VARIABLE RATE IRRIGATION ON CENTER PIVOTS. WHAT IS IT? SHOULD I INVEST?

R. Troy Peters, Markus Flury[1]

ABSTRACT

Variable rate irrigation (VRI), also sometimes referred to as 'precision' or 'site-specific' irrigation, is the ability of an irrigation system to apply different amounts of water to different areas of the field. This paper discusses the various VRI options for center pivots, when they might save water, energy and create higher crop yields, and when it might be unreasonable to expect these kinds of improvements. Some of the remaining challenges associated with VRI are discussed, and a simple soil-water balance model is used to illustrate water savings estimates from various soils and how VRI might be used to take advantage of significant, in-season rainfall events.

VARIABLE SPEED IRRIGATION VS. VARIABLE ZONE IRRIGATION

Recently center pivot manufacturers and some third party equipment dealers have been offering variable rate irrigation (VRI) as an option or upgrade on their pivots in a couple ways: variable speed irrigation, and variable zone irrigation.

Variable Speed Irrigation does not require additional hardware on the pivot. It simply uses a more sophisticated control panel that will slow down or speed up the pivot to apply more or less water in different areas of the field. Many of the newer pivot control panels already have this ability built into them. After-market solutions from third-party equipment dealers usually mount on the last tower of the pivot, have an integrated GPS receiver to determine field position, and interrupt and re-send the movement control signal to the last tower to vary the speed of the pivot in different areas of the field. Despite variable speed irrigation's obvious limitations to variations only in pie-shaped wedges (Figure 1), variable speed irrigation is fairly low cost ($2,000 - $4,000) since the only modifications to the pivot are to the pivot electronic controls. These costs will likely decrease over time. The overall pivot flow rate remains constant.

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[1]R.T. Peters, (troy_peters@wsu.edu), Professor and Extension Irrigation Specialist, Irrigated Agriculture Research and Extension Center, Washington State University, 24106 N. Bunn Rd., Prosser, WA 99350; M. Flurry (flury@mail.wsu.edu), Professor of Soil Science, Washington State University Puyallup Research and Extension Center, 2606 W. Pioneer Ave., Puyallup, WA 98371. **In**: Proceedings, 2017 Western Alfalfa and Forage Symposium, Reno, NV, Nov 28-30. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other alfalfa conference Proceedings.)

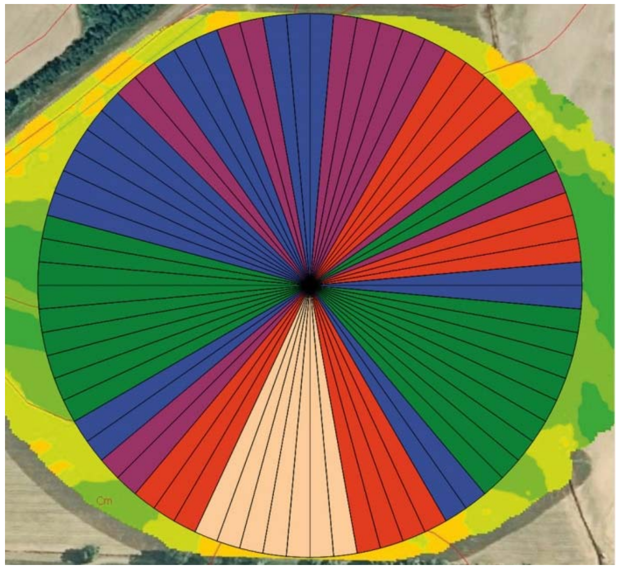

Figure 1. Variable Speed Irrigation.   The pivot varies travel speed to apply variable amounts of water to defined zones within the field. Colors indicate areas with different amounts of water applied. Image used by permission from pivotirrigation.com.au.

Some additional useful applications for variable speed technology:

- On a pivot that can't go all the way around (a "wiper") it is possible to vary the speed going into or coming out of the hard stops (ends of the field where the pivot must reverse direction) to avoid running the pivot in overly wet areas in an attempt to reduce wheel-tracking issues. For example: if the wiper is applying 0.5 inches in a pass (1 inch for every back-and-forth wipe), the pivot might speed up to apply 0.2 inches of water in the 20 degrees of angle before the hard stop so the field stays drier. Then after reversing, slow down to apply 0.8 inches until it reaches the 20 degree mark again where it speeds up slightly again to return to applying 0.5 inches.
- In areas of the field where infiltration is an issue due to tight soils or steep slopes, it is possible to speed up to wipe back and forth across that area of the field to allow additional time between water applications for water to infiltrate and move deeper into the soil before water is again applied to the surface. For example: If there is always runoff on a slope between 20 and 40 degrees, and the grower is applying 0.75 inches of water in a clockwise rotation, the pivot could speed up at 20 degrees to apply 0.25 inches over the trouble spot, then reverse at 40 degrees to apply 0.25 inches, travel back to 20 degrees where the pivot would again reverse to apply 0.25 inches (for a total of 0.75 inches on the trouble spot). The pivot would then slow down at 40 degrees to apply 0.75 inches to the rest of the field. The same total amount of water was applied to the trouble

spot, but the back-and-forth movement gives more time between water applications for the water to move into the soil in that spot hopefully increasing infiltration and reducing runoff.

- Speed up slightly when climbing hills to account for tire slippage (Chavez et al., 2010).

Variable Zone Irrigation includes the ability to vary the speed of the center pivot as it moves in a circle *and* vary the application rate along the pivot lateral (Figure 2). Variations in the application rate along the lateral works in conjunction with variations in the pivot speed creating the ability to apply a wide variety of irrigation depths to different areas of the field. The application rate along the lateral is usually varied by pulsing sprinklers on and off for various amounts of time. In some cases, zones of sprinklers are controlled independently, in other cases every sprinkler is controlled independently. Because additional hardware must be mounted on the pivot, as well as more sophisticated control technology, variable zone irrigation is significantly more expensive than variable speed irrigation ($15,000 - $25,000; Milton et al., 2006). These costs will also likely decrease over time. Variable zone irrigation is much better at responding to the spatial variations in the field. Turning sprinklers on and off varies the overall flow rate to the pivot and therefore a water delivery system that can absorb these variations is necessary.

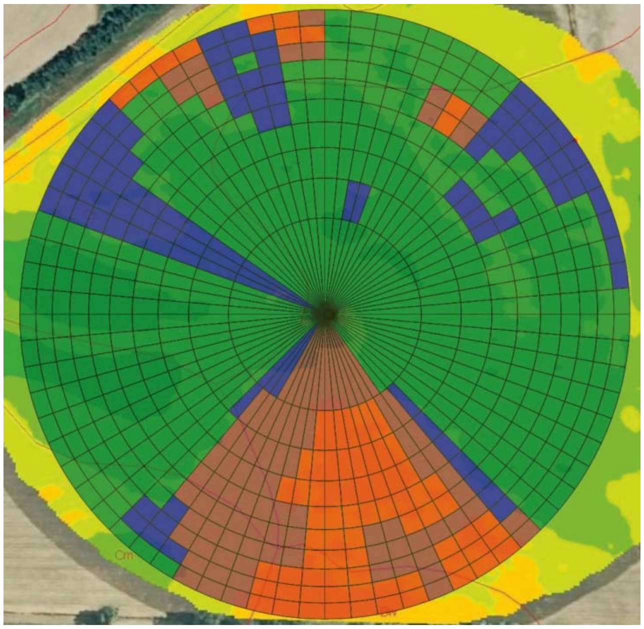

Figure 2. Variable Zone Irrigation. The pivot varies both travel speed and application rate along the lateral to apply variable amounts of water to defined zones within the field. Colors indicate areas with different amounts of water applied. Image used by permission from pivotirrigation.com.au.

IS IT WORTH IT?

Is variable rate irrigation right for your pivot? The answer is "It depends". The upfront costs of VRI, especially variable zone systems, can be substantial. The ongoing management costs can also be high. In many cases, modifying the management of existing soils can eliminate the perceived need for VRI. On the other hand, in certain instances it may save substantial amounts of water in the long run.

Variable rate irrigation in response to variable soils

The water use of healthy crops with access to sufficient water and nutrients will not be significantly dependent on what kind of soil they are grown in. Crops grown in sandy soils will not use significantly more or less water than crops grown in silt or clay soils. So, for example, even in a field with highly variable soils, all areas of the field will be using ¼ inch of water every day. Because of this, applying different amounts of water to different areas of the field only makes sense if the crops are getting water from another source besides where the center pivot irrigation system is applying it, or if the crops are using less water in some areas of the field due to disease or pest pressure. More discussion on this follows below.

"I apply more water to the sandier areas of my field during each irrigation."

Sandy soils do not need more water. They cannot hold the extra water. If they are watered more each time then the additional water will be lost to deep percolation. They need to be watered in smaller amounts more frequently. Because of this, if the entire field is managed as a whole to prevent water stress and water losses to deep percolation in the *sandy* areas of the field then *all other areas* of the field will be fine (Figures 3 and 4).

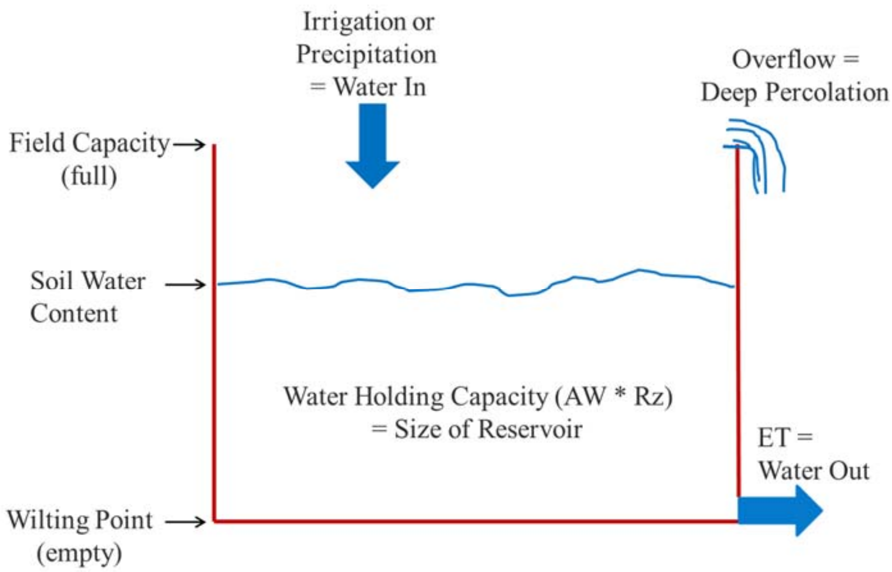

Figure 3. Soil serves as a reservoir for water and nutrients. The size of the reservoir depends on the soil's water holding capacity (how much water it can hold per inch of root depth; AW), and the rooting depth of the soil or crop (Rz). Irrigation or precipitation that infiltrates into the soil when there is space in the soil to hold that water is stored for later use by the crop. If more water is applied to the soil than the soil can hold, then that extra water is lost (leached) out the bottom of the root zone (shown as overflow). Crop water use, or evapotranspiration (ET), is largely independent of the soil type.

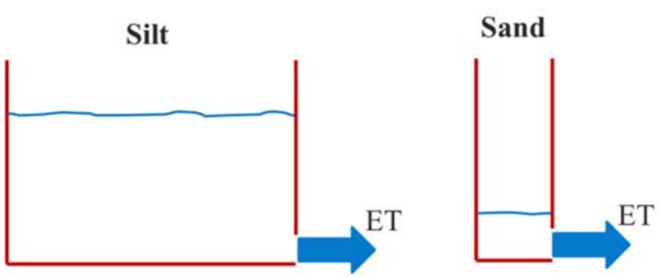

Figure 4. If the same field has areas that are both silt and sand, then if they both started full, then after a given amount of time the sandy areas will be getting dry and exhibiting crop water stress, while the silty areas will appear fine. If the entire field is managed for no stress, or no water losses to deep percolation in the sand (overflow in the diagram), then the silty areas will also be fine. If more water is applied to the sand when refilling the soil, that additional water will be lost to deep percolation.

Some simulations were done using Irrigation Scheduler Mobile (http://weather.wsu.edu.ism, Peters, 2014) to model what the soil water content would look like in a sandy area of the field (Figure 5) and in a silty area of the field (Figure 6) if the whole field was managed for the sand.

A similar simulation was done of the sandy (Figure 7) and silty (Figure 8) areas of the field if instead the whole field was managed for the silt. It can be seen that when the entire field is managed for the soils with the lowest water holding capacities that all areas of the field are fine. This is, however, not the case if the field were managed for the soil with the larger water holding capacity (the silt). In that case, the sand would show water stress.

"I have runoff on the steeper slopes, and the crop is water stressed in that area of the field so I apply more water to those slopes."
If water is already running off a slope, applying more water will result in *all* of the additional water also running off, possibly causing erosion, and that additional runoff water may pond in the low spots of the field, making the overall irrigation and crop uniformity problems in the field worse. If the water is running off, then less water, not more, needs to be applied to slopes in a pass to ensure that the applied water infiltrates into the soil. But to ensure that these areas of the field don't fall behind the rest of the field this means speeding the pivot up on the entire field as spatial variation would result in these areas falling permanently behind. The "wiping" method described above can help to reduce or eliminate runoff. As an alternative to speeding the pivot up, or as additional runoff-prevention measure, runoff in these steep sloped areas can be mitigated by changing the tillage methods, and possibly the crop row orientation. Modifying the sprinkler system so that it applies water at a slower *rate* can also help improve infiltration. This might include using boombacks or draping every other sprinkler around the outside of the truss rods, or using sprinklers with a much larger wetted radius. If the soil is hydrophobic (water balls up and runs off of dry soil instead of infiltrating) then using soil surfactants may also help with infiltration.

Because of these things, *in low rainfall areas purchasing VRI in response to highly variable soils has little opportunity to increase profitability in comparison to optimally managing the entire field uniformly for the problem soils.*

SITUATIONS WHERE VRI CAN CONSERVE WATER AND IMPROVE PROFITIABILITY

Do not irrigate non-cropped areas
VRI can save water, agrochemicals, and reduce maintenance problems by completely shutting the water off in areas of the field that should not be irrigated (Sadler et al., 2005). These might include rock piles, ponds, or streams, waterways or roads that cross through the field or areas under the irrigation system that are otherwise not farmable. Sometimes pivots overlap. Shutting the water off on one of these pivots in the overlapped areas will reduce overwatering those areas. These constant, unchanging prescriptions where the water is turned off completely will result in

the largest water and power savings at the lowest long-term management costs. Consequently most VRI systems being sold are primarily being used in this application (Evans et al., 2012). Avoiding off-target application of agrichemicals or liquid wastes is another large driver for the adoption of VRI.

Areas of the field getting water from other sources

VRI can conserve water by applying less water to areas of the field where the crops are getting water from sources. This may be either a high water table, or an area where water is ponding in the field due to runoff from sub-optimal operation of the pivot, or from water running onto the field from outside sources. Watering these areas less can reduce over-irrigation, saturation of soils, losses of nitrates through leaching, and losses of yield due to waterlogging (Sadler et al., 2005). It may be necessary to modify the VRI prescription (variable irrigation map or plan) throughout the season to irrigate these areas more or less because the alternative sources of water may not be constant or able to keep up with ET throughout the entire season.

Leave room in the soil to capture rainfall

In humid areas where there is significant in-season rainfall, periodically shutting the water off to the areas of the field with larger water-holding capacities will leave space in the soil to capture and hold anticipated rainfall. The sandy areas will still have to be irrigated on a regular basis to avoid stress because of their small water holding capacity; however, the water in the silty or clay areas can be depleted. Then, during significant rainfall events, there will be capacity to hold this rainfall in the silt or clay areas of the field. At these events there will be unavoidable rain water losses to deep percolation in the sandy areas. Doing this accurately requires additional data collection of the soil water content in the different areas of the field, good irrigation scheduling techniques, and in-season modifications to the VRI prescription in response to timing and depth of the precipitation events. See the section in Appendix B on 'Soil Water Simulations of Various Scenarios' and Figures 9, 10, and 11 for a better explanation.

Different crops in the same field

VRI will allow growing different crops in different areas of the field and managing the water for these areas separately. This may be especially useful to those who cannot or do not want to plant in pie-shaped sections. It also may be especially useful for researchers or seed growers who have a wide variety of different plots, crops, or water treatments under the same pivot.

Avoid overwatering the inside span

The sprinkler flow rates required on the first span of a center pivot (nearest the pivot point) are so low that these small nozzle sizes can be plugged with small debris in the water. Because of this, many pivot dealers put on larger nozzles. Variable zone irrigation could be used to periodically shut these nozzles off to avoid over-watering these two inside spans. Allowing the canopy in these areas to dry more often may reduce plant diseases and therefore disease spreading to other areas of the field.

Variations in Crop Water Use (ET)
If there is a large variation in crop water use across the field (ET) applying *less* water to the areas where the ET is *lower* might conserve this water. These lower ET rates may be due to disease or pest pressure among other possibilities. Because these areas are using less water, applying the same amount of water as other areas may result in additional water losses to deep percolation. This might be counterintuitive because most people want to water areas that are not doing well more, not less.

Use pivot as a variable rate sprayer
VRI may come in very handy when you use it for chemigation or fertigation and you wish to apply these at a variable rate. This can be especially beneficial for those applying liquid wastes.

Control for uniform dry down
In some instances it may be desirable for the crops in all areas of a field with highly spatially variable soils to experience water stress at the same time. In this case it may be desirable to restrict irrigation water to areas that have greater water holding capacity (deep silts or clays) sooner so that the soil profile will be depleted at about the same time as the areas with lower water holding capacities (shallow or sandy soils).

Variable rate irrigation will be more profitable if the costs of water, or the marginal opportunity cost of lost water is high. The marginal opportunity cost of lost water is greatest when growing high value crops and water is already very limited.

CREATING AND MODIFYING VRI PRESCRIPTIONS. NOT TRIVIAL!

The off-the-shelf VRI systems sold by pivot manufacturers and third party dealers have been shown to be effective at applying the targeted amounts of water to the desired locations in the field (Dukes and Perry, 2006; O'Shaugnessy, et al., 2013; Higgens et al., 2015a). In other words, the control systems and hardware work well and the equipment's ability to apply variable rates across the field is not a barrier to the adoption of VRI. The primary barrier is developing and modifying VRI prescriptions in a way that improves the overall profitability.

Prescriptions are the maps, or plans for how the irrigation amounts will be varied in the different areas of the field. These are often developed based on experience, GPS or GIS mapping, and/or GPS-referenced soil sampling. Electrical conductivity (EC) mapping, which is often used to indicate the differences in soil texture or water holding capacity throughout the field, is also widely used. This data collection is often time consuming, expensive, and plagued by high degrees of uncertainty (Higgens et al., 2015b) and sources of variability. In addition it must be done by fairly educated and skilled (i.e. expensive to employ) personnel who are often hired consultants. Once the data that characterizes the variations in the field has been collected, it is not always clear how to vary irrigation amounts and timing in response to this data. Additional research is ongoing on these topics.

Further, irrigation decisions must be reevaluated many times over a season. Crop performance relative to other areas of the field, the soil surface conditions that affect infiltration rates and the various alternative sources of water (size of the pond in your field) rarely remain constant throughout a growing season. In addition, using variable rate irrigation to leave space in soils with larger water holding capacities to take advantage of water from anticipated rainfall events requires in-season modifications to avoid stressing the lower water holding capacity areas and to adjust for the fact that the anticipated rainfall may not materialize. Therefore, it may be necessary to modify the prescriptions many times throughout the season. Such modifications can be especially challenging with continuously variable soils. This greatly increases the amount of data collection, analysis, decision-making, and modifications made to the VRI prescriptions throughout the season. This can be time consuming, complex, and therefore expensive.

However, if the specific on-farm conditions allow the use of a consistent VRI over time then significant savings in management time and costs can be achieved and will likely result in considerable water savings. For instance, when there are non-cropped areas which can be left non-irrigated, or if the crops are getting water from a consistently high water table then the VRI prescription need not change over time, and therefore these scenarios have the greatest potential for long-term implementation and measurable water savings.

WHAT OTHER RESEARCHS HAVE FOUND

Because the conditions under which VRI can be profitable do not apply to all fields, VRI does not always save water or conserve power (Stone et al., 2010). Israeli researchers found using simulation models that adopting practices to increase infiltration and using irrigation systems with high uniformity increased total yields per unit of applied water, but that the impacts of VRI were ambiguous (Feinerman and Voet, 2000). They also found that increasing the number of management units in a field did not necessarily result in more optimal water use, and that VRI did not guarantee savings and in many cases could yield the opposite result.

Several researchers used computer simulations to show that using VRI on center pivot fields with large differences in water holding capacities in humid regions with frequent, heavy rainfalls during the growing seasons had the potential to save significant amounts of water and reduced deep percolation (Hedley, et. al., 2009, 2010). These simulated benefits depend on the base line, which might be suboptimal (see discussion of Figures 5, 6, and 7 in Appendix A). Hedley et al. (2010) also found that larger water savings were related to years with rainfall events during the irrigation period. These studies show that large differences in the water holding capacities in the field, and frequent, large rainfall events strengthen the potential savings of VRI from rainfall capture. While computer simulations show potential benefits of VRI, published in-field testing results demonstrating similar benefits are still lacking.

Adoption of VRI has been generally limited and its use by early adopters has not always been sustained (Evans et al., 2012). The complexity of installing, maintaining, and effectively managing VRI systems has been a significant barrier to adoption. In many instances the economic returns from adopting these technologies have not been easy to consistently demonstrate (Feinerman and Voet, 2000; Berne et al., 2015). However, increased costs of water and energy, and severe water limitations will likely increase the financial incentives to adopt VRI (Evans et al., 2012).

CONCLUSION

Variable rate irrigation gives a grower the ability to vary the amount of water that is applied to different areas of the field. On center pivots, this can be done fairly simply and relatively inexpensively using variable speed irrigation. However, the spatial variations are limited to pie-shaped wedges. There are several other applications of variable speed irrigation besides VRI that can provide benefits in certain fields. Variable zone irrigation includes the ability of the system to vary both the speed and the amount of water applied along the lateral. It is more sophisticated, and flexible, but also much more expensive.

In-field variations in soil water holding capacities and infiltration rates can be largely mitigated by proper water management to the entire field as a whole for the problem soils. If the whole field is irrigated to avoid deep percolation and water stress in the soils with the lowest water holding capacity, the rest of the field will be fine. Likewise managing the field as a whole to limit runoff in certain problem areas has little negative effects on the rest of the field.

Variable rate irrigation may provide water and power savings, or crop yield benefits in the following circumstances: withholding irrigation in non-cropped areas, not irrigating areas of the field that are getting water from other sources, keeping the soil water content at a level so that rainfall can be captured (rainfall harvesting), varying irrigation of for the different water needs of different crops in the same field, responding to spatial variations in crop water use (ET) due to crop health variations, to use pivot as a variable rate sprayer or waste disposal system, or to avoid overwatering the inside span of the pivot.

The VRI systems currently being sold can fairly accurately implement uploaded VRI prescriptions. However, the data collection, analysis, and creation of optimal VRI prescriptions for a specific field's needs can be complex, time consuming and expensive, especially since many field situations require these prescriptions to vary both in time, and in space. This is currently a significant barrier to the profitable use of VRI.

Variable speed irrigation currently has greater potential to be a good investment. Variable zone irrigation systems that are used to consistently avoid irrigating non-cropped areas are likely to be the most manageable and beneficial, especially when injecting agrichemicals or waste products and it is unlawful to apply these to non-cropped areas.

APPENDIX A.

SOIL AND WATER SIMULATIONS TO ILLUSTRATE VRI ON VARIABLE SOILS

With variable rate irrigation, although the amounts of water applied to different areas of the field can be varied, the whole field must be irrigated on the same intervals. So in the case of variable soils, there are three different choices: (1) irrigate to meet the needs of the shallow or sandy areas, (2) irrigate to the deeper silt or clay soils, or (3) irrigate to some "average" condition. We used the free mobile irrigation scheduling tool on AgWeatherNet (weather.wsu.edu/ism) to simulate these different strategies and evaluate their effects on soil moisture content (Peters, 2014). We did a simulation for a potato crop with a beginning root zone depth of 12 inches, and an ending root zone depth of 24 inches. The growing root zone causes the graphs to increase during the first part of the season.

Managing for Sandy Soils (Figures 5 and 6)

Let's assume that there is a potato field with areas of both fine sand and silt loam soils with a water holding capacities of 0.8 and 2.3 inches per foot respectively. Figure 5 shows the soil water content over time of the sandy soil that was irrigated for sandy soils such that there was no water stress (soil water content remained between the "Full" and "First Water Stress" lines) and limited water loss to deep percolation (leaching). This includes a growing root zone which accounts for the relative upward sloping lines in the first part of the growing season. Because the water holding capacity of sands is small, frequent irrigations (green squares) of small amounts are required to avoid water stress and losses to deep percolation.

Figure 6 shows how the *silt loam soil* section of this same block would fare in that same field that was managed for the sandy soil. The applied irrigation dates and amounts are the same for both scenarios. Under this management scenario, the following results (Table 1; Figures 5 & 6) are seen:

- There is no water stress in either block.
- The total crop water use (ET) in both the sandy and in the silt soils of the block are exactly the same.
- The total losses to deep percolation are exactly the same, and occur on the same dates.
- There is no stress in either areas of the field and therefore the yields in both areas will be the same.
- At the end of the season the silty soil will have much greater residual water available than the sand.

Table 1. Comparison of the different sections of the field (sandy or silty soils) when the whole field is managed uniformly for the sand. All water depths are in inches.

Scenario	Figure Ref.	Season Total ET	Total Irrigation	Total Rainfall	Deep Perc.	Yield Loss
Sandy soil. Managed for the sand, by replacing deficits.	Fig. 5	24.1	21.5	3.2	1	0
Silt soam soil that is managed for the sand (above).	Fig. 6	24.1	21.5	3.2	1	0

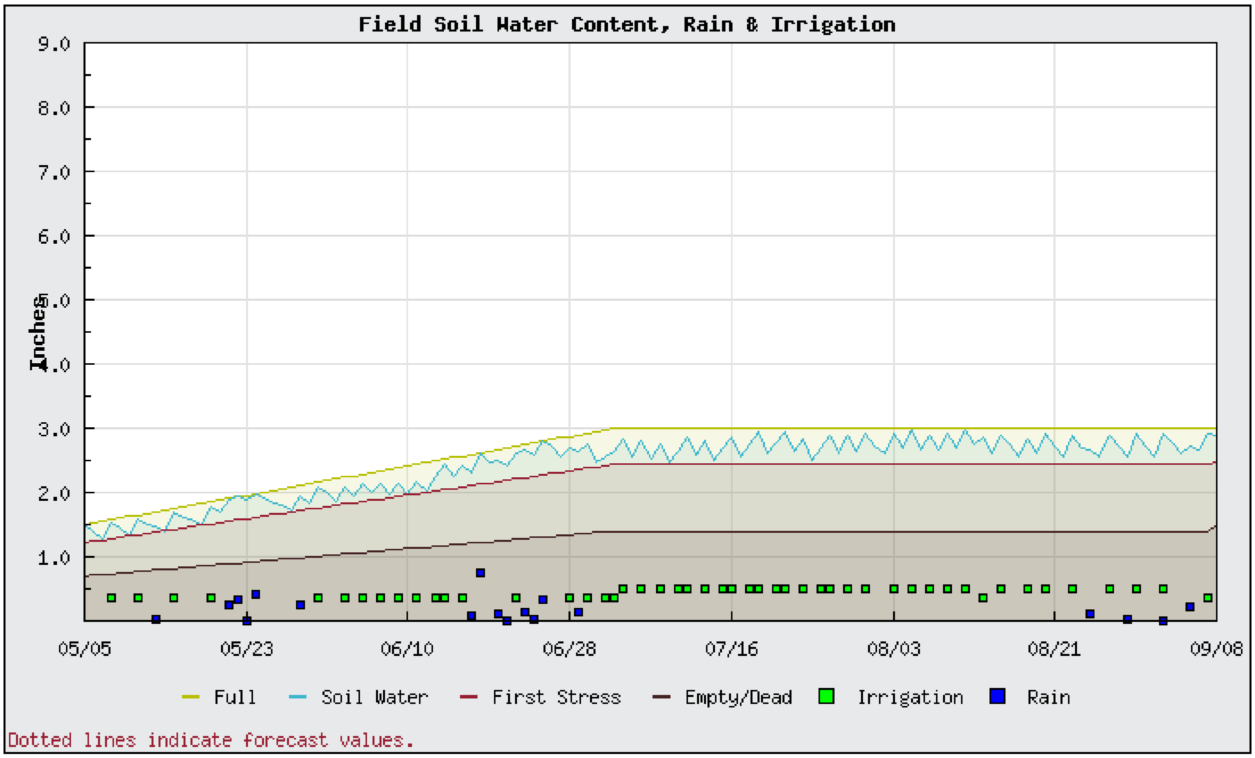

Figure 5. Soil water content over time in relation to the full (field capacity), first stress (management allowable depletion) and empty/dead (permanent wilting point). Chart for a Fine Sand. In this situation a total of 1 inch of water was lost during the season to deep percolation due to untimely rainfall events.

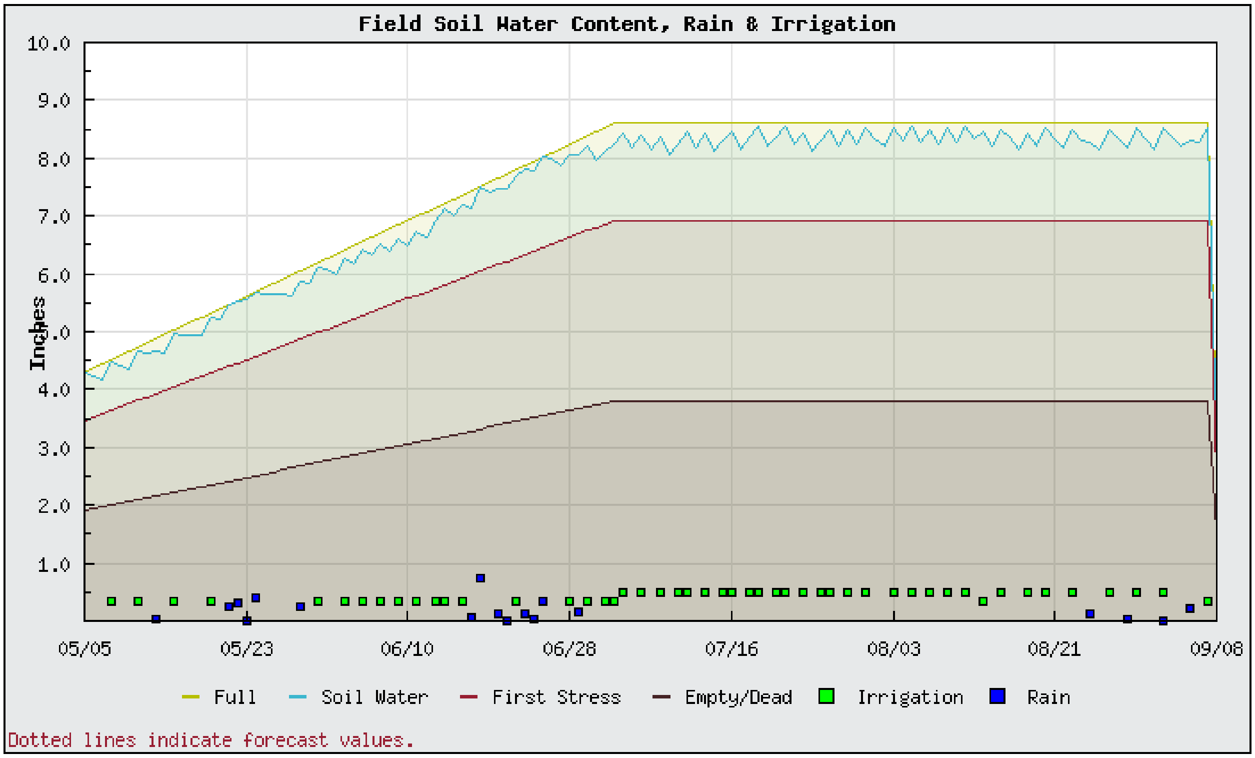

Figure 6. Soil water chart for a silt loam soil managed for the fine sand.

Managing for Silty Soils (Figure 7 and 8)

What if the water for the whole field is managed for the deep silt or clay soils? In this case, much more water can be applied at each irrigation event and these events can be much less frequent. The soil water content under this management strategy on the silt soils over time is shown in Figure 7.

Figure 8 shows how the *sandy areas* of the field would fare if the whole field was managed uniformly for the silty soils. While the same amount of water is applied on both the silt and the sand sections, under this scenario in the *sandy areas*:

- 3.4 inches MORE water is lost to deep percolation (Table 2). More water is applied to the soil than it can hold in the root zone.
- There is a 17% yield reduction due to water stress.
- The vines would use 4 inches LESS water (ET) in the sandy areas due to shutting down as a result of water stress.

Table 2. Comparison of two different areas of the field if the whole field is managed uniformly for the silt loam soil with deeper irrigations applied less frequently. All water depths are in inches.

Scenario	Figure Ref.	Season Total ET	Total Irrigation	Total Rainfall	Deep Perc.	Yield Loss
Silt soil that is managed to replace the deficits in silt (deeper irrigations).	Fig. 7	23.8	19	3.2	0	0
Sandy soil that is managed for silt (deeper irrigations).	Fig. 8	19.8	19	3.2	3.7	17%

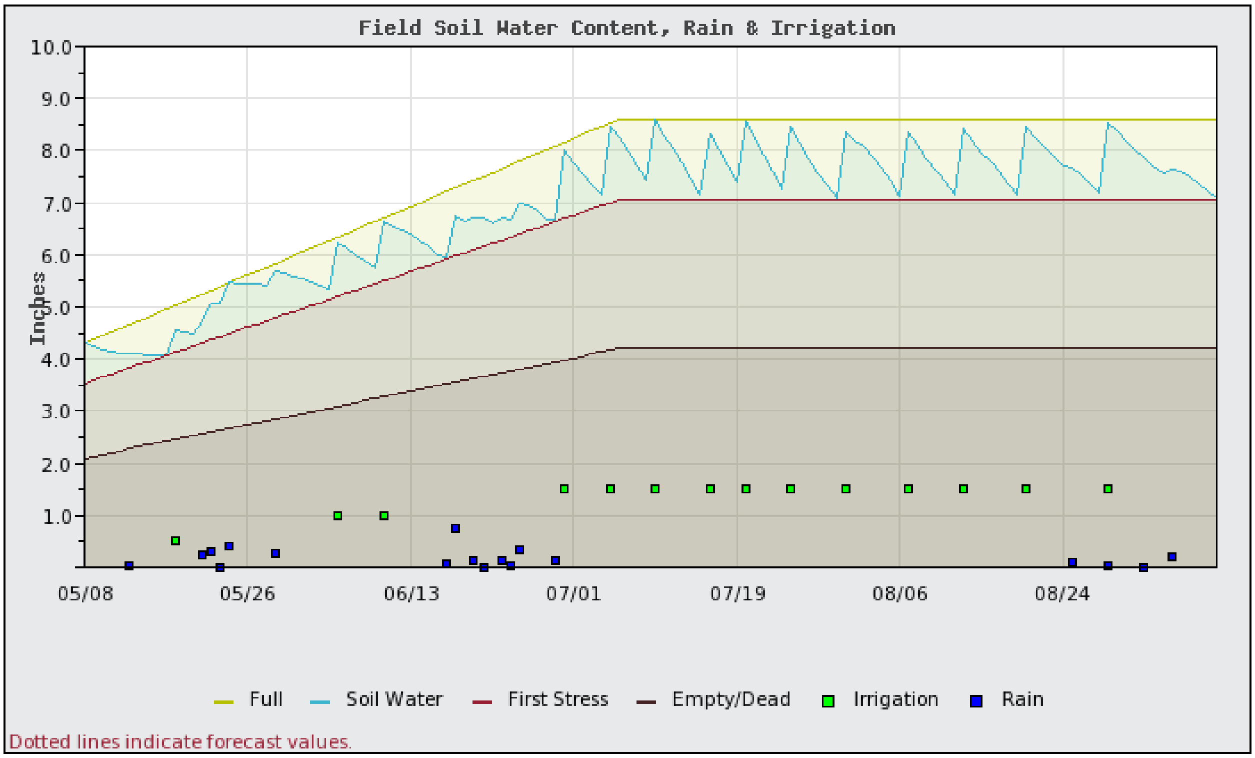

Figure 7. Soil Water Content Chart. Irrigation for Silt on Silt. No water stress. 0.04 inches of DP early in the season due to rain.

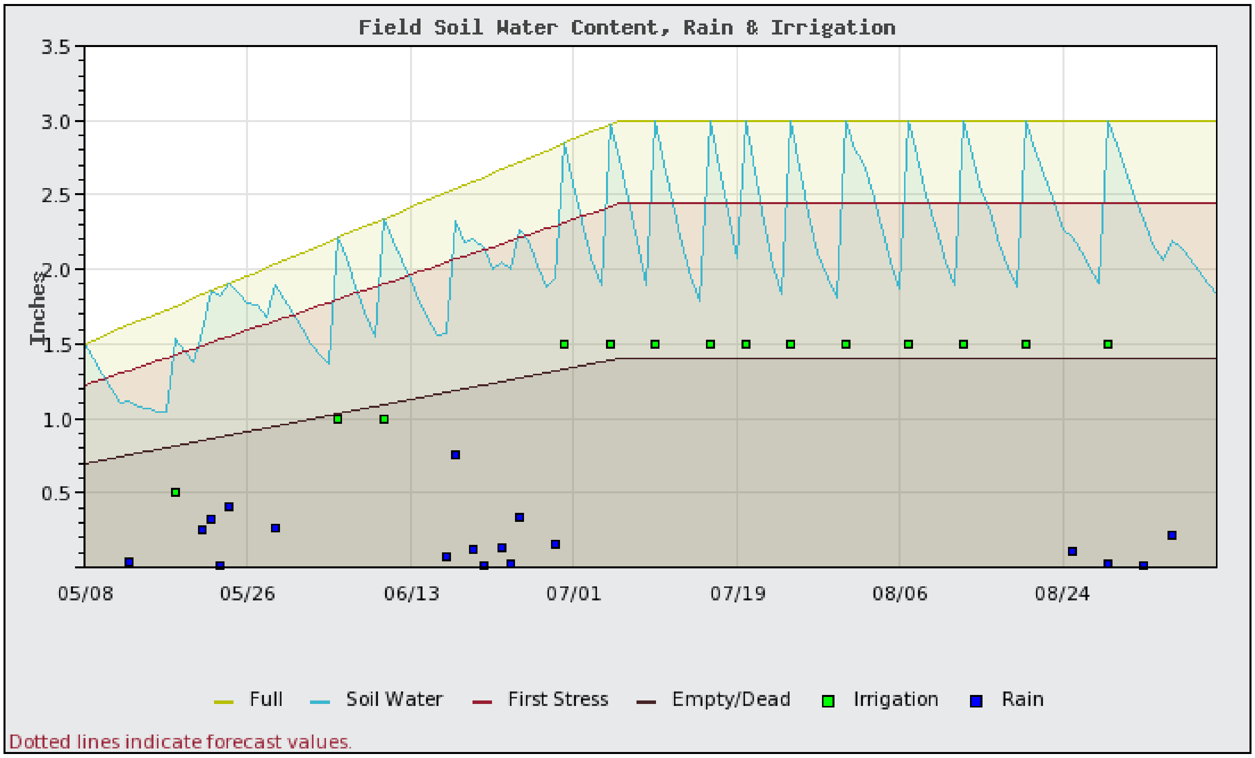

Figure 8. Soil Water Content Chart. Irrigation for Silt on Sand.

Appendix B.

Soil Water Simulation to illustrate how VRI Can be Used to Take Advantage of Significant In-Season Rainfall

This section covers an example of how VRI might be used in a field with large variations in the soil's water holding capacity in a humid region to take advantage of significant rainfall events that occur in-season. Figure 9 shows the soil water content over time in the sandy area of the field where 0.35 inches of water was applied every time that there was capacity in the soil to hold it to ensure that the soil water content remained high. Figure 10 shows how the silt loam soil would fare if the field was managed uniformly under this scenario. It can be seen from the season totals in Table 2 that both of these scenarios resulted in the same amount of total crop ET, total irrigation amounts, that no crop water stress was experienced by the crop throughout the season. However there was a lot of water loss in all areas of the field to deep percolation because the soil water content was kept high and there was little available space to capture this water. So, although in this simulation the rainfall infiltrated into the soil, that excess water was lost to deep percolation.

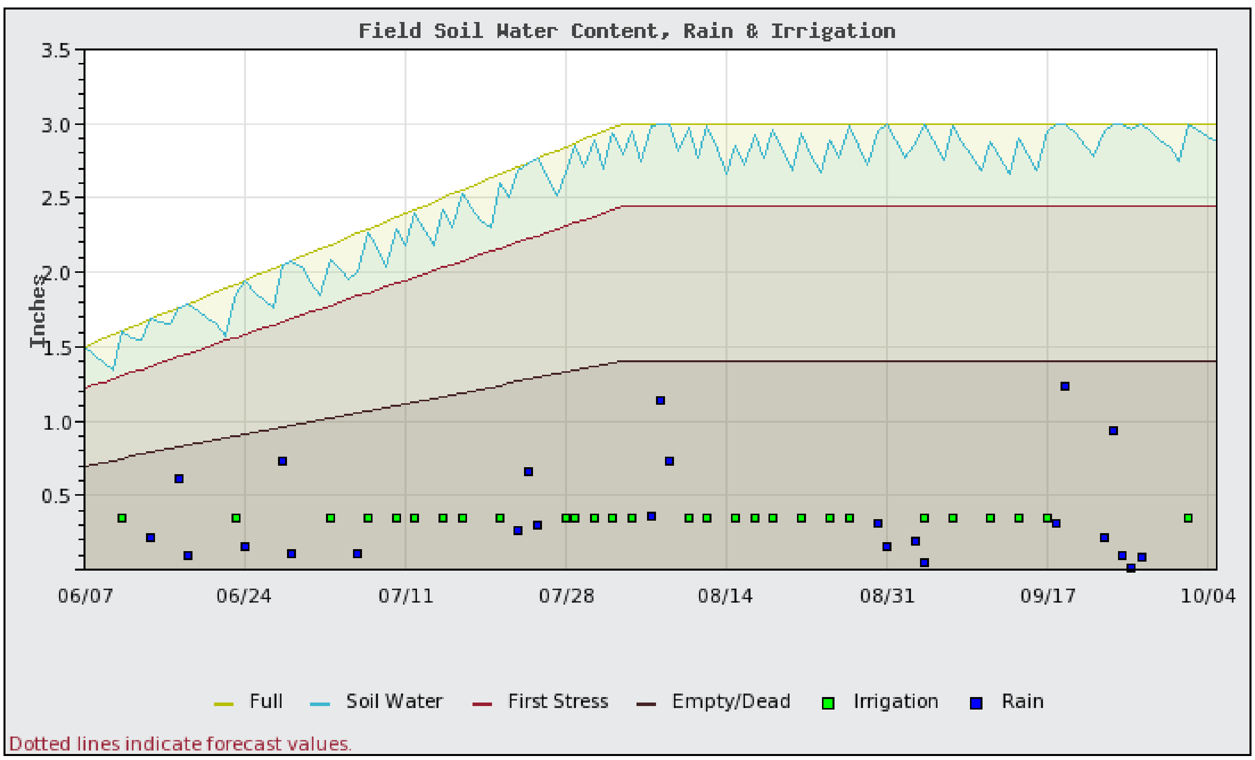

Figure 9. Sandy Soil managed to minimize stress in a humid region with significant in/season rainfall. The large rainfall events resulted in excessive deep percolation.

Table 2. Simulated season total water use in a humid region with significant in-season rainfall. A sandy area of the field is compared with the silt-loam soil that is of the field if the whole field is managed uniformly for the silt loam soil with deeper irrigations applied less frequently. All water depths are in inches. Deep percolation is primarily caused by rainfall.

Scenario	Figure Ref.	Season Total ET	Total Irrigation	Total Rainfall	Deep Perc.	Yield Loss
Sandy soil managed to limit water stress.	Fig. 9	13.1	9.8	9.1	5.9	0
Silt soil managed uniformly for the sand.	Fig. 10	13.1	9.8	9.1	5.9	0
Silt soil managed with VRI to maintain space for in-season rainfall.	Fig. 11	13.1	4.9	9.1	1.3	0

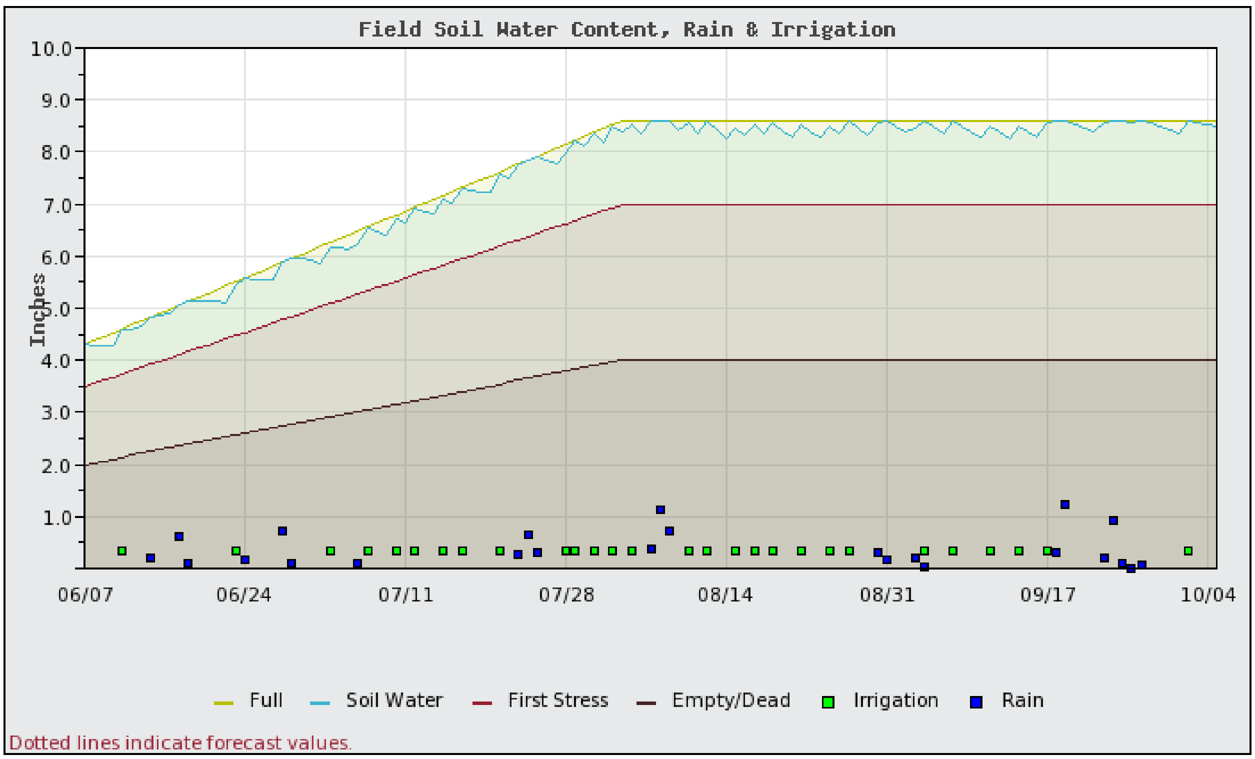

Figure 10. Silt Loam Soil in the field managed to minimize stress in the sandy soil in a humid region with significant in/season rainfall. The large rainfall events also resulted in excessive deep percolation.

If, instead, the irrigation system was shut off over the areas of the field with larger water holding capacities (deep silt or clay soils) until the crop was just about to experience water stress (Figure 11), then there is much more capacity in the soil to absorb the in-season rainfall.

Table 2 shows that although the crops did equally well in both areas, the silty areas of the field in the VRI scenario saved almost 5 inches of rainfall and had much less water lost to deep percolation. Hedley et al. (2009) also found large water savings potential under similar circumstances and that the water savings from VRI were related to rainfall events throughout the season (Hedley et al., 2010).

However, managing for these kinds of results takes very sophisticated management practices since:

- maintaining the soil water content right next to the water stress point leaves little margin for error,
- soil water holding capacities are continuously variable across the field requiring variable water restart periods for the spatially variable areas of the field,
- accurate decisions on how long to leave the water off and when to restart the irrigations to the different areas of the field would be complicated and vital to avoid crop yield losses to water stress,
- these decisions have to be re-evaluated, and new prescriptions uploaded to the VRI machine on a frequent basis throughout the season, and
- this would all be further complicated in the event that rainfall did not completely refill the soil.

Therefore, the complexity of implementing this scenario may be a deterrent until more sophisticated data collection and decision support systems are available to help analyze the data and upload prescriptions that vary in both time and space.

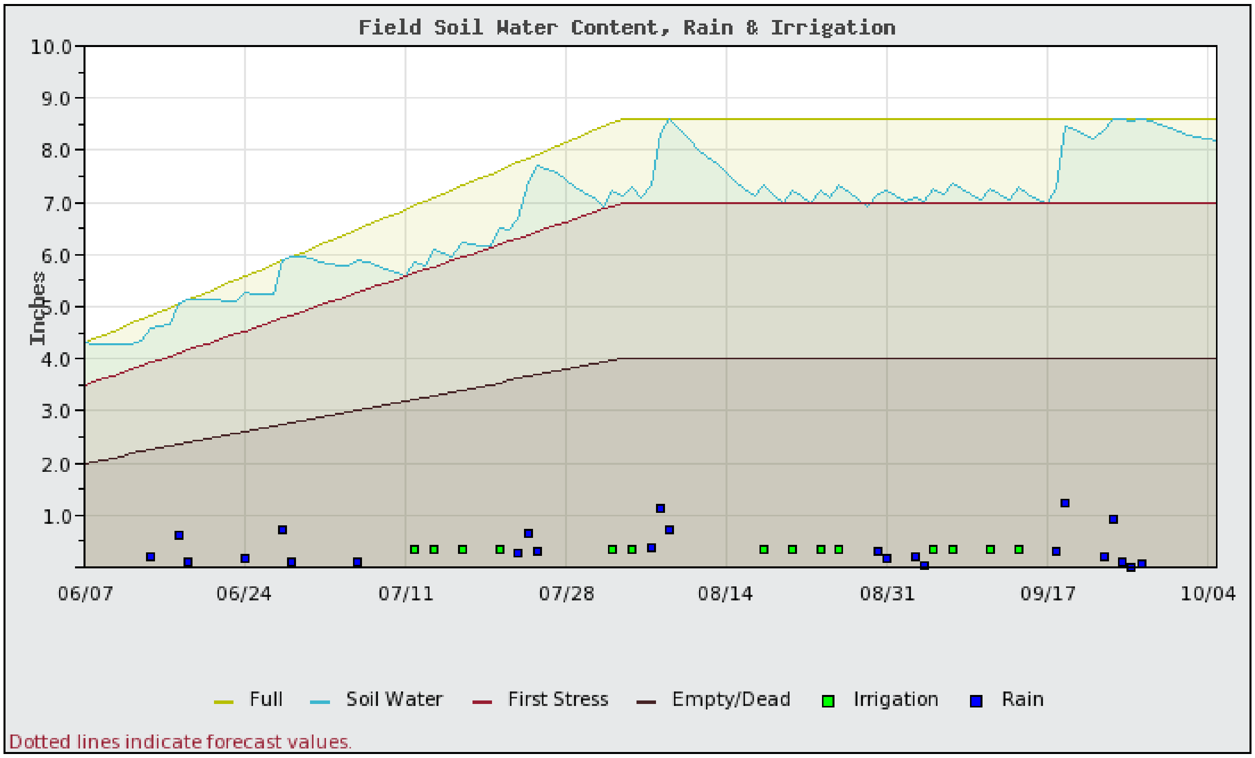

Figure 11. Silt Loam Soil in the field managed to leave space in the soil to absorb significant in-season rain events in a humid region with significant in/season rainfall. VRI was used to withhold irrigations for these areas until the soil water content was near the first stress line. Because there was excess room in the soil it was possible to absorb the large rainfall events to avoid losses to deep percolation, and irrigation water was conserved while waiting for the soil to dry down to near the first water stress point again.

REFERENCES

Berne, D., P. Valent, and K. Whitty. 2015. Agricultural Irrigation Initiative: Grower Experience. Northwest Energy Efficiency Alliance. Research report #E15-005. Available online at: http://neea.org/docs/default-source/reports/grower-experience.pdf?sfvrsn=4

Chavez, J.L., F.J. Pierce, and R.G. Evans. 2010. Compensating inherent linear move water application errors using a variable rate irrigation system. Irrigation Science 28:203-210.

Dukes, M.D. and C. Perry. 2006. Uniformity testing of variable-rate center pivot irrigation control systems. Precision Agriculture 7: 205–218.

Evans, R.G., J. LaRue, K.C. Stone, and B.A. King. 2012. Adoption of site-specific variable rate sprinkler irrigation systems. Irrigation Science 31:871–887.

Feinerman, E., and H. Voet. 2000. Site-Specific Management of Agricultural Inputs: An Illustration for Variable-Rate Irrigation. European Review of Agricultural Economics.27:17-37.

Hedley, C.B., I.J. Yule, M.P. Tuohy, and I. Bogeler. 2009. Key Performance Indicators for Simulated Variable-Rate Irrigation of Variable Soils in Humid Regions. Transactions of the ASABE 52:1575-1584

Hedley, C.B., S. Bradbury, J. Ekanayake, I.J. Yule, and S. Carrick. 2010. Spatial Irrigation Scheduling for Variable Rate Irrigation. Proceedings of the New Zealand Grassland Association 72:97-102.

Higgens, C., C. Bar, C. Hillyer, J. Kelley, and K. Whitty. 2015a. Agricultural Irrigation Initiative: Precision Water Application Test. Northwest Energy Efficiency Alliance. Research report #E15-009. Available online at: http://neea.org/docs/default-source/reports/precision-water-application-test.pdf?sfvrsn=4

Higgens, C., J. Kelley, Z. Liu, and C. Hillyer. 2015a. Agricultural Irrigation Initiative: Using Soil Electrical Conductivity Mapping for Precision Irrigation in the Columbia Basin. Northwest Energy Efficiency Alliance. Research report #E15-010. Available online at: https://neea.org/docs/default-source/reports/using-soil-electrical-conductivity-mapping-for-precision-irrigation-in-the-columbia-basin.pdf?sfvrsn=4

Milton, A.W., C.D. Perry, and A. Khalilian. 2006. Proceedings of the ASABE International Meeting in Portland, Oregon. 9-12 July, 2006. Paper number 061075.

O'Shaughnessy, S.A., Y.F. Urrego, S.R. Evett, P.D. Colaizzi, and T.A. Howell. 2013. Assessing Application Uniformity of a Variable Rate Irrigation System in a Windy Location. Applied Engineering in Agriculture. 29:497-510.

Peters, R.T. 2014. Irrigation Scheduler Mobile User's Manual and Documentation. Available online at: http://weather.wsu.edu/ism/ISMManual.pdf

Sadler, E.J., R.G. Evans, K.C. Stone, and C.R. Camp. 2005. Opportunities for Conservation with Precision Irrigation. Journal of Soil and Water Conservation. 60:371-379.

Stone, K., P. Bauer, W. Busscher, J. Millen, D. Evans, and E. Strickland. 2010. Variable-Rate Irrigation Management for Peanut in the Eastern Coastal Plain. Proceedings of the 5th National Decennial Irrigation Conference. CD-ROM. Phoenix, AZ. Dec. 5-8, 2010. paper IRR10-8977.