Evaluation of Variable Rate Irrigation in Humid Region

Ruixiu Sui, Research Agricultural Engineer
USDA-ARS Crop Production Systems Research Unit, Stoneville, Mississippi, USA

Abstract. Variable rate irrigation (VRI) is a new irrigation method in irrigation industry. VRI technologies allow producers to site-specifically apply irrigation water at variable rates within a field to adjust the temporal and spatial variability in soil and plant characteristics. Adoption of VRI has the potential to improve water use efficiency. VRI method was evaluated in soybean and corn in Mississippi Delta. Soil apparent electrical conductivity (EC) was used to delineate VRI management zones and create VRI prescription maps. Irrigation was scheduled using soil moisture content measured by soil moisture sensors. Crop yields and irrigation water productivity in VRI treatment was compared to that in the uniform rate irrigation (URI) treatment. Results demonstrated that the VRI saved 25% irrigation water in soybean and 21% in corn. Irrigation water productivity (WP) of VRI in soybean was 31% higher than the URI. WP of the VRI in corn was 27% higher than the URI. VRI management was superior to the URI in terms of irrigation water use efficiency. Soil EC coupled with soil physical properties could be used to establish irrigation management zones for VRI practice.

Keywords. Irrigation, soil electrical conductivity, variable rate irrigation, water management

Background

Irrigation plays a critical role in crop production. Irrigated crops produced more and stable yields than dryland crops. Irrigated agriculture in US is a major consumer of freshwater, accounting for 80% of the nation's consumptive water use (Schaible and Aillery, 2015). Limited water resources are becoming an increasing constrain in agriculture. To meet global demands in food and fiber while maintaining agricultural production sustainable, crop water use efficiency has to be increased.

In recent years, acreage of irrigated land in US has increased rapidly in the humid regions including the Mississippi Delta (MD). MD is one of the major crop production regions in the United States. Main row crops in this region are corn, soybean, and cotton. Uncertainty in the amount and timing of precipitation has become one of the most serious risks to crop production in MD. Studies demonstrated that supplemental irrigation in this humid region could increase crop yield and reduce production risk (Cassel et al., 1985, Boquet, 1989, Sui et al., 2014). The producers have become increasingly reliant on supplemental irrigation to ensure adequate yields. In this region, approximately 90 percent of irrigated cropland relies on the groundwater supply from the Mississippi River Valley Alluvial Aquifer. Excessive withdrawal of the groundwater resulted in a decline in aquifer levels across the region. Ongoing depletion and stagnant recharging of the aquifer jeopardize the long-term availability of the aquifer and place irrigated agriculture in the region on an unsustainable path.

Variable rate irrigation (VRI) is a new irrigation method. VRI technologies allow the producers to site-specifically apply irrigation water at variable rates within the field to adjust the temporal and spatial variability in soil and plant characteristics. Adoption of VRI has the potential to improve water use efficiency. VRI technologies are normally implemented on self-propelled center-pivot and linear-move sprinkler irrigation systems. Similar to other variable rate application systems in precision agriculture, VRI practices require specialized hardware and software. VRI hardware requirements include a GPS receiver to determine the spatial position of the irrigation system and an intelligent electronic device to control individual sprinklers or groups of sprinklers to deliver the desired amount irrigation water on each specific location within the field according to the VRI prescription. The software required includes the algorithms to calculate the water application rates and the computer programs to create VRI prescription maps. Two control methods can be used for VRI, the speed control and the duty-cycle control (LaRue and Evans, 2012). The speed control method changes the travel speed of the sprinkler irrigation system to vary the water application depth. The speed control is able to vary the application rate only in the travel direction of the irrigation system, not along the lateral pipeline, resulting in difficulty to develop VRI for randomly-shaped management zones to address the variability of soil and plant characteristics across the field. The duty-cycle control method changes the duty cycle of individual sprinklers or groups of sprinklers installed along the lateral pipeline. The duty-cycle control method is capable of varying the irrigation rate in the system's travel direction and along the lateral pipeline, which offers more flexibility in development of the management zones. VRI practice requires a prescription map. A prescription map provides the information to the controller of a VRI system for how much water to deliver at each specific management zone within the field. The VRI prescription map should include spatial coordinates of each management zone and the irrigation water depth associated with each management zone within the field. Normally the prescription map can be created using the software associated with the VRI system.

One or multiple inputs including soil properties, plant water stress, crop yield potential, field topography, and other relevant parameters could be used with geographical information system (GIS) software to delineate each management zone and determine the irrigation water application rate. Currently, VRI systems are commercially available. However, development of algorithms and models using various inputs for calculating the appropriate amount of water to site-specifically apply is a bottleneck of VRI technologies and one of the great challenges faced by VRI researchers.

The objective of this study was to develop and evaluate VRI method to improve water use efficiency in crop production.

Procedures

The study was conducted for two years in 2014 and 2015 in two adjacent fields (Field A and Field B) in Stoneville, Mississippi, USA (latitude: 33°26'30.86", longitude: -90°53'26.60"). Each field is 6.7 ha with a 1% slope from West to East. Soil samples were taken from Fields A and B in a 0.3-ha grid and 15-cm depth, and analysed for soil physical properties in 2013. Though silt loam was the predominant soil type, variability in clay and sand content existed across the fields. Fields A and B were under the coverage of a VRI centre pivot irrigation system, and occupied half of the pivot's full circle between 0 to 180 degree (clockwise from north). Field A was in the circular angle 0° to 90° while Field B was in 90° to 180°.

The experiment layouts in the fields were showed in Figure 1. In 2014 and 2015 season, each field was equally divided into two sectors. One sector was assigned to VRI treatment, another one to URI treatment, and the remaining area not covered by the pivot in each field was assigned to the rainfed treatment.

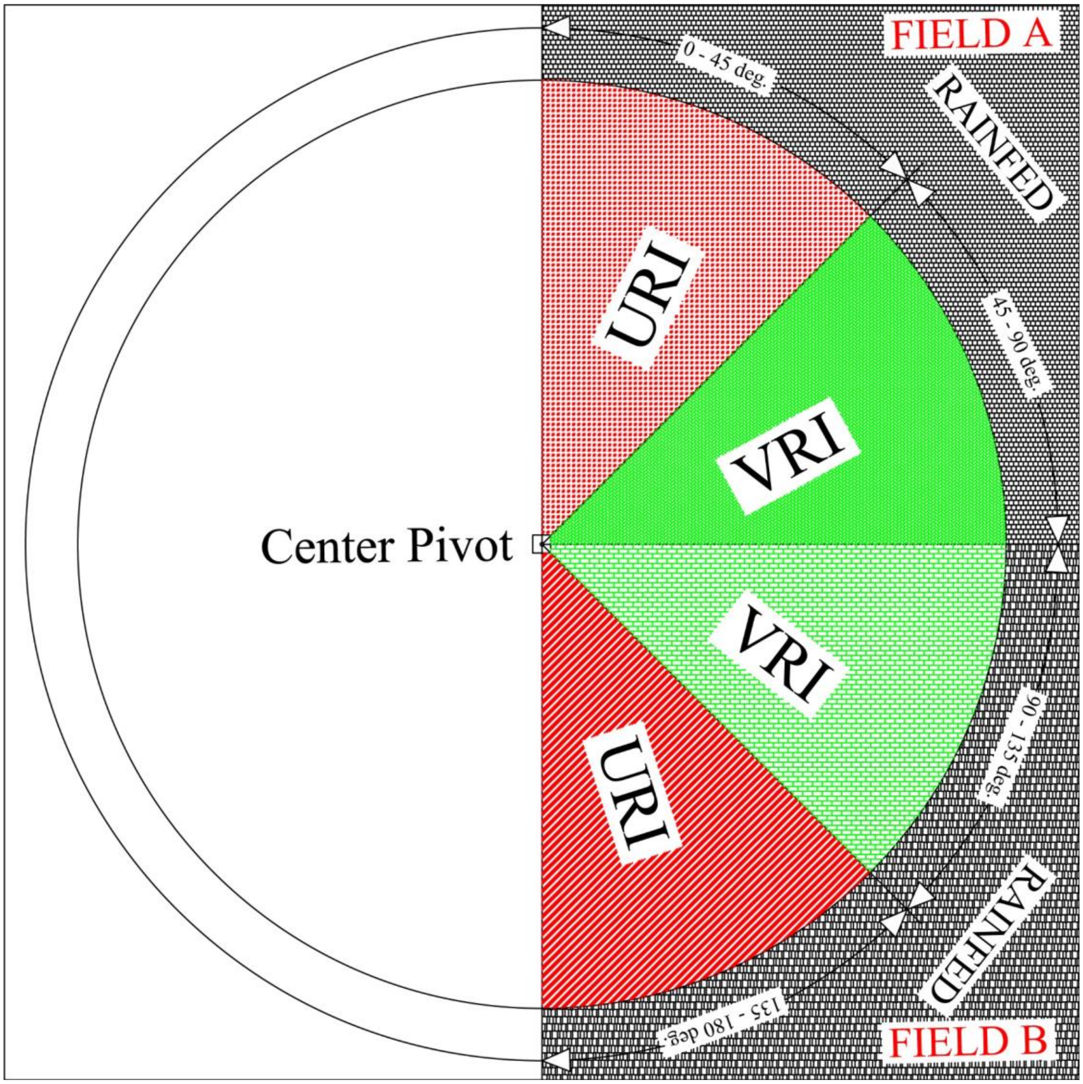

Fig. 1. Experimental layout in 2014 and 2015

The irrigation system used in this study consisted of a Valley 8000 Standard Pivot coupled with the Valley VRI zone control package (Valmont Irrigation, Valley, NE, USA). Field tests showed that this centre pivot VRI system had a coefficient of uniformity of 86.5% with constant rate application and 84.3% with variable rate application (Sui and Fisher, 2015). The system was configured in 4 spans with a total length of 233 m. Sprinklers along the length of the centre pivot were divided into 10 control zones, with each zone covering the same surface area of 1.7 ha. The Valley VRI controller included the zone control units, solenoid valves, a GPS receiver, and software. The zone control unit controlled the duty cycle of the sprinklers by turning electric solenoid valves on and off to achieve desired application depths in individual control zones. The GPS receiver determined the pivot's position in the field for identification of control zones in real time. VRI prescriptions were created using the software provided with the VRI system.

Management zones for VRI management were created based on soil electrical conductivity (EC). Soil EC of Field A and Field B was measured using the Veris 3100 soil EC mapping system. An EC_{dp} map of Field A and B was created using software ArcMap (version 10.2.1, Esri, CA) (Fig. 2)

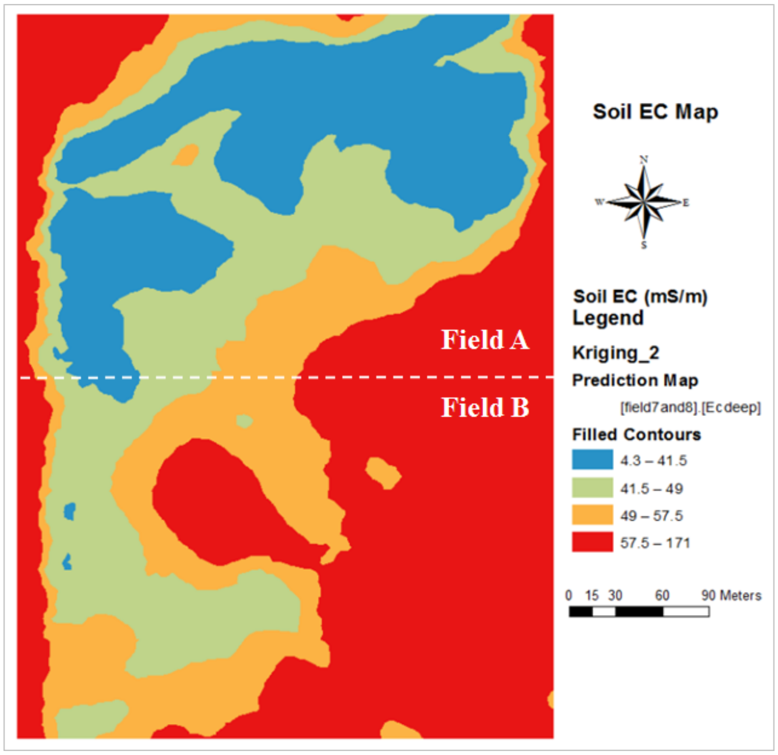

Fig. 2. Soil electrical conductivity map of Field A and Field B. The filled contours correspond to soil EC_{dp} categories 1-4 (in blue to red on legend).

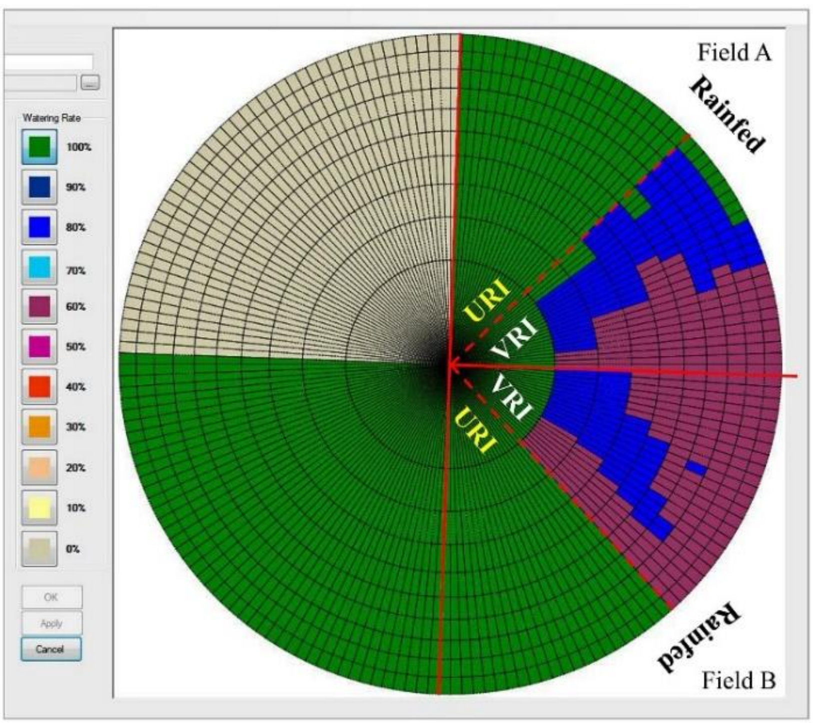

Fig. 3. Prescription map for variable rate irrigation in 2014 and 2015. Irrigation water application rates were indicated by different colours on the map.

Three management zones were created based on the soil EC_{dp}. In Field A, areas in EC_{dp} category 1 and 2 were assigned as management zones A (MZ-A) and B (MZ-B), respectively. Areas under EC_{dp} category 3 and 4 were combined together to be assigned as management zone C (MZ-C). In Field B, areas in EC_{dp} category 1 and 2 were merged and assigned as MZ-A, and the areas in the category 3 and 4 were assigned as MZ-B, and MZ-C, respectively.

On account of their soil properties under the EC_{dp} categories and previously observed yield potential, irrigation rates of 100% (R100), 80% (R80), and 60% (R60) were respectively applied to MZ-A, MZ-B, and MZ-C in the VRI treatment. Irrigation rate R100 was applied to the entire URI treatment. No irrigation was applied to the rainfed treatment. Irrigation rate R100 represented the irrigation rate that was determined using soil water content measured by soil moisture sensors and the application rates of the other management zones were scaled based on their percentages. With soil EC_{dp} map as the background image, a VRI prescription was generated using software provided by the VRI system manufacturer (Valmont Irrigation, Valley, NE, USA). In the VRI prescription map, various depths of irrigation water were applied to different management zones according to the irrigation rate assignments (Fig. 3).

Soil water content sensors were installed at depths of 15 cm, 30 cm and 61 cm in the predominant soil of the field to measure soil water content (SWC). The sensors were calibrated with the soil from the field. The weighted average of the soil water contents in the three depths was used for irrigation scheduling. Percent plant available water (PPAW) is calculated using equation 1 to trigger irrigation events.

$$PPAW = \frac{(Sensor - measured\ SWC) - (SWC\ at\ wilt\ point)}{(Field\ Capacity - SWC\ at\ wilt\ point)} \quad \text{(Eq. 1)}$$

Irrigation was triggered when PPAW dropped approximately to 50%.

The amount of irrigation water used in the VRI and URI treatments was measured using a water flow meter installed at the inlet of lateral pipeline of the centre pivot. Crop yield data from 18 sampling locations in each crop-year of 2014 and 2015 were collected and analysed to compare the effect of the irrigation treatment on yield and irrigation water productivity (WP). WP was defined as follows.

$$WP\ (\frac{kg}{m^3}) = \frac{Amount\ of\ grain\ produced\ with\ Irrigation\ Water\ (kg)}{Amount\ of\ Irrigation\ Water\ used\ (m^3)} \quad \text{(Eq. 2)}$$

Results and Discussion

In soybean, VRI treatment used 25% less irrigation water than the URI. There was no significant differences between the yields in VRI and URI. The yield of the rainfed treatment significantly differed from that of the VRI and URI. Compared with the URI and rainfed treatment, VRI management increased soybean yield by 2.8% and 37.2%, respectively.

In corn, there was no significant yield difference among the irrigation treatments, VRI used 21% less irrigation water than the URI. Yield comparison across management zones indicated no difference between VRI and URI treatments. However, yield in both the VRI and URI treatments significantly differed from the yield of the rainfed. Irrigation increased the corn yield by 18%.

The WP in soybean was 0.84 kg/m^3 in the VRI management and 0.64 kg/m^3 in the URI, which indicated that the WP in the VRI was 31.2% higher than that in the URI. In 2014 corn, the VRI treatment had the highest WP of 2.49 kg/m^3 because only 2.54 cm irrigation water applied made 3.2% yield increase. In 2015 corn, the WP in the VRI treatment was 1.69 kg/m^3, which was 27.1% greater than the WP in the URI. This result was consistent with the result in soybean, showing the VRI management was able to use irrigation water more efficiently.

Conclusion

There was no significant difference between the yields in the VRI and URI treatment. However, the amount of irrigation water applied to the VRI treatment was 25% and 21% less than the URI treatment in soybean and corn, respectively. It was obvious that the VRI management resulted in significant water savings. The yield of the rainfed treatment significantly differed from that of the VRI and URI treatment in a dry year. In soybean, WP in the VRI was 31.2% higher than that in the URI. In corn, the WP in the VRI was 27.1% greater than the URI. Results indicated the VRI management was able to use irrigation water more efficiently in Mississippi Delta region.

With a large spatial variability of soil EC in a field and understanding the relationships among the soil EC, soil properties, and yield potential of the field, the method reported in this article has the potential to be used in other climates and fields to improve irrigation management.

Even though the use of soil EC to generate irrigation management zones could be an easy-to-use method in VRI management, researches on the algorithms with multiple input variables for delineating VRI management zones and determining VRI application rates are needed because there are many factors affecting crop water requirements for irrigation.

Acknowledgments

Author thanks Mr. Jonnie Baggard for his assistance in this study.

Disclaimer

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U. S. Department of Agriculture and does not imply approval of the product to the exclusion of others that may be available.

References

Boquet, D.J. 1989. Sprinkler irrigation effects on determinate soybean yield and lodging on a clay soil. *Agron. J.* 81, 793-797.

Cassel, D.K., C.K. Martin, and J.R. Lambert. 1985. Corn irrigation scheduling in humid regions on sandy soils with tillage pans. *Agron. J.* 77, 851-855.

LaRue, J., and R. Evans. 2012. Considerations for variable rate irrigation. In: Proc. the 24th Annual Central Plains Irrigation Conference, 111-116, Colby, Kansas, February 21-22, 2012.

Schaible, G., and M. Aillery. 2015. *Irrigation & water use.* Retrieved from http://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use.aspx.

Sui, R., R.K. Byler, D.K. Fisher, E.M. Barnes, and C.D. Delhom. 2014. Effect of supplemental irrigation and graded levels of nitrogen on cotton yield and quality. *J. Agric. Sci*. 6(2), 119-131. doi:10.5539/jas.v6n2p119.

Sui, R., and D.K. Fisher. 2015. Field test of a center pivot irrigation system. *Appl. Eng. in Agric*. 31(1), 83-88. doi 10.13031/aea.31.10539. .