crops) to consider a potential 10-year installation. SDI flow rates for alfalfa should be designed to meet maximum daily ET requirements, similar to other crops. SDI systems for alfalfa should be able to refill the profile after about 15-17 days of zero irrigation, necessitated by frequent harvests, which might be 2-3" in a few days. Thus narrower spacing (e.g. 30") may have advantages for alfalfa, depending upon soil type. Consult a specialist on specific designs for a given soil/water quality combination.

We recommend retaining infrastructure for an occasional surface irrigation on SDI installations.

**Understand Your Soil Properties.** SDI has been demonstrated to work on soils ranging from sandy to heavy clay. However, designs and management are likely to differ based upon soil type. The vertical and horizontal movement of moisture is particularly important, as is the influence of gravity on water (disappearing below the root zone), or the excessive movement of water up to the surface.

**Proper Stand Establishment.** We cannot overemphasize the importance of proper stand establishment techniques for SDI, which create vigorous root systems capable of extracting moisture from deep in the profile. SDI delivers water deep in the profile, so roots must reach this moisture. Surface irrigation (sprinklers or sometimes flood) irrigation are required to establish an alfalfa crop, after which SDI can be implemented. Optimum planting time (e.g. early fall), seeding depth, irrigation management (sprinklers), weed control are also important. This is a

function of both the small seed size, the broadcast shallow planting requirement. Excellent depth of roots are important to obtain moisture from SDI installations. Some of the mistakes we've seen have resulted from improper timing of planting (too late in fall), or failing to irrigate to assure good deep rooting depth over 3-4 months before switching to SDI.

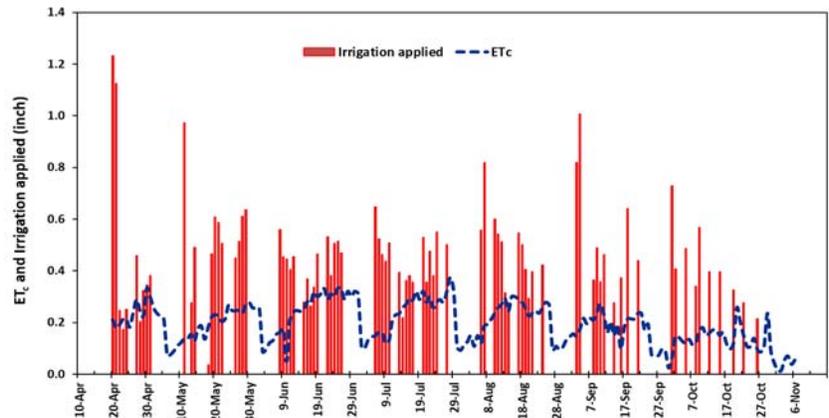


**Figure 6.** SDI generally results in excellent Distribution Uniformity throughout the field, as in this Imperial Valley field (left). However, a 'corrugation' effect can be seen on some soil types and some lateral spacing, resulting in poorer growth between lateral drip lines, as per this field in Fresno County (right). This may be especially seen during early root development, but can be mitigated by early flood irrigations or closer lateral spacing.

**Need to Retain Diverse Water Application methods, especially flood.** 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 this 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 inadequate for seedling growth. After establishment, an occasional flood irrigation is likely to be beneficial. 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. Rodent management in particular is benefitted with flood irrigations. Utilizing 1-2 flood irrigations/year could be beneficial. We've observed growers who have done away with their supply ditches and checks have regretted it and often come back and re-installed surface systems.

**Irrigation - Fill the Profile Early.** With all irrigation strategies, it's very important to start the year with a full soil profile. But this is particularly true with SDI – which is excellent at sustaining moist conditions, but sometimes limited in filling the soil profile. Use a normal soil probe, shovel, or soil moisture sensors placed at different depths (to measure the depth of moisture), and use a soil probe to understand the effect of lateral spacing on moisture in-between the drip lines. It may be necessary to utilize a single flood irrigation

**Irrigation Scheduling – Follow ET.** A huge advantage of SDI is the ability to carefully follow the Evaporative demands of the crop on a daily, weekly, or monthly basis. However, this requires some system to understand the ET demands of the crop (ET<sub>c</sub>) during the spring, summer and fall months, since water demands vary. The simplest way to do this is to look up the real-time (or even average across years) ET of your region, and use that as a benchmark goal for water applications. Once the soil profile is filled, water should be applied to meet those daily needs.



**Figure 7.** Frequency of SDI irrigation in comparison with the ET demands of the crop, SDI experiment, Davis, CA, 2015. Note that the ET<sub>c</sub> goes down each month due to the harvest schedule, and is lower in the fall of the year.

One must learn by experience the maximum number of hours that a system can be run – this is typically from 4-10 hours. Remember that the profile must be refilled just after a harvest, so longer irrigations are necessary to make up for the 10-18 day drought.

**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.

**Rodent Management –** The management of rodents is the key to the implementation of SDI in alfalfa in many environments. The largest problems have been with pocket gophers and voles. We have observed that this appears to be a lesser problem in desert southern environments, but has resulted in SDI failures in many areas. In general the problem originates with a failure to prioritize rodent management among the many tasks on a farm – thus assignment of a full time individual to manage gophers may be necessary. A range of techniques can be used to manage rodents – please see Baldwin, 2015 for much greater detail. Infestation can be reduced by initial soil preparation (deep ripping), fallowing and crop rotation, and a combination of frequent monitoring, scouting for sources of invasion. Several techniques have been used, including trapping, use of toxic baits using hand baiting or burrow builders, carbon monoxide gassing the use of predators (owl boxes). For gophers, trapping, although labor intensive, may be more satisfying since one **knows** that the infestation has been reduced. Vole populations may reach

high levels and harm SDI systems, and trapping is generally ineffective – Zn phosphide baits are likely the only option. Flood irrigation is often important for reducing populations, and is recommended as an occasional treatment for SDI fields for that purpose. Many of these techniques require further evaluation as to their effectiveness, but a high level of management and vigilance which integrates many techniques should be considered a requirement for effective management of SDI in alfalfa.

***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
- Irrigation scheduling under SDI systems to maximize yield
- Interactions of SDI combined with controlled traffic
- Ability of SDI to conserve water and perform under deficit (drought) conditions
- Economic returns of SDI under different economic, crop rotation, 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 source 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.

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