Thriving in Drought with Subsurface Drip Irrigation (SDI): Case Studies and Tools

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Abstract. *As the worst drought in 50 years gripped America's farmland in the summer of 2012, three Nebraska producers reported increased soybean yields and significantly lower water use at the same time by using Subsurface Drip Irrigation (SDI) to deliver water and nutrients directly to the roots of their crops. This was in contrast to the typical practice of applying water to the surface with gravity or sprinkler irrigation systems. In addition to improved yields and resource use efficiency (RUE), other benefits cited included an improved ability to farm in drought conditions, improved flexibility and improved convenience. In each of these case studies, the producer found SDI a worthwhile investment.*

Considering the potential benefits of SDI, Toro has developed several tools that help producers with the transition. First, the Drip/Micro Payback Wizard is an online calculator that estimates how long it will take to pay for an investment in SDI by comparing before and after yield and production financial data. In addition, it estimates how many additional acres may be farmed with the water saved by adopting SDI. Second, AquaFlow Drip Irrigation Design Software allows users to quickly and easily design a drip irrigation system by entering field parameters and then selecting appropriate laterals, sub-mains and mainlines. Third, the 129-page, four-color, fully illustrated second edition of Toro's Drip Irrigation Owner's Manual is available in both English and Spanish, with measurements in English and metric units. All of these tools are available for free download from toro.com and driptips.toro.com.

Keywords. *Subsurface Drip Irrigation (SDI), Drought, Drip Irrigation Economics, Drip Irrigation Design, Drip Irrigation Operation and Maintenance.*

Introduction

Micro-Irrigation, also commonly called drip irrigation, is the fastest growing irrigation technology in the Unites States. It was commercially introduced over four decades ago, and its usage has since spread to 3.5 million acres of diversified farmland throughout the US as of 2008 (USDA, 2008). Documented case studies have shown that farmers adopt drip irrigation for a variety of reasons, including improved crop response from the spoon feeding of water and nutrients directly to the crop's rootzone, and improved resource use efficiencies. These benefits often boost farm income and reduce irrigation related production costs enough to pay for the investment quickly. In addition, runoff, wind drift and deep percolation of irrigation water is minimized, and access to the field is improved compared to other irrigation methods (Toro Grower Solutions, 2007-2012). Figure 1 graphically describes these typical benefits (Corcos, 2012).

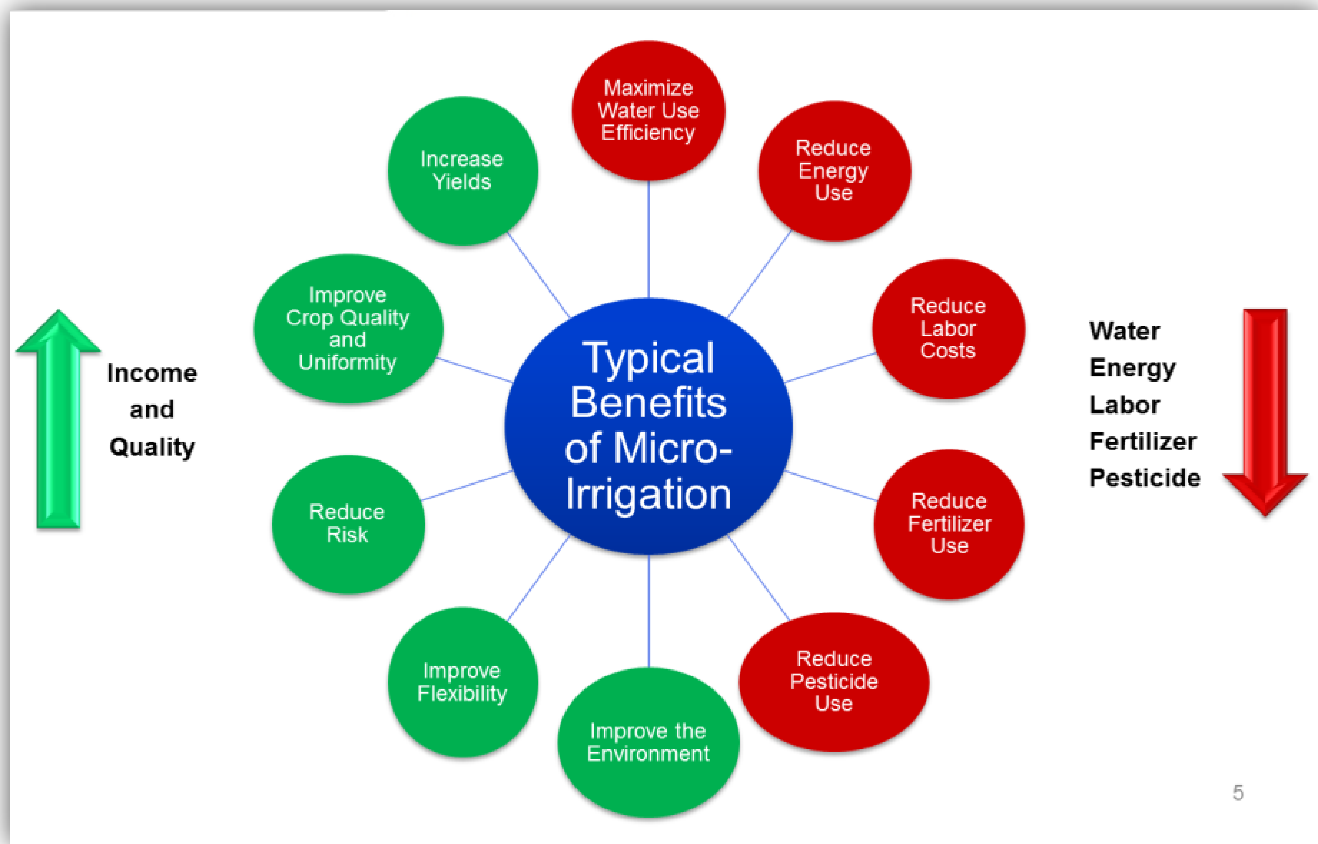

Figure 1 - Typical Benefits of Micro-Irrigation showing increased income and quality, and decreased water, energy, labor, fertilizer and pesticide costs.

Drip irrigation differs from gravity and sprinkler irrigation in a number of ways. A drip system consists of a network of plastic pipes and emission devices that deliver pressurized water directly to the soil at a low pressure and low flow rate. It is typically operated at frequent intervals, and the duration of operation may be adjusted to accomplish numerous changing objectives. The system is flexible and may accommodate a wide range of block sizes and shapes and flow rates. Source water is filtered to prevent clogging of drip system emission devices, and chemical injection systems are used to apply fertilizers, crop protection materials and drip system maintenance chemicals (Stetson, 2011). Figure 2 shows a Typical Drip System Layout for field crops (corn shown), row/vegetable crops (lettuce shown), vineyards and orchards (almond trees shown). (Toro, 2012).

Subsurface Drip Irrigation (SDI), the topic of this paper, is a specialized sub-set of drip irrigation where lateral lines are buried beneath the soil surface. In the case of SDI for field crops such as soybeans, corn, cotton and alfalfa, drip tape laterals are buried 6 – 18 inches deep and are connected to sub-mains that are buried 2 to 3 feet deep and remain undisturbed for many years. Research at Kansas State University has shown that these systems are capable of performing well for over 20 years without replacement and that "annual system performance evaluations have shown that dripline flowrates are within 5% of their original values." (Lamm, et al 2011). This longevity enhances the economic viability of drip for crops that typically have lower profit potential in comparison with the fruit, nut and vegetable crops that have historically adopted drip first. The graphic at the bottom left of

Figure 2 is a good example of how SDI systems are configured for the soybean crops that are described in the following case studies.

n the course of documenting the following three case studies from the state of Nebraska, it becomes apparent that the benefits of drip for soybeans, a field crop, in this drought stricken region are somewhat different than those usually cited for fruit, nut and vegetable crops, or even field crops, in non-drought stricken areas. While yield increases and resource use efficiency are common benefits of using drip irrigation in numerous crop situations, these producers especially appreciated the improved ability to farm in drought conditions using SDI, as well as the SDI system's flexibility and convenience. As a result, the contents of the "Benefits of SDI" as shown later in Figure 5 are different than the "Typical Benefits of Micro-Irrigation" shown in Figure 1.

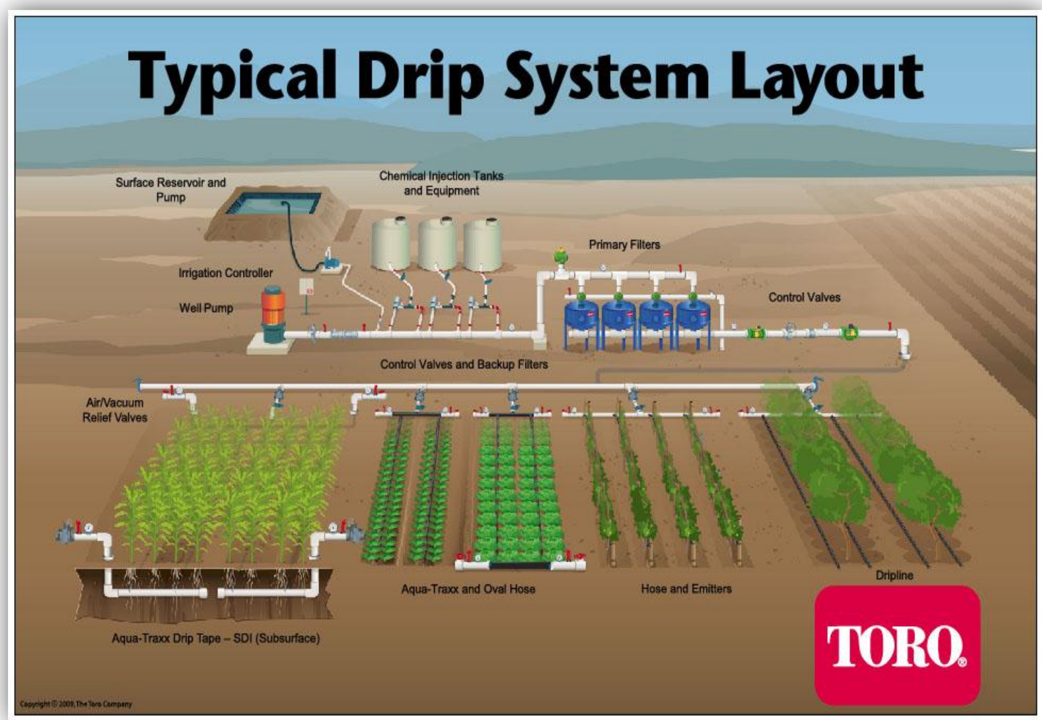

Figure 2 - Typical Drip System Layout showing how drip is used in field and vegetable crops, and orchards and vineyards.

Case Studies

As the worst drought in 50 years gripped America's farmland in the summer of 2012 and crop failure was rampant, three Nebraska producers reported increased soybean yields and significantly lower water use at the same time by using Subsurface Drip Irrigation (SDI) to deliver water and nutrients directly to the roots of their crops. This was in contrast to the typical practice of applying water to the surface with gravity or sprinkler irrigation systems. In addition to improved yields and resource use efficiency (RUE), other benefits cited included an improved ability to farm in drought conditions, improved flexibility and improved convenience. In each of these case studies, the producer found SDI a worthwhile investment. Following is a summary of their experiences as shared with Toro by interview on August 16 and 17th, 2012 and published by Toro and others shortly afterwards (Farm Progress, AgriMarketing, 2012).

Ken Seim Farms, Grand Island, NE area

Ken Seim of Grand Island, Nebraska, has farmed 1,400 acres of corn and soybeans for over 35 years. Currently, he farms 100 acres with SDI; 13 acres on 4^{th} year and 87 acres on 2^{nd} year. In addition, he has 1,300 acres under pivot irrigation. His first SDI system was installed to replace a labor intensive gravity pipe field. A pivot would have left a 13 acre parcel un-irrigated due to the obstruction caused by a home, thus was a less attractive option.

As of August 16, 2012, Seim reported that in addition to 3.5 inches of rainfall, he had only applied 9 inches of water to the SDI field to achieve the same yields as the field where he had applied 20 inches of water with a center pivot irrigation system; his gravity fields received 22 inches of water. The improved water use efficiency with SDI is attributed in part to the lack of evaporation that occurs with flood and sprinkler irrigation. Seims believes the application uniformity on his gravity fields is about 40 percent, on his pivot fields between 60-70 percent, and on his drip fields over 90 percent.

In addition to the improved efficiency of using drip vs. gravity or pivot irrigation, Seims reports that SDI blocks can be more easily sized to match the available water source, which is very important as aquifers and well production decline. This is in contrast to other irrigation methods which require a minimum amount of flow to operate – in many cases, the required flow is no longer available. Seims believes that in the future, groundwater supplies will be reduced just as surface water supplies already have been. For example, two of his wells used to provide 1,600 gpm and now they are only providing 400 gpm, which is not sufficient flow to operate a pivot. SDI blocks may also be successfully configured to irrigate half mile runs, a challenge for gravity irrigation systems.

Seims also reported that his labor costs with SDI are about one-third compared with flood, but are about the same as a pivot. However, SDI labor requirements occur in the spring when repairs are easier to perform and less detrimental to the crop. In contrast, pivot repairs occur in the middle of the summer when tall crops make gear box repairs difficult.

Seims noted that one of his biggest challenges was determining when to irrigate since the soil surface was dry. He uses soil probes and sensors, and will be experimenting with capacitance sensors in the future.

Finally, Seims reports that adopting SDI was easy with excellent dealer and manufacturer support. He believes that "efficient subsurface drip Irrigation is the future of irrigation, and that the adoption rate of SDI technology is rapidly rising. Producers will have to invest in technology to remain efficient and productive - we want to be proactive, not reactive."

Gary Greving Farms, Grand Island, NE area

Gary Greving farms 1,100 acres mostly with pivots. He installed 10 acres of drip 4 years ago, and installed another 18 acres of drip 2 years ago. He adopted drip primarily to reduce labor costs, which ended up being equal compared to pivots, but unexpectedly experienced other benefits including reduced water use, yield increases and improved field accessibility.

His first year soybean yields were 7-8 bushels per acre better. At a value of $8/bu, that equated to $56 - $64/acre increased income. Since then, he has increased yields 40 percent using SDI, primarily because he has achieved tremendous plant health. "The stem of the plant was twice as thick, the leaf area larger, the plant taller, and the pod count over double (for pods that would produce two or more beans)."

Figure 3 was photographed on August 21, 2012 and shows that the SDI irrigated soybean plant on the top measured 48 inches long and received 9 inches of irrigation while the pivot irrigated plant on the bottom measured 36 inches long and received 22 inches of irrigation. Figure 4 shows the fields where the plants were growing: the soybean plants on the right were irrigated with SDI, the plants on the left with a center pivot.

Figure 3 – The SDI irrigated soybean plant on the top measured 48 inches long and received 9 inches of irrigation while the pivot irrigated plant on the bottom measured 36 inches long and received 22 inches of irrigation.

Figure 4 – Fields where the plants in Figure 3 were growing: the soybean plants on the right were irrigated with SDI, the plants on the left with a center pivot.

In addition to the 40% increase in yields, 60% less water was applied to the SDI field than the adjacent pivot field: the SDI fields received 9 inches of water while the pivot fields received 22 inches. Greving believes that as water supplies tighten, the investment in SDI may spell the difference between farming and not farming. "If we are only allocated 9 inches of water a year, as we already are in some parts of the state, we will have to irrigate with SDI in order to produce a crop. You can't grow a crop with 9 inches of water using pivots or gravity irrigation."

Greving noted that there is a learning curve with new technology, but that once he mastered SDI he found it was easier to use than pivots and was as close to 100 percent efficient as possible. Due to the improved water use efficiency with the SDI system, he typically irrigated 4 days each week instead of 7 with the pivot, and at a much lower pressure. This saved water, energy and labor. Finally, field accessibility was improved since the SDI fields have no obstructions, while pivot or gated pipe fields always have something in the way that has to be moved in order to perform field activities.

Don Anthony Farms, Lexington, NE area

Don Anthony has farmed 1,300 acres in the Platte Valley for over 40 years using gated pipe, pivots and now, SDI. He uses 2/3 to 3/4 the water and energy with SDI versus a center pivot. "If 1.0 inch of water is applied via a pivot, only 0.6 inches is beneficially or effectively used by the plant. Drip is more efficient." In addition to application efficiency, Anthony takes SDI one step further. "With SDI, I can 'play chicken' with the weather and sometimes take advantage of a rainfall event that I couldn't otherwise." Anthony explains that it takes 3 days for his pivots to complete an irrigation cycle, and over two weeks for his gravity fields. “With SDI, I can apply a small amount of water quickly and avoid plant stress. Therefore, I can wait longer for the rain and apply a short irrigation quickly if the rain doesn’t come. If the rain does come, I have saved myself an irrigation cycle.” Anthony is also using SDI to stretch limited water supplies so that all his land remains irrigated. “Since irrigated land has higher value, I have used SDI to avoid a balance sheet devaluation of my assets.”

Anthony notes that fertigation with SDI is really fast, easy and efficient, too. “I have more options with SDI – I can fertigate a single block and easily track the results in a square sized block rather than a pie shaped block.”

Regarding the investment, Anthony believes that producers have enjoyed great crop production over the past ten years, and that they have always had to reinvest during the good times in order to get through the tough times. “I am investing in pivots and drip now – both technologies have their place. There’s not much to it – I have good local support.”

Summary

In summary, each of these established Nebraska producers experienced substantial benefits using SDI. In all cases, water use efficiency was improved, i.e. substantially less water was applied to the crop vs. pivot or gravity systems to achieve the same, or even substantially higher, yields. Energy savings were also cited since the SDI system operated fewer hours, and at lower pressure, than pivots. Labor was equal to pivots, but was generally required in the spring when it was easier to perform and less detrimental to the crop. In addition, producers noted that SDI systems are easier to configure for lower and/or changing water supply flow rates, for odd-shaped fields and/or fields with obstructions, and for fields with long ½ mile runs. Also, SDI enables producers to successfully farm even if water allocations are reduced to 9 inches, and can also help producers wait and take advantage of a rainfall event by applying small amounts of water quickly in case rain doesn’t occur. SDI also helps maintain “irrigated land” status by stretching limited water supplies over more acres of land. The producers also enjoyed ease of field access with SDI, and the ease by which fertilizers could be injected into the system either for the whole crop or for small, square block fertilizer trials. Finally, each producer cited excellent support from the local dealer and manufacturer of the SDI system. Table 1 describes these benefits in tabular form:

Table 1: Advantages of SDI on Soybeans during 2012 Crop Year - Nebraska, US

	Seims	Greving	Anthony
Farmed Acres	1,400	1,100	1,300
Acres of SDI	100	28	250
Inches of rainfall	3.5	3.5	
Inches applied with SDI	9	9	2/3 - 3/4 vs. pivots
Inches applied with pivots	20	22	
Inches applied with gravity	22		
Soybean Yields	Same as pivot	Increased 40%	
Labor	1/3 vs gravity; same as pivot	Same as pivot	
Energy		SDI runs 4 days per week instead of 7 and at lower pressure than pivot	2/3 - 3/4 vs. pivots
Can more easily configure an SDI system to:			
Fit changing/lower flow rates in the water supply	✓		
Efficiently irrigate 1/2 mile runs (vs. gravity)	✓		
Accommodate odd-shaped fields or obstructions	✓		
Crop may be produced with 9 inches of water		✓	
Can quickly apply a small amount of water if needed to take advantage of a rain event			✓
Stretch limited water supplies over more acres to maintain "irrigated status" on more land.			✓
Ease of fertigation, and fertigation trials			✓
Labor comes at an easier time of year	✓		
Field accessibility is improved		✓	
Excellent dealer and manufacturer support	✓	✓	✓

Figure 5 shows these benefits graphed on a wheel chart similar to Figure 1. When graphed in this manner, it is clear that the ability to farm in drought conditions, and increased flexibility and convenience, are important benefits of using SDI in field crops in addition to increased yields and reduced costs.

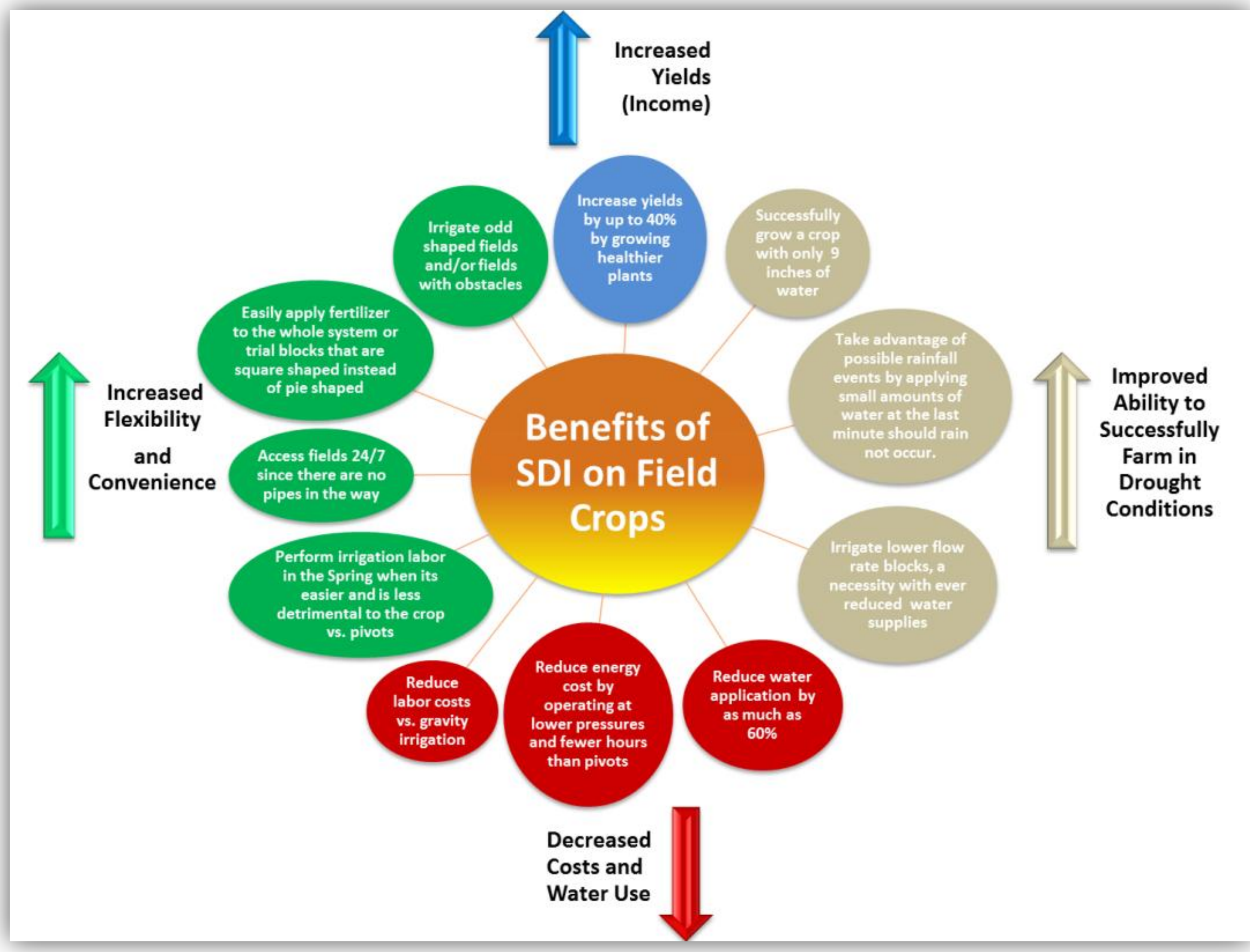

Figure 5 – Benefits of SDI on Field Crops. Note that these benefits are somewhat different than the "Typical Benefits of Micro-Irrigation" cited in Figure 1.

SDI Tools

Considering the potential benefits of SDI, Toro has developed several tools that help producers with the transition. First, the Drip/Micro Payback Wizard is an online calculator that estimates how long it will take to amortize an investment in SDI by comparing before and after yield and production financial data. In addition, it estimates how many additional acres may be farmed with the water saved by adopting SDI. Second, AquaFlow 3 Drip Irrigation Design Software allows users to quickly and easily design a drip irrigation system by entering field parameters and then selecting appropriate laterals, sub-mains and mainlines. AquaFlow's unique dashboard format displays system hydraulic parameters on one screen for both irrigation and flushing events, and includes a user friendly, color-coded uniformity map. Third, the second edition of Toro's Drip Irrigation Owner's Manual is available in both English and Spanish, with measurements in English and metric units. This 129-page, four-color, fully illustrated, spiral-wound document is a comprehensive guide to the operation and maintenance of both new and existing micro-irrigation systems for row, field and permanent crops. All of these tools are available for free download from toro.com and driptips.toro.com.

Drip-Micro Payback Wizard

As mentioned earlier, many case studies have shown that the investment in drip irrigation is often paid back in less than 3-5 years, sometimes less. The Drip Micro Payback Wizard was created to help producers easily estimate potential revenue increases and cost decreases that are normally associated with the adoption of drip irrigation so that they could evaluate whether the potential payback period was reasonable for their own operation. The Wizard also helps producers estimate how much water could be saved and/or how many additional acres could be farmed due to higher application uniformities associated with drip. If the results appear favorable, the producer may then decide to seek additional guidance from local government resources, academia, consultants, associations, equipment manufacturers or suppliers.

The Payback Wizard database is populated with estimated investment costs along with Cooperative Extension production cost, yield and revenue data for each crop in each of the 50 United States. After the crop, state, acres, current type of irrigation system and water cost per acre are entered by the user, the Payback Wizard reports the estimated payback period on the investment, and the additional acres that could be farmed with the water saved. This report may then be printed, or, the user can view and edit the detailed data to better reflect a specific production scenario. Figure 6, 7 and 8 are screen captures of Steps 1, 2 and 3 when using the Payback Wizard.

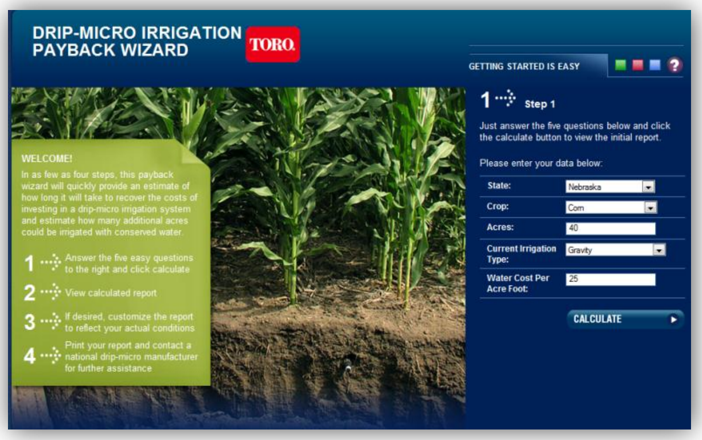

Figure 6 – Step 1 of the Payback Wizard

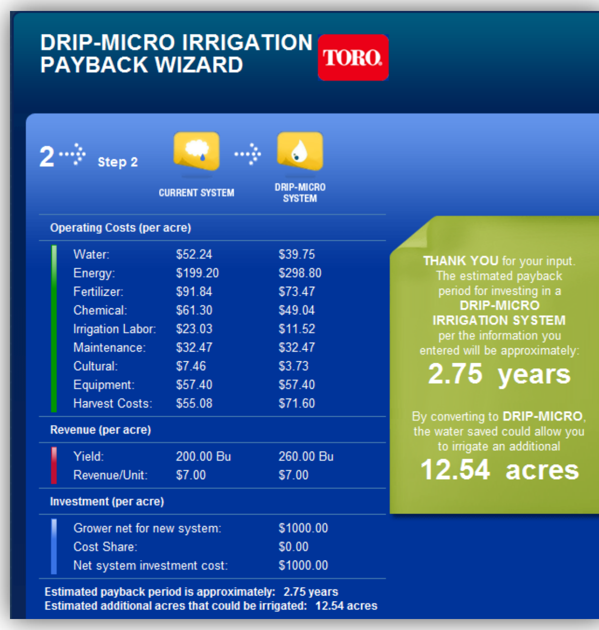

Figure 7 – Step 2 of the Payback Wizard

Figure 8– Step 3 of the Payback Wizard

Figures 6, 7 and 8 are screen captures of Steps 1, 2 and 3 when using the Payback Wizard. This example converts 40 acres of corn in Nebraska from gravity to drip irrigation assuming $25 per acre foot water costs. The payback period is estimated at 2.75 years, and it's estimated that an additional 12.54 acres could be irrigated with the conserved water. This estimate assumes a $1,000 per acre drip system investment cost, a 30% yield increase and a crop value of $7 per bushel. These are estimates only and do no guarantee results.

AquaFlow 3 Drip Irrigation Design Software

AquaFlow 3 is a new software program available for free download at toro.com upon approved registration. AquaFlow 3 features a unique dashboard which allows users to view changes to inputs instantaneously on one screen. This is in contrast to other design programs which require toggling between screens to view the results of lateral and submain irrigation and flushing design choices. Figure 9 shows the dashboard that appears immediately after launching the program from the desktop icon, and after selecting the Chart Tile function.

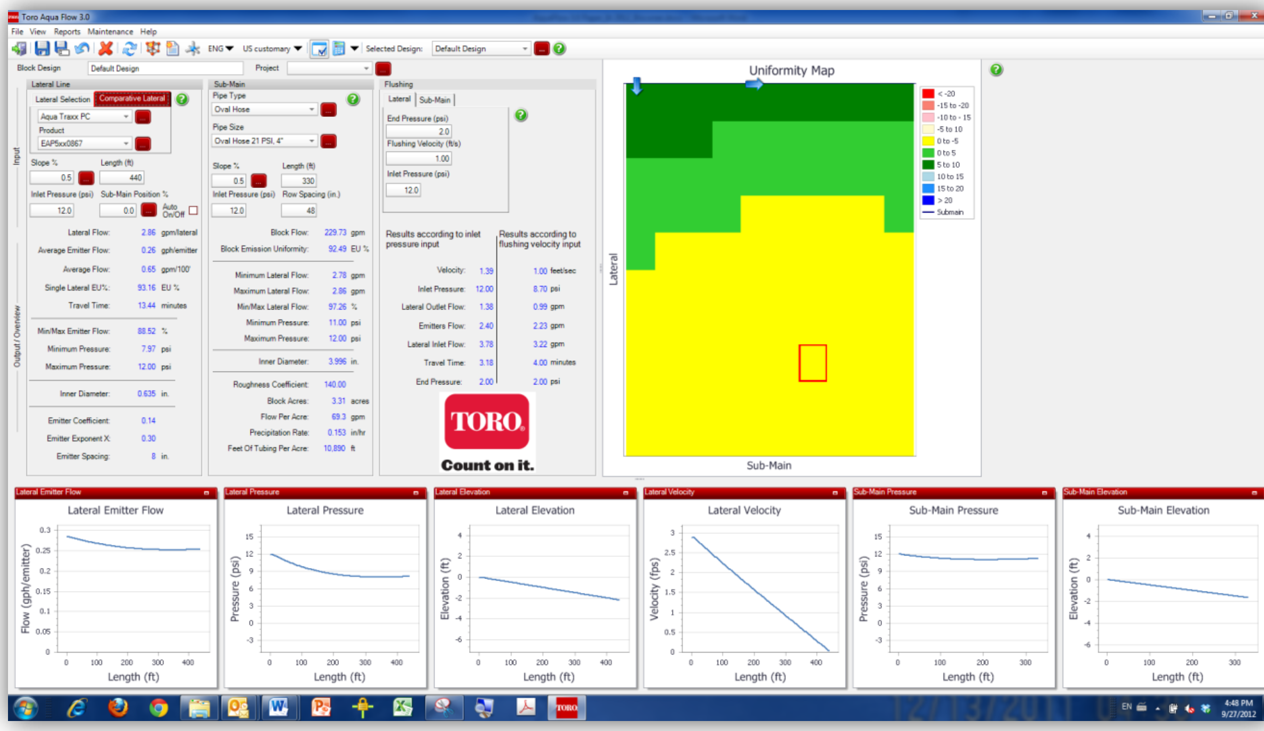

Figure 9 – AquaFlow 3 Drip Irrigation Design Software dashboard as it appears immediately after program launch and selection of the Chart Tile function.

AquaFlow supports a wide variety of lateral, submain and mainline pipeline choices and allows the entry of multiple slopes for each of them. In addition, sub-mains and mainlines may be telescoped. The results of design choices are readily displayed in tables, graphs, a color coded uniformity map, and in customizable reports that may be exported in a variety of formats such as pdf. Two different lateral choices may be easily compared as well, and sub-mains auto-positioned for maximum irrigation emission uniformity (EU). AquaFlow supports English and Spanish languages, and standard English and metric units.

AquaFlow is uniquely valuable to designers of SDI systems since SDI is expected to last for long periods of time and must be designed to be properly flushed. This aspect of design is often overlooked in some traditional short term drip irrigation systems. AquaFlow allows the designer to immediately view the results of lateral and sub-main design choices in terms of both the irrigation uniformity (such as EU) and the flushing parameters (velocity, inlet pressure and end pressure). This capability results in a more efficient design process and potentially better design results.

Toro Micro-Irrigation Owner's Manual, 2nd Edition

Figure 10 and 11 below show the cover and table of contents of this 129-page, four-color, fully illustrated, spiral-wound document. It is a comprehensive guide to the operation and maintenance of both new and existing micro-irrigation systems for row, field and permanent crops, including the operation and maintenance of SDI systems. It is available in both English and Spanish, with measurements in English and Metric Units.

Figure 10 – Cover of Toro Micro-Irrigation Owner's Manual.

Figure 11 – Table of Contents of 2nd Edition of Manual.

The Owner's Manual is especially useful for those who have adopted SDI systems since monitoring, flushing and maintenance are important to maximize the system's life expectancy. Figures 12, 13 and 14 are Owner's Manual illustrations of these concepts.

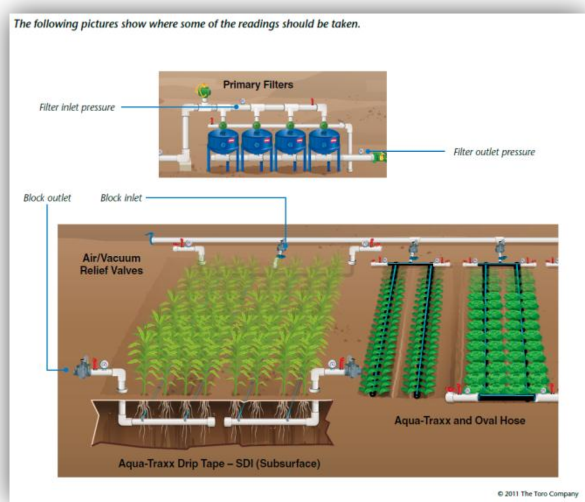

Figure 12 – Recommended pressure monitoring locations for SDI systems. Note that the flushing sub-main has been divided in half to facilitate proper flushing velocities.

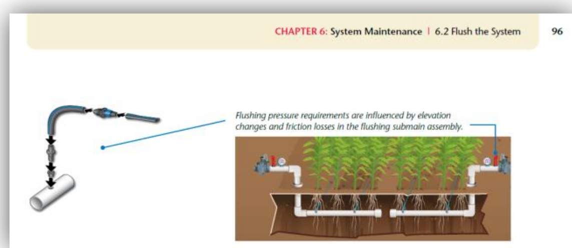

Figure 13 – Sub-main flushing details for an SDI system.

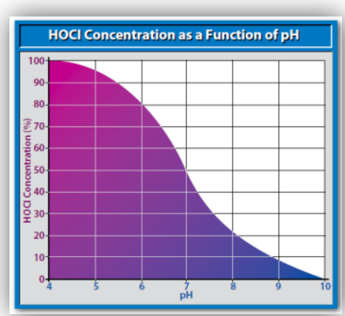

Figure 14 – HOCL concentration as a function of pH. Chlorine is often injected into SDI systems to control biological contaminants. Note that its efficacy is greatly reduced if the water pH is over 6.0.

Conclusion and Summary

In conclusion, the use of drip irrigation, and subsurface drip irrigation (SDI) in particular, is growing rapidly in the United States as a result of the many benefits that producers realize after adopting it. Three case studies document the positive experiences of three established producers who grew soybeans with SDI in Nebraska during the drought of 2012, the worst in fifty years. These producers reporter increased soybean yields and significantly lower water use at the same time using SDI to deliver water and nutrients directly to the roots of their crops. This was in contrast to the typical practice of applying water to the surface with gravity or sprinkler irrigation systems. In addition to improved yields and resource use efficiency (RUE), other benefits cited included an improved ability to farm in drought conditions, improved flexibility and improved convenience. In each of these case studies, the producer found SDI a worthwhile investment.

The specific benefits are listed in both chart and wheel graph form. Water use efficiency was improved, i.e. substantially less water was applied to the crop vs. pivot or gravity systems to achieve the same, or even substantially higher, yields. Energy savings were also cited since the SDI system operated fewer hours, and at lower pressure, than pivots. Labor was equal to pivots, but was generally required in the spring when it was easier to perform and less detrimental to the crop. In addition, producers noted that SDI systems were easier to configure for lower and/or changing water supply flow rates, for odd-shaped fields and/or fields with obstructions, and for fields with long ½ mile runs. Also, SDI enabled the producers to successfully farm even when water allocations were reduced to 9 inches, and helped producers wait and take advantage of rainfall events by allowing the application of small amounts of water quickly in case rain didn't occur. SDI also helped maintain "irrigated land" status by stretching limited water supplies over more acres of land. The producers also enjoyed ease of field access with SDI, and improved ease of crop fertilization since fertilizers could be injected into the system either for the whole crop or for small, square block fertilizer trials. Finally, each producer cited excellent support from the local dealer and manufacturer of the SDI system.

It is interesting to note that while yield increases and resource use efficiency are common benefits of using drip irrigation in numerous crop situations, these particular field crop producers especially appreciated the improved ability to farm in drought conditions using SDI, as well as the SDI system's flexibility and convenience. As a result, the contents of the "Benefits of SDI on Field Crops" wheel chart as shown in Figure 5 are different than the "Typical Benefits of Micro-Irrigation" wheel chart shown in Figure 1.

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