Variable rate irrigation management for soybean and corn

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Abstract

Variable rate irrigation (VRI) is a new irrigation method developed in precision agriculture. VRI technologies allow the 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. Use of VRI in agricultural production has the potential to improve water use efficiency. Developing VRI practice and documenting the benefits of VRI to producers are critical to accelerate the adoption of VRI technologies. Comparison of VRI with uniform rate irrigation (URI) in soybean and corn crops was studied in Stoneville, Mississippi, USA. A center pivot VRI system was employed for delivering irrigation water. Soil apparent electrical conductivity (EC) of the fields was used to delineate VRI management zones and create VRI prescription. Irrigation was scheduled using soil moisture content measured by soil moisture sensors. Crop yield and irrigation water productivity in VRI treatment was compared to that in the URI treatment. There was no significant difference in yields of soybean and corn between VRI and URI treatments. Compared to URI, VRI treatment saved 25% irrigation water in soybean and 21% irrigation water in corn. Irrigation water productivity (WP) of VRI was 31.2% and 27.1% higher than the URI in soybean and corn, respectively. Results demonstrated that VRI management was superior to the URI in terms of water use efficiency. Soil EC coupled with soil physical properties could be used to establish VRI management zones. Development of novel algorithms with more inputs to site-specifically determine appropriate amount of water to apply is a major challenge facing VRI industry.

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. Local governments, organizations, and producers in the region are realizing the necessity of seeking improved irrigation technologies to increase water use efficiency for sustainable use of water resources.

Variable rate irrigation (VRI) is a new irrigation method developed in precision agriculture. 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 increase water use efficiency. Similar to other variable rate application systems in precision agriculture, VRI practices require specialized hardware and software, including GPS receiver to determine the spatial position of the irrigation system, 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, and the algorithms and programs to create VRI prescription maps which provide the information to the VRI controller for how much water to deliver at each specific management zone within the field. 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 management zones and determine the water application rates.

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

Materials and methods

Experimental site. The study has been conducted for 4 years from 2014 to 2017 in two adjacent fields (Field A and Field B) at the USDA-ARS Crop Production Systems Research Unit research farm 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. In 2016 and 2017, VRI and URI treatments were randomly assigned to the plots under the pivot coverage while the rest of the field was used as rainfed treatment.

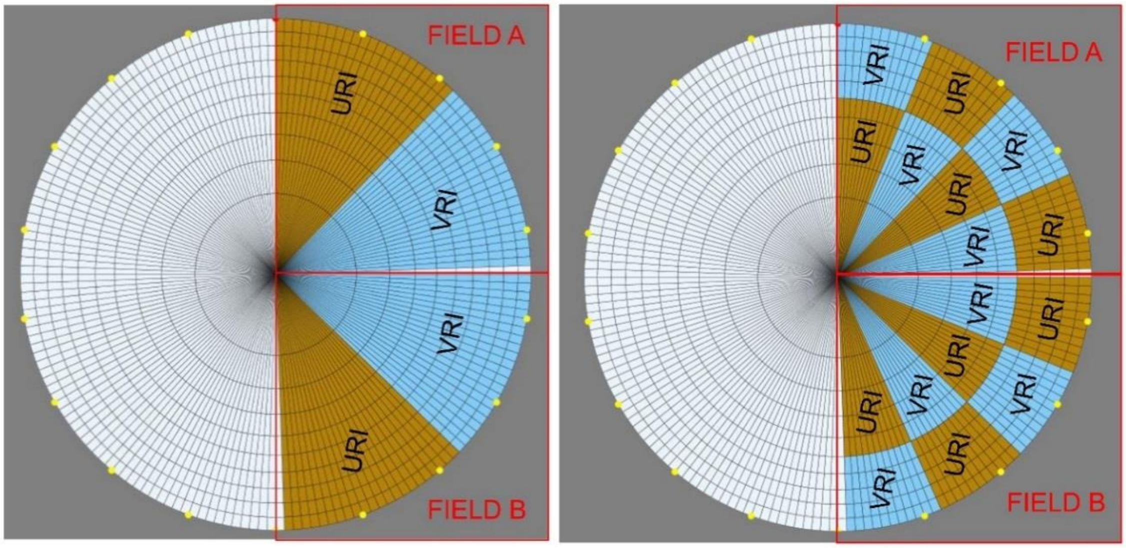

Figure 1. Experimental layout in 2014 and 2015 (left), in 2016 and 2017 (right)

Center pivot VRI system. 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 zone delineation and prescription map creation. 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 ECdp map of Field A and B was created using software ArcMap (version 10.2.1, Esri, CA) (Fig. 2)

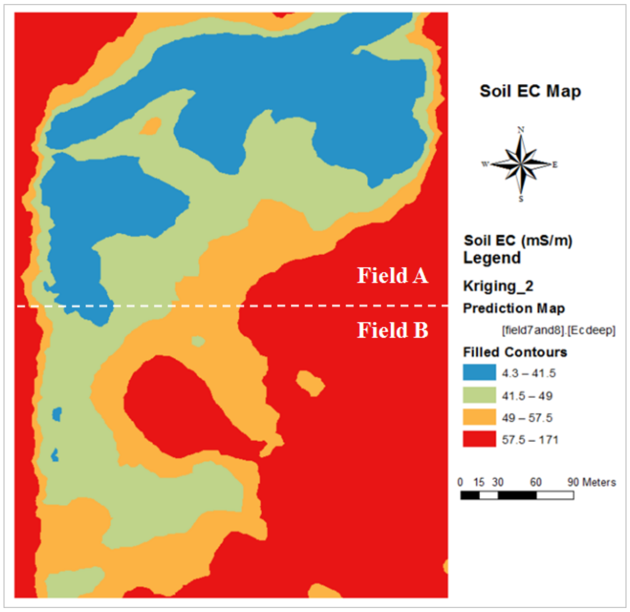

Figure 2. Soil electrical conductivity map of Field A and Field B. The filled contours correspond to soil ECdp categories 1-4 (in blue to red on legend).

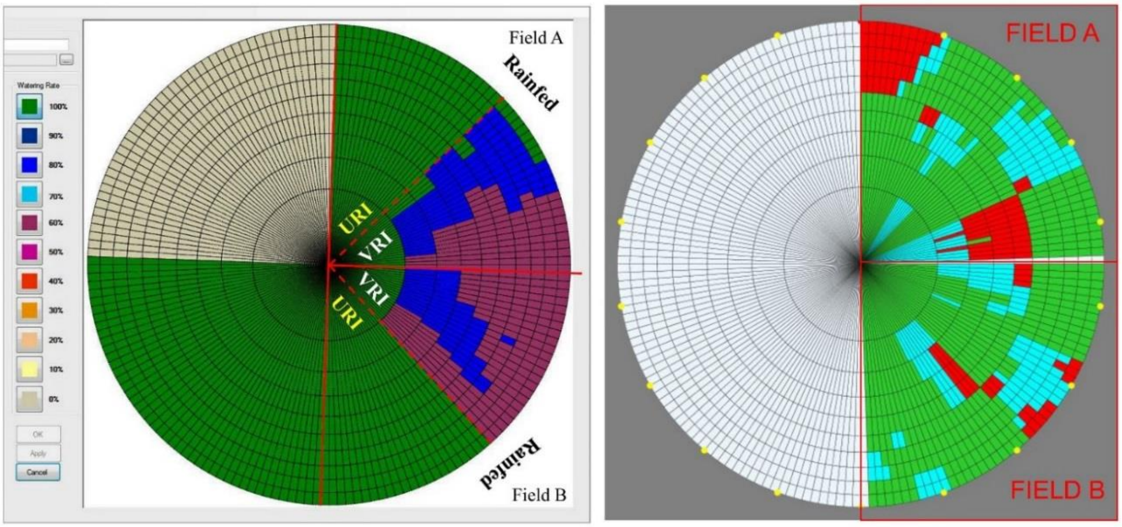

Figure 3. Prescription map for variable rate irrigation in 2014 and 2015 (left), and 2016 and 2017 (right). Irrigation water application rates were indicated by different colours on the map.

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

Field management. In 2014, soybean was planted in Field A and corn in Field B. In 2015, the crops were rotated, with soybean was planted in Field B and corn in Field A. In 2016 and 2017 season, corn was planted in Field A and soybean in Field B. Nitrogen fertilizer at 224 kg N/ha was applied as a urea-ammonium nitrate solution (N-sol, 32% N) to the corn field with a side knife drilled in each season. Insects and weeds in both soybean and corn fields were controlled with generally recommended procedures in the region throughout the growing seasons.

Irrigation scheduling and application. 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 3 depths was used for irrigation scheduling. Percent plant available water (PPAW) is calculated using equation 1 to trigger irrigation events.

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

Irrigation was triggered when PPAW dropped approximately to 50%.

Data collection and analysis. 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.

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

Data analysis for 2016 and 2017 has not been completed. Results reported in this paper were for seasons 2014 and 2015 only. As we finish the analysis of all data, the 4-year results would be reported in a separate article with more detail information.

Results and discussion

Crop Yield. Compared to URI, VRI treatment used 25% less irrigation water than the URI in soybean. 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 in 2014. Due to the large amount of rainfall, only 2.5 cm water was applied to the VRI treatment in one irrigation event, and there was no irrigation water applied in both the URI and rainfed treatments in corn. Yield in the VRI treatment was 3.2% higher than the average yield of the URI and the rainfed. The only irrigation event during the season was scheduled on 105 DAP. At that time, most of the local corn producers had stopped irrigation for the season. However, results in this study showed that an additional 2.5 cm of irrigation water generated a 3.2% yield increase. Corn yield could be affected by terminating the irrigation too early.

In 2015 corn, VRI used 21% less irrigation water than the URI. Yield comparison across management zones indicated no difference in VRI and URI treatments. VRI treatment had the highest yield compared to the URI and rainfed treatments. The yield of the rainfed treatment was the lowest. Yield in both the VRI and URI treatments significantly differed from the yield of the rainfed. Irrigation increased the corn yield by 18%. It demonstrated again that supplemental irrigation in the Mississippi Delta region was necessary and was able to increase the crop yield significantly.

Irrigation water productivity. Irrigation water productivity (WP) in the VRI and URI treatments was calculated. The WP equals the amount of grain produced by irrigation water divided by the amount of irrigation water applied. In 2014 soybean, the WP in the VRI treatment was slightly lower than the WP in the URI. However, in 2015 season, the WP in the VRI treatment was 60.1% higher than the WP of URI. In the 2-year averages, the WP in soybean was 0.84 kg/m3 in the VRI management and 0.64 kg/m3 in the URI. 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/m3 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/m3, which was 27.1% greater than the WP in the URI. This result was consistent 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 though yield of the VRI was slightly higher than the URI. However, the amount of irrigation water applied to the VRI treatment was 23% less than the URI treatment. 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 (2015). In soybean, WP in the VRI was 31.2% higher than that in the URI. In 2015 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 apparent electrical conductivity to generate irrigation management zones could be an easy-to-use method in VRI management, research 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.

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Disclaimer

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