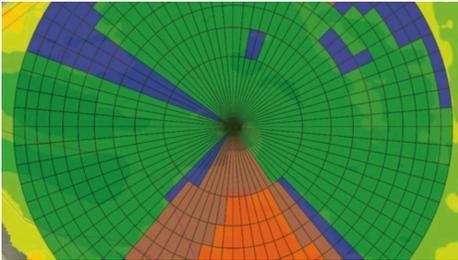


# Precision Irrigation Guide for Center Pivots



## Introduction

Precision irrigation is a process involving technology and specialized equipment to improve the efficiency and effectiveness of agriculture irrigation management. This management process is beneficial in allocating water based on spatial variability throughout fields and can sometimes conserve water and improve crop quality. Many field characteristics like topography, yield, and soil properties contribute to the spatial variations in irrigation needs throughout fields. **Variable rate irrigation (VRI)** for center pivots is a large part of precision irrigation as it can section out a field into zones or sectors to apply different irrigation rates based on the water needs of those specific areas.

Depending on the characteristics of a field, different approaches may be valuable for developing irrigation prescription maps. These approaches can range from using simple and accessible data to more costly but potentially very valuable data collection. A VRI system can be a beneficial management tool for improving irrigation efficiency with an understanding of the tools, time, and equipment needed for successful operation. In this fact sheet, we discuss the various VRI options for center pivots, when they might reduce water use and energy, produce higher crop yields, and when it might be unreasonable to expect these kinds of benefits.

## Highlights

- Variable rate irrigation (VRI) can improve water use efficiency and produce water savings in some conditions.
- Speed and zone control VRI systems are available to fit different budgets and the variability within the field.
- Options for creating prescription maps are addressed.

## What Is VRI?

VRI is a technology used on agricultural irrigation systems to vary the water application rate and/or speed of the irrigation to cater to the different needs throughout a field. When fields have varying soil properties, topographical features, or crop density, a VRI system can provide the correct amount of irrigation to each area. This technology has been used with the goal of improving water and crop water productivity primarily on center pivot irrigation systems (O'Shaughnessy et al., 2019). VRI can be implemented by either speed or zone control.

## Speed Control Example

- *If there is always runoff on a slope between 20 and 40 degrees, and the grower is applying 0.75 inch of water in a clockwise rotation, the pivot could speed up at 20 degrees to apply 0.25 inch over the trouble spot, then reverse at 40 degrees to apply 0.25 inch, and travel back to 20 degrees, where the pivot would again reverse and apply 0.25 inch (for a total of 0.75 inch on the trouble spot).*
- *The pivot would then slow down at 40 degrees to apply 0.75 inch to the rest of the field.*
- *The same total amount of water is 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, increasing infiltration and reducing runoff.*

## Speed Control VRI Systems

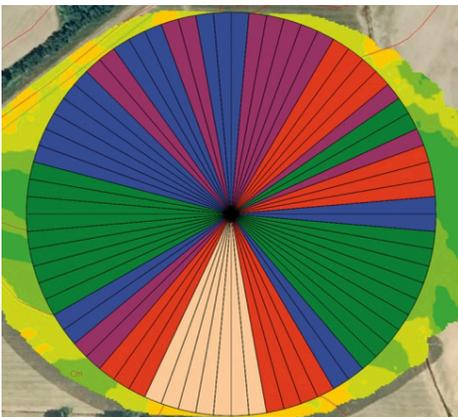
Speed control VRI systems have a much lower implementation cost than zone control VRI systems. All that must be adjusted when implementing a speed control system are some modifications within the control panel (Figure 1), and potentially adding a GPS unit at the end of the pivot. Most of the newer pivot 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 pivot speed in different areas of the field.

Speed control systems allow the pivot to run at different speeds throughout the field, creating pie-shaped zones (Figure 2). The flow rate of the pivot is not modified with speed control. The varying speeds can reduce problems in areas that have infiltration issues due to varying soil properties or topographical differences by irrigating in a wiper pattern at different speeds across any problem

areas (see “Speed Control Example” box; Peters & Flury, 2017; O’Shaughnessy et al., 2019). These systems can also benefit a field that has multiple crops when planted within a sector pattern to meet the water requirements for each crop (O’Shaughnessy et al., 2019). Speed control systems are also easier to learn from the beginning than zone control VRI due to less technology, equipment, and skills required.



**Figure 1.** *Pivot Panel With Speed Control Variable-Rate Irrigation Capability*



**Figure 2.** *Speed Control Irrigation Map, Where the Pivot Can Travel at Varying Speeds at Different Field Locations*

*Notes.* The colors depict the different zones and water amounts that will be applied.

Image used with permission from Peters and Flury, 2017.

### Additional Useful Applications for Variable Speed Technology

- **Reduce wheel ruts** On pivots that are not full circles (referred to as 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). This avoids running the pivot in overly wet areas in an attempt to reduce wheel-rutting issues.
- **Increase water infiltration** In areas of the field where infiltration is an issue due to clay soils or steep slopes, it is possible to speed up and wipe

back and forth across that field area to allow additional time between water applications for water to infiltrate and move deeper into the soil.

- **Address geographical challenges** Pivot tires sometimes slip slightly when climbing hills or when going down steep slopes. This can result in unintended differences in irrigation application rate. A speed control system based on actual ground travel speed can alter the pivot speed setting to account for tire slippage (Chavez et al., 2010).

### Zone Control VRI Systems

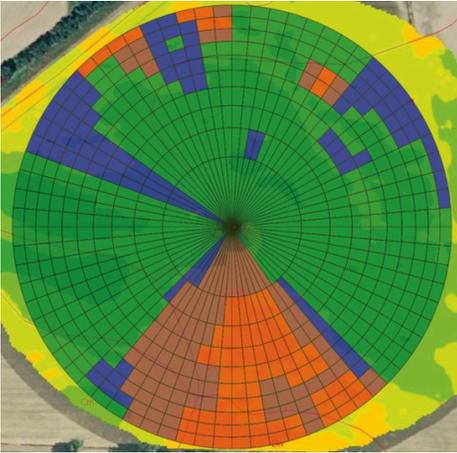
Zone control VRI systems have a much higher upfront cost than speed control systems because additional components must be installed along the pivot in addition to advances made within the control panel. A zone control system requires a VRI zone control box, a VRI software system, and individual valve that can be programmed by the VRI zone control to pulse “on” and “off” on each outlet of the pivot (Figure 3). Sometimes only specific sections of a pivot are outfitted with control valves. In some cases, groups of sprinklers are controlled together; in other cases, every sprinkler is controlled independently. Variable zone irrigation is much better at responding to the spatial variations in the field than speed control VRI. Turning sprinklers on and off varies the overall flow rate of the pivot. Therefore, a water delivery system that can absorb these variations is necessary.

Zone VRI systems can adjust the pivot speed as well as the watering rates along the pivot (Figure 4). This provides much more potential spatial variability in irrigation rates based on crop water demands, soil property differences, and topographical differences. These systems can also be used to omit watering in areas that are un-farmable (Sadler et al., 2005).



**Figure 3.** *(left) Control Node Boxes and Valves on Each Pivot Drop, Required for Zone VRI; and (right) Add-on Panel to Existing Pivot, Enabling Zone VRI*

*Note.* New panels with built-in zone capability are preferred due to fewer communication issues.



**Figure 4.** Zone Control Irrigation Map, Where the Pivot Can Adjust Speed and Application Rate to Apply Variable Irrigation Throughout a Field

*Notes.* The colors represent irrigation zones. Image used with permission from Peters and Flury, 2017.

## How Much Does It Cost to Install and Maintain VRI Systems?

The cost of speed or zone control VRI systems will vary greatly depending on many factors, such as field size, labor rates, inflation, interest rates, hardware costs, equipment lifespan, and many other related characteristics. Due to this variability, it is difficult to provide accurate cost estimates for each condition. Those interested in VRI systems should consult irrigation dealers and other VRI users for more precise estimates. However, to provide guidance and a starting point to estimating costs, Utah State University and Washington State University developed an irrigation investment tool, the [Irrigation Investment Calculator](#), that allows users to input their expected labor, prices, and interest rates to estimate VRI system costs.

### Speed Control Cost

Despite variable speed irrigation's obvious limitations to apply only in pie-shaped wedges (Figure 2), variable speed irrigation has a lower cost than zone VRI. Since most modern pivots have speed control capability, the only modifications are to the pivot electronic controls.

The default settings (which can be modified by users) in the Irrigation Investment Calculator were used to estimate the costs of speed control VRI (Figure 5). The default setting is a common 120-acre center pivot that irrigates for 20 weeks a year, has a lifespan of 20 years, does

not increase crop yield, reduces water application by 0.7 inches per year, and assumes various labor and management costs. In these conditions, the total **annual** cost for implementing speed control VRI was \$880 per pivot or \$7.33 per acre per year. The cost per acre is less than most tillage or pesticide operations and may be an affordable way to improve irrigation management and production for many growers.

General Assumptions	Value	Intermediate Results
Management Cost Rate (\$/hr):	35	**
Labor Cost Rate (\$/hr):	15	**
Operating or Equip Loan Interest Rate (%):	5	**
Inflation Rate (%):	2	**
Irrigation Season Length (weeks):	20	**
Field Size (acres):	120	**
Upfront, One-Time, Non-Recurring Costs:		Upfront/Installation Results
Upfront Total Hardware Costs (\$):	1800	**
Hardware/Equipment Lifespan (years):	20	**
Upfront Management Time Required (hours):	10	**
Upfront Unskilled Labor Required (hours):	0	**
Annual Recurring Cost Assumptions		Annual Recurring Cost Results
Management Time Required (hrs/year):	1	**
Labor Time Required (hrs/year):	0	**
Ongoing Expenses (\$/year):	0	**

Upfront/Installation management time costs are \$350, and upfront/installation labor time costs are \$0. For a total labor cost of \$350. Annualized over the life of the equipment using loan interest and inflation rate, this is \$24 for labor, and \$124 for hardware, for a total annualized upfront cost of \$148.

The total of the ongoing annual management time costs are \$55. The total of the annual recurring labor costs are \$0. Including the annual ongoing expenses of \$0, this gives an total ongoing annual costs of \$55.

**Figure 5.** Irrigation

**Investment Calculator Estimates for Annual Cost of Speed Control VRI Systems Using Default Settings**

### Zone Control Cost

Zone control is more expensive to implement than speed control because more hardware, labor, technical skills, and maintenance are required. To estimate the costs of zone control VRI, we again used the [Irrigation Investment Calculator](#) with the same default general assumptions that were used in the speed control example—including a 120-acre pivot that irrigates for 20 weeks and the same labor and inflation rates. The upfront hardware costs increased from \$1,800 for speed control up to \$20,000 for zone control, and the upfront and recurring labor rates were much higher (Figure 6). Yield increases were considered zero in this example, and any yield increases (highly feasible in some conditions) would help offset the costs of zone VRI. In these conditions, the total **annual** cost for implementing zone control VRI was \$3,163 per pivot or \$26.36 per acre per year. While this is more than 3 times the cost of speed control VRI, the zone VRI cost may still be affordable for many operations that commonly spend this amount per acre to till or apply pesticides.

General Assumptions	Value	Intermediate Results
Management Cost Rate (\$/hr):	15	
Labor Cost Rate (\$/hr):	15	
Operating or Equip Loan Interest Rate (%):	5	
Inflation Rate (%):	2	
Irrigation Season Length (weeks):	20	
Field Size (acres):	130	
<b>Upfront, One-Time, Non-Recurring Costs:</b>		
Upfront Total Hardware Costs (\$):	20000	Upfront/Installation management time costs are \$1400, and upfront/Installation labor time costs are \$0, for a total labor cost of \$1400.
Hardware/Equipment Lifespan (years):	20	Amortized over the life of the equipment using loan interest and inflation rates, this is \$94 for labor, and \$1344 for hardware for a total annualized upfront cost of \$1438.
Upfront Management Time Required (hours):	40	
Upfront Unskilled Labor Required (hours):	0	
<b>Annual Recurring Cost Assumptions</b>		
Management Time Required (hrs/year):	15	The total of the ongoing annual management time costs are \$525.
Labor Time Required (hrs/year):	0	The total of the annual recurring labor costs are \$0 including the annual ongoing expenses of \$500.
Ongoing Expenses (\$/year):	500	this gives an total ongoing annual costs of \$1025.

Figure 6. Irrigation

### Investment Calculator Estimates for Annual Cost of Zone Control VRI Systems Using Default Settings

All the inputs in the [Irrigation Investment Calculator](#) can be modified to allow potential VRI users to get a more precise cost estimate for implementing VRI. The default settings were determined based on experience of the authors and consultation with the irrigation industry. *Be sure to tailor the settings and remember that there is a disclaimer on this tool that it does not provide actual prices, and detailed and precise quotes should be sought from irrigation equipment providers.*

## How Do I Make Variable Irrigation Prescriptions?

Irrigation needs throughout a field typically are not uniform. This could be due to multiple reasons, such as varying soil textures that require different amounts of irrigation to reach field capacity; varying soil water properties, topography changes resulting in ridges and swells where runoff and ponding may occur; rock outcroppings and areas with less topsoil, which result in lower crop productivity and reduced water needs; and so forth. When a VRI software system is put in place, built-in parameters usually assist in prescribing zones or sectors, such as soil survey data. However, some of this data may not be accurate enough for VRI prescription development or even available for all farming areas.

Setting the prescription or variable irrigation map is one of the most important features of VRI systems. Methods for setting these maps vary greatly, and research is in progress to evaluate the ability of various simple and complex approaches to optimize crop production and water use. We will describe a few of the common datasets and approaches used.

When gathering data to create prescription maps, it is important to understand what variables might be causing

the most variations in irrigation and yield throughout the field, as well as what data is cost-effective in collecting for prescribing zones.

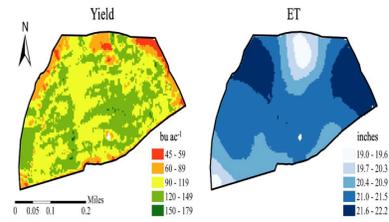


Figure 7. Examples of Spatially Variable Yield and Evapotranspiration (ET) Within a Field Used to Prescribe Zones for a VRI System on a Center Pivot

Prescription maps are commonly created from one or more of the following:

- soil texture and soil water property data (e.g., soil water-holding capacity),
- apparent electrical conductivity (ECa) data,
- elevation data, and/or
- maps of uncropped areas.

Less common parameters might be:

- yield maps,
- satellite or drone imagery,
- evapotranspiration (ET; Figure 7), and/or
- spring green-up soil water content data.

While soil texture, soil water property, ECa, soil water content, and ET data have been shown to be valuable parameters for prescription maps, gathering this information can be expensive and time-consuming, and not the best option for all fields. Elevation and yield data are cost-effective parameters because these can typically be accessed from grower's data, but again, these may not be the best option depending on the field.

The sectors or zones in a prescription map have the potential to be either static or dynamic. Static maps are created at the beginning of the growing season, and they stay the same throughout the season. Dynamic zones will change depending on how farmers want to track spatial and temporal changes of crop and water stress throughout the growing season. Dynamic zones continue to be researched with different approaches for determining when and how to change prescription maps. Many times, this is monitored through infrared temperature sensors or drone imagery that is converted to different vegetative indices to determine changes in crop water stress or ET. While this process may improve the precision of VRI, it

may not be a cost- or time-effective management process at this time for many growers.

## How Do I Decide Which Prescription Map Approach to Use?

When deciding which datasets to use to develop sectors or zones for prescription maps, focus first on datasets that best describe the variation in irrigation needs throughout a given field, which are cost-effective. Also, focus on datasets that match the capabilities of your VRI system. If using speed control, detailed spatial data may be interesting, but the system may not be able to match the variability, so invest wisely. For both speed and zone control, the likely starting point for many producers will be a combination of experience irrigating the field, known problem areas, and datasets that might come at no additional cost, such as soil survey maps from the Natural Resources Conservation Service (NRCS), yield data from a combine or forage yield monitor, satellite imagery, and elevation. It is generally wise to use these variables first and then invest in other datasets when they help describe additional variation in irrigation needs. *Please note that the NRCS soil survey maps were not developed at a scale intended for precision agriculture.*

## VRI Advantages

While every field may be affected differently by VRI, there are general possibilities of advantages from using VRI on center pivots. There is a potential to save water and have optimal to improved yields (Barker et al., 2018; Flint et al., 2023; Hedley et al., 2009; O'Shaughnessy et al., 2019; Sui & Yan, 2017). VRI can also improve the uniformity of the dry-down process in crops by irrigating areas with larger water-holding capacities less toward the end of the irrigation season (Peters et al., 2017). Runoff and deep percolation can be reduced, thus reducing nutrient loss and improving water quality. This can be one of the most significant benefits of VRI. When there are topographical differences within a field, VRI can be useful in reducing soil erosion, runoff on slopes, and ponding in swells within fields. In areas where there might be heavy rainfall during the growing season, the irrigation systems can be shut off in areas where water-holding capacity levels are larger so those areas can, in turn, harvest the rainfall and use it for crop growth rather than have it lost to deep percolation (Lo et al., 2016).

VRI can also be useful in maximizing profit throughout a field by increasing irrigation in historically higher-yielding areas and reducing irrigation in areas where yields are not

as profitable and are not limited by water. Irrigation within the inside span of a center pivot can be reduced to avoid overwatering. Water can also be shut off in areas like rock outcroppings, canals, or roadways to improve water savings (O'Shaughnessy et al., 2019). If growing more than one crop within a field, a VRI system can irrigate according to the unique water needs of each crop. Overall crop water productivity could be improved if irrigation is applied correctly within the differing portions of the field. VRI can also be used for variable rate fertigation to meet the spatially variable nutrient needs of the crop (O'Shaughnessy et al., 2019).

## VRI Disadvantages

Some disadvantages of VRI systems are the upfront costs, particularly a zone-controlled system, with the payback period variable depending on how well the system performs on the field, and maintenance costs within that period. Sprinkler packages and, potentially, pumps will require updating, which adds to the initial cost. Zone control systems have many more components than typical center pivots and therefore have greater maintenance requirements. Zone control VRI systems currently require regular visual inspection by the operator to ensure no equipment is malfunctioning. A speed control VRI system will not be as costly upfront, but the control panel on the center pivot may require updating, as well as a GPS system attached to the pivot (O'Shaughnessy et al., 2019). Further, for most applications, the additional cost will be a subscription service from the pivot manufacturer to cover the cost of telemetry to control and program pivots remotely.

Secondary technologies like soil and canopy sensors or drones may also be used to assist in making irrigation management decisions but do add costs to this system. Some benefits that might be observed with VRI may actually be caused by the use of technology and increased attention to irrigation management. The time taken to learn the system and create management zones for the growing season for each irrigation event can be extensive at first. Gathering data to create management zones can be time-consuming and expensive.

## Summary

Improved irrigation management can be achieved with either a speed or zone control VRI system. Most pivots currently have the capability for speed control VRI that could be implemented for less than \$10 per acre per year. Speed control VRI can help address variable irrigation needs but is limited in its ability to precisely match those

needs in highly variable fields. Zone control VRI can address high spatial variability in irrigation needs and provides many other benefits in various applications but costs nearly \$30 per acre per year to implement and operate, and maintenance requirements are significantly greater than for non-VRI center pivots. This guide provides a starting point for those interested in exploring the use of VRI systems. VRI systems research is ongoing, and forthcoming companion fact sheets will present detailed data on their performance.

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