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Variable Rate Irrigation Technology: A Step-by-Step Guide to Field Implementation[1]

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Introduction

Variable rate irrigation (VRI) is an advanced irrigation technology that allows farmers to customize and apply variable amounts of water based on specific field and plant conditions (Evans et al. 2013). VRI technology can be considered when field variability (topography, soil type, depth, etc.), different crops, or the same crop with different planting dates are included under the same irrigation system (O'Shaughnessy et al. 2019). The technology allows varying amounts of irrigation to be applied to specific locations at different times (Hedley et al. 2013). VRI technology uses precision agriculture techniques and can be employed to optimize water use, protect water quality, and improve crop yield (Sadler et al. 2005). This fact sheet will explore VRI technology and its components and provide specific examples of field-scale applications of VRI technology with step-by-step guidelines for data collection, data interpretation, developing VRI prescription maps, and uploading maps for implementation. Information included in this publication may be useful to growers, Extension agents, state agency personnel, research scientists, and students.

Types of Variable Rate Irrigation Technologies

Variable rate irrigation (VRI) technologies can be broadly categorized into three main types.

Speed control VRI: Since the flow rate through the system is constant, the irrigation application rate is adjusted by changing the speed at which the irrigation system moves across the field. For example, a center pivot or linear move system can either speed up or slow down to vary the amount of water applied in different areas (O'Shaughnessy et al. 2019). This method is relatively simple and can provide different water application rates across the field, but it lacks the precision of more advanced systems. While effective for large-scale variability, it may not be as accurate when addressing finer, localized differences in soil moisture or crop water needs (Evans et al. 2013).

Zone control VRI: The irrigation system is divided into multiple management zones, typically comprising groups of sprinklers that are controlled together. Each zone can be programmed to apply different irrigation rates based on field-specific variables such as soil texture, topography,

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and crop type (Sadler et al. 2005). This approach allows for more targeted irrigation than speed control VRI and can better accommodate varying field conditions. However, because zones are controlled in groups rather than individually, there can still be some inefficiencies if the water needs within a zone are highly variable (Evans et al. 2013).

Individual sprinkler control VRI: This is the most advanced and precise form of VRI technology. Each sprinkler is controlled independently, allowing for highly customized irrigation applications (O'Shaughnessy et al. 2019). This enables the application of irrigation only where and when needed, based on detailed data such as soil moisture maps, crop growth stages, or real-time weather conditions. The level of precision in this system reduces waste and optimizes crop growth, making it ideal for fields with significant spatial variability in water needs. However, it is also relatively complex, requiring technical skills and knowledge to manage, and expensive to implement and maintain (Evans et al. 2013).

Major Components of a VRI System

Irrigation system (hardware): The irrigation system hardware in VRI consists of key components working together for precise water delivery. The system consists of sprinklers, spans, pipes, hoses, and valves needed to transport water from the source and distribute it throughout the field.

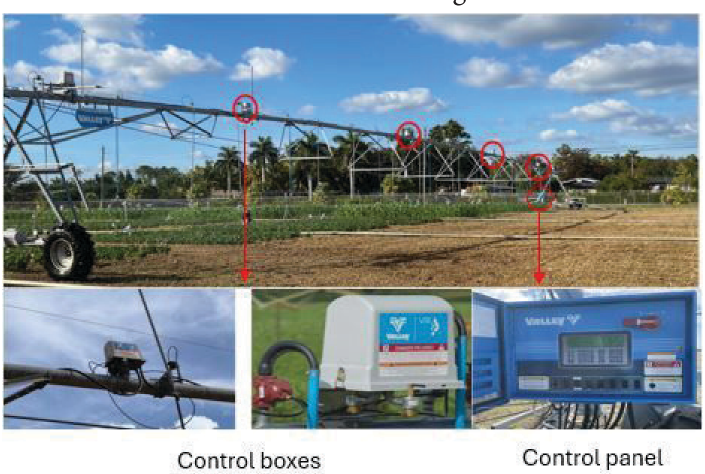

Figure 1. Components of a zone control VRI system include control boxes along the span and a control panel, which is typically located on the water supply side of the irrigation system.
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Control system (software and electronics): A control panel houses the electronics and software needed to program and control the system. Depending on the system, VRI technology can be remotely monitored and controlled using mobile devices, allowing farmers to send commands and adjust irrigation rates and schedules in real time from anywhere with an internet connection.

Sensing and measurement systems: Irrigation systems can be equipped with sensors and other measurement devices, such as soil moisture and infrared sensors, cameras, rain gauges, remote sensing, etc., for continuous monitoring of field and weather conditions. Such data can be used for irrigation decision-making.

Developing VRI Management Zones

VRI management zones can be developed based on soil properties (texture, depth, electrical conductivity, etc.), land use type (cropland vs. water body), crop type, crop growth stage, etc. Some factors delineating VRI zones are permanent, while others vary over time. The underlying factor used for VRI zone delineation can also affect the type of VRI prescription map needed. A prescription map is a spatial map with a detailed set of instructions developed with irrigation application rates needed to be applied for each management zone. These maps are created using the VRI control panel or software. When software is used to develop prescription maps, the map must be sent to the VRI system remotely using an internet connection or a cable connecting a laptop to the VRI system. There are two types of prescription maps: 1) static map, which is one map that can be used throughout the crop growing season; and 2) dynamic map, which needs to be adjusted to match the changing crop water needs throughout the growing season.

Examples of Prescription Map Development Based on Different Approaches

Field Information

A 1000 ft long and 296 ft wide field in south Florida is divided equally into four parcels and planted with tomato, snap beans, sweet corn, and squash (Figure 2). The soil is 8 inches deep with field capacity and a permanent wilting point of 0.28 in/in and 0.12 in/in, respectively. The management allowable depletion (MAD) is 0.2 in/in (Figure 3). A single-span linear move irrigation system (85% efficiency) with VRI technology irrigates the field. The linear span is 520 ft wide with 8 VRI zones.

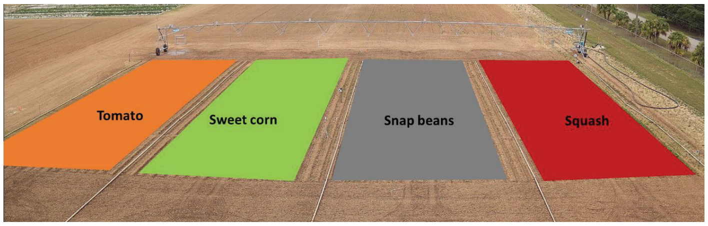

Figure 2. VRI field with four vegetable crops under a VRI system.
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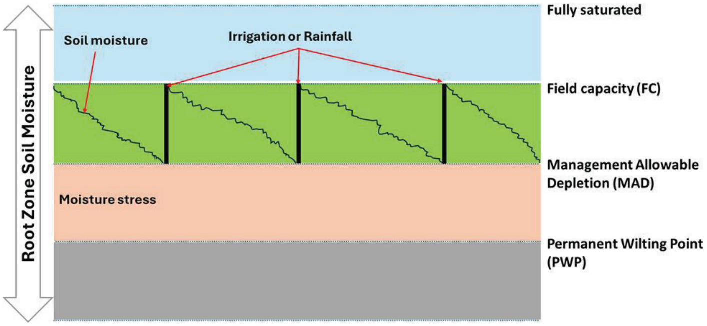

Figure 3. Schematic of root zone soil water relationships.
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Steps in Creating VRI Prescription Maps

Once the field and information are collected, the next step is to decide the irrigation scheduling technique that will be used to develop prescription maps. Regardless of the map type, the following steps can be followed to generate a zone control VRI prescription map to vary the rate of irrigation water applied to different crops. This helps ensure water is applied only where needed, reducing waste and maximizing crop yield.

1. **Data collection**: Gather representative soil moisture data covering each field. Different techniques, including sensors, can be used to gather soil moisture data. Representative soil moisture readings must be done frequently to avoid delays in irrigation and stress to plants (Table 1). Additional information on the number of sensors needed for irrigation and monitoring purposes can be found in Zotarelli et al. (2024). Assume the moisture reading on a given day for the four crops is as follows in Table 1.

2. **Data analysis**: Once average moisture data is collected, the next step is determining the adequate rooting depth for each crop. Then, multiply root depth by the difference between the field capacity (FC) and the average moisture content (AMC) as follows:

   CWR = (FC – AMC) x RD

   where CWR is total crop water requirement (in), and RD is root depth (in).

   Next, calculate the total irrigation depth (Di) for each crop by dividing the total crop water requirement (CWR) by the irrigation application efficiency (IAe) (e.g., 0.85 for the sprinkler system) (Table 2).

   Di = CWR / IAe

3. **Creating prescription maps**: VRI software is needed to create detailed prescription maps. A Valley VRI Software v8.55 (© 2024 Valmont Industries, Inc.) will be used for this example. However, it is important to note that there are various types of VRI software available, depending on the manufacturer, such as Reinke, Zimmatic, and T-L Irrigation. The underlying prescription development is similar.

After opening the VRI software, make appropriate selections about the irrigation system type (center pivot vs. linear) and the type of VRI technology on the machine and click OK. A new screen will open (Figure 4).

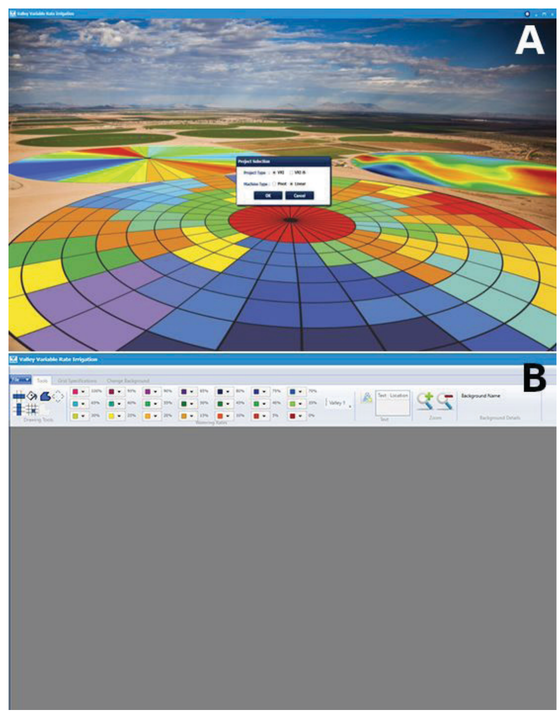

Figure 4. Valley VRI Software v8.55 interface: (A) shows the different types of machines and VRI, and (B) is the first window interface that opens after choosing the appropriate machine and VRI types for the project.
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The next step is creating a new project. From the file dropdown menu, choose the New Project option. Then, a new window will open, setting up the new project with file name, field information, linear dimensions, and sprinkler zones and length (Figure 5).

- Linear length = 296 ft
- Linear run length = 1000 ft
- Segment = 50 ft
- Number of zones = 4 (1 zone will be used for each crop)
- Width of each zone = 54 ft
- Buffer area between blocks and edge of field = 20 ft

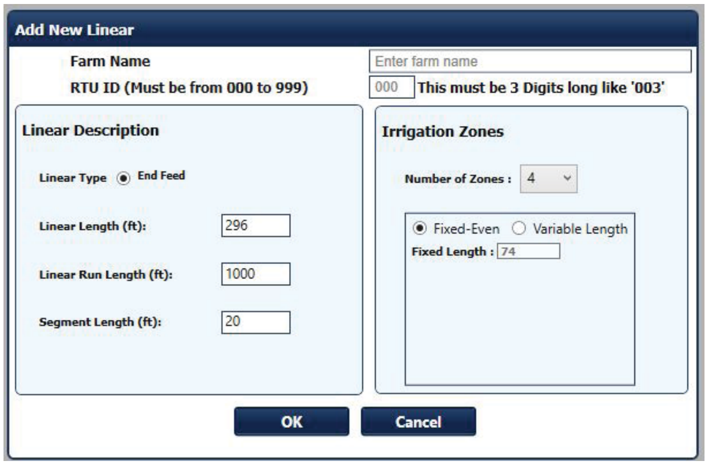

Figure 5. Creating a new VRI project.
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Next, import a background image for the field. This can be obtained from Google Maps and Google Earth for the field of interest. The image is needed to visualize the field layout. Once the image is imported, the field boundary should be approximately adjusted using the rectangular red and white lines. The rectangle can be adjusted and rotated using the points outside the rectangle (Figure 6).

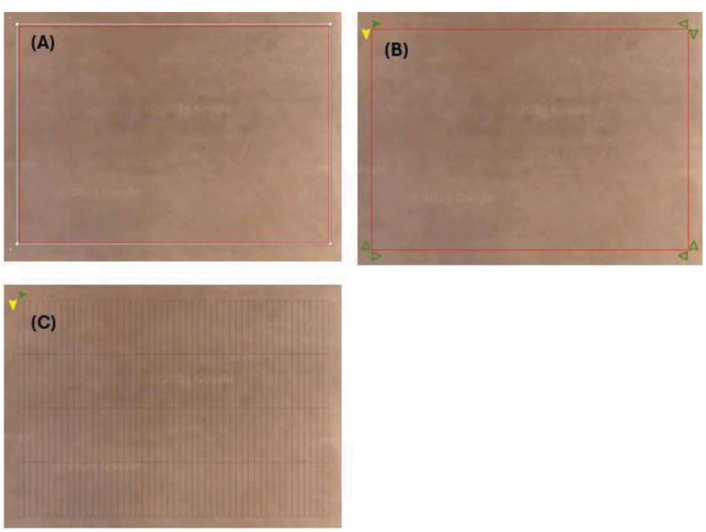

Figure 6. Setting field boundary (A), VRI system path and machine span direction (yellow arrow) (B), and horizontal and vertical gridding (C). The green and yellow arrows on the top-left corner of (B) and (C) represent the directions of the machine's linear path and span.
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Next, click the Machine Path button to set the machine's path and direction of the linear span. Then click the Draw Linear Grid button. This will create horizontal and vertical grids throughout the field. At this stage, the gridding of the field is complete.

The gridding is now complete with vertical grids (blocks) for each crop and horizontal grids that can be used to change irrigation rates along the linear path. In this case, the horizontal grids in each block will have the same irrigation rate.

The next step is filling each grid with corresponding irrigation rates. However, irrigation rates in the prescription map are entered in percentages, while a single value of irrigation depth will be entered in the control panel. The crop with the highest irrigation rate will be assigned 100%, while the irrigation rates for the other crops will need to be provided in the form of percentages using the crop with a 100% irrigation rate. The conversion of the irrigation requirements for the four crops is shown in Table 3 below. Since tomato has the highest irrigation requirement (0.85 in), it will be assigned 100%, and in the control panel, 0.85 will be entered. To adjust the irrigation rates for the other three crops, their irrigation rates need to be converted into percentages using 0.85 as a denominator (Table 3).

After converting irrigation depths into percentages, grids must be filled to corresponding values. The vertical sector tool can be used since irrigation is the same within each block (Figure 7). The watering rate buttons specify the amount of water to be applied to each block.

The prescription map is complete and needs to be saved with an appropriate name and folder. Click ***File*** > ***SaveAS Project*** > ***Save*** > ***OK***.

4. **Uploading prescription maps:** Maps must be uploaded to the irrigation system for execution. Uploading maps can be done using different approaches, including remote uploading to the cloud or a computer cable. Another approach is using a web browser for the AgSense portal (for Valley systems). Follow the steps below (Figure 8).

- Enter https://www.wagnet.net/ in a web browser.
- Log in using username and password.

Once the map is uploaded, click ***Send & Enable*** (Figure 9). A confirmation message that says ***Cmd Sent*** will be received. The prescription map is now saved in the machine and will be executed when running the irrigation system while the VRI is ***Turned ON***.

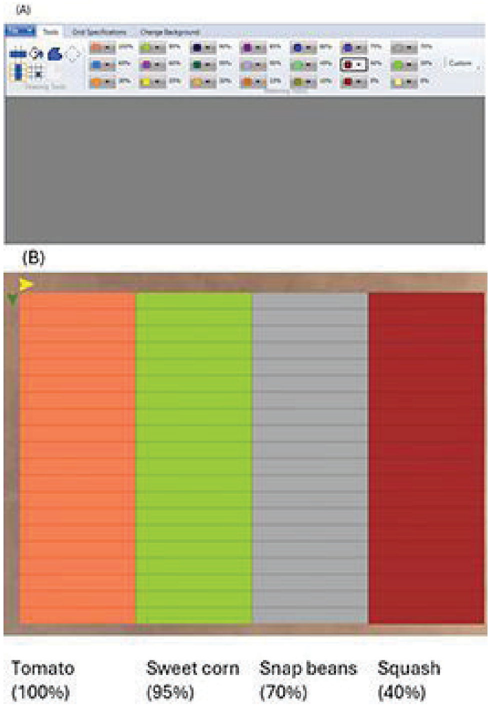

Figure 7. Assigning irrigation rates to blocks using a prescription color scheme. (A) Color scheme with a gradient representing different watering rates, ranging from 0% to 100%. (B) Prescription map with the corresponding watering rates.
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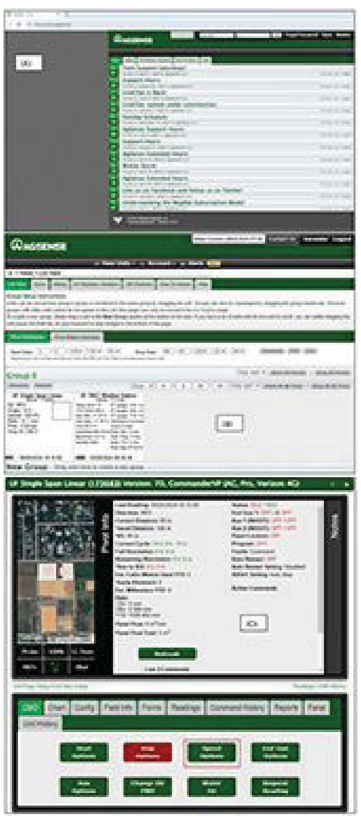

Figure 8. Uploading prescription maps through the AgSense web portal. (A) Login portal requiring a username and password. (B) A display of machines and equipment associated with the user account. (C) Detailed information for the selected equipment, including options to upload prescription maps.
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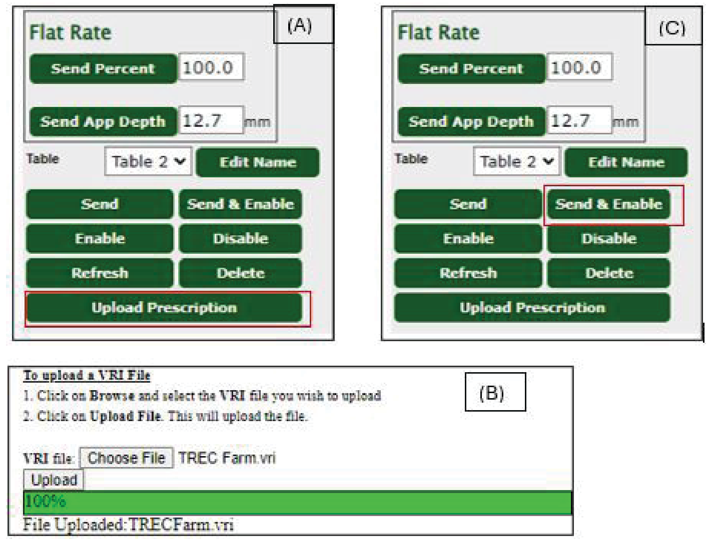

Figure 9. (A) Uploading a prescription map. (B) Selecting the file, uploading, and saving the prescription map. (C) Sending and enabling the prescription map for implementation.
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Note that every time soil moisture reaches MAD, similar maps will need to be continuously prepared and uploaded throughout the crop's growing season.

Developing Prescription Maps Based on Weather and Crop Information

Weather (evapotranspiration) and crop information can also be used to develop prescription maps. Most of the steps in developing prescription maps are the same. However, reference evapotranspiration (ET) data can be used when different crops are irrigated using the same system. Crop ET needs to be calculated for each crop using appropriate crop coefficient (Kc) values, taking growth stage and other factors into account. Similarly, when crop physiological parameters (e.g., crop stress index, sap flow, stomatal conductance, etc.) are used, parameter values must be converted to proportional irrigation water requirements. Once all the information in Table 1 is prepared, the same procedure can be followed to prepare prescription maps regardless of the irrigation scheduling technique.

Summary

In summary, VRI technology offers multiple benefits to irrigation management, including improved efficiency, reduced water and fertilizer waste, and increased crop yield (Table 4). By leveraging precision agriculture techniques, farmers can optimize water use and ensure that crops receive the optimal amount of water to grow. While there are challenges and considerations to implementing VRI, such as investment cost, data management, and technical expertise, its opportunities make it a valuable tool for precision agriculture. However, it should also be noted that this document does not cover critical information related to the selection, maintenance, and day-to-day operation of VRI systems.

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Table 1. Average moisture reading from four vegetable fields.

Crop	Average Moisture Reading (in/in)	Remark
Tomato	0.19	Below MAD, irrigate to avoid stress
Sweet corn	0.18	Below MAD, irrigate to avoid stress
Snap beans	0.2	Threshold to trigger irrigation
Squash	0.22	Slightly above MAD*
*The moisture reading is slightly above MAD for squash, and irrigation can be delayed for this crop/plot. However, considering overall operational costs, since the same irrigation system is run for all crops, it would be better to apply irrigation for squash at the same time as others.		

Table 2. Calculating irrigation depth from moisture readings.

Crop	Average Moisture Content (AMC; in/in)	Root Depth (in)	Total Crop Water Requirement (CWR; in)	Irrigation Depth (in)
Tomato	0.19	8	(0.28 - 0.19) x 8 = 0.72	0.72/0.85 = 0.85
Sweet corn	0.18	7	(0.28 - 0.18) x 7 = 0.7	0.7/0.85 = 0.82
Snap beans	0.2	5	(0.28 - 0.2) x 5 = 0.5	0.4/0.85 = 0.47
Squash	0.22	5	(0.28 - 0.22) x 5 = 0.3	0.3/0.85 = 0.35

Table 3. Calculating irrigation percentage for each crop for prescription mapping.

Crop	Average Moisture Content (AMC; in/in)	Root Depth (in)	Total Crop Water Requirement (CWR; in)	Irrigation Depth (in)	Prescription Value*
Tomato	0.19	8	0.09 x 8 = 0.72	0.85	100%
Sweet corn	0.18	7	0.1 x 7 = 0.7	0.82	95%
Snap beans	0.2	5	0.08 x 5 = 0.5	0.59	70%
Squash	0.22	5	0.06 x 5 = 0.3	0.35	40%
*The values are rounded to the nearest 5% since prescription map values are available in a 5% increment.					

Table 4. Summary of key advantages and disadvantages of VRI technology.

Advantages	Disadvantages
• Improves water use efficiency by allowing precise water application. Increases crop yield by providing optimal amounts of water that plants need. • Reduces energy costs for pumping and other irrigation-related operations due to reduced water use. • Minimizes nutrient leaching and runoff, thereby reducing pollution of water bodies.	• Cost: Acquiring VRI systems and associated software can be costly. • Operational complexity: Creating and managing prescriptions requires new skills and knowledge. • Regular maintenance is needed to ensure accuracy and reliability. • Data requirements: Collecting input data for developing dynamic prescription maps can be challenging.