International Journal of Design & Nature and Ecodynamics
Vol. 19, No. 1, February, 2024, pp. 191-200
Journal homepage: http://iieta.org/journals/ijdne

Performance Assessment of Variable (VRI) Versus Constant Rate Irrigation (CRI): Review

Zeena M. Alomari*, Thair J. Alfatlawi

Civil Engineering Department, University of Babylon, Hilla 51002, Iraq

Corresponding Author Email: mm893505@gmail.com

https://doi.org/10.18280/ijdne.190121

Received: 20 May 2023
Revised: 4 September 2023
Accepted: 19 September 2023
Available online: 29 February 2024

Keywords:
self-propelled irrigation systems, precision irrigation, variable rate irrigation, management zones, water application uniformity

ABSTRACT

Variable Rate Irrigation (VRI) hold potential for enhancing the efficiency of center pivot and linear movement irrigation by adapting water supply to diverse soil conditions within fields. We evaluated VRI technologies, considering their benefits, drawbacks, challenges, and the performance of Variable (VRI) versus Constant Rate Irrigation (CRI). Studies on VRI technologies have demonstrated significant promise in enhancing crop water productivity with reduced energy demands. Research findings indicate that these technologies have the potential to improve crop water productivity by an average of 20% compared to traditional irrigation methods, while simultaneously reducing energy consumption by approximately 18%. Evidence from studies of VRI supported that water saving of up to 50% can be achieved. However, it's essential to consider that adopting VRI involves higher initial costs due to precision irrigation equipment and infrastructure installation. Despite the upfront investment, the potential long-term advantages in terms of increased crop yields and water conservation may well justify these initial expenses. These technologies effectively mitigate water wastage and environmental pollution. They offer valuable solutions for irrigation scheduling, considering temporal and spatial variations in crop water requirements. The application uniformity of VRI was found to be equal to or greater than 90%. Additionally, VRI systems achieve at least comparable uniformity of irrigation to systems operating under CRI. This review synthesizes diverse information and lays the foundation for informed decision-making, future research, and the advancement of more efficient and environmentally conscious automated irrigation systems.

1. INTRODUCTION

Freshwater resources are under strain from a variety of issues, including pollution, population growth, and climate change (global warming). As global temperatures rise, the intricate balance of water availability and demand becomes more precarious, necessitating innovative solutions in critical sectors like agriculture, where water consumption is substantial. Optimizing irrigation efficiency is crucial as water supplies constrained by urbanization. Variable Rate Irrigation (VRI) is a technology that may improve irrigation water productivity (yield produced per unit of water diverted for irrigation), or when combined with sensor feedback, improve crop water productivity (CWP yield produced per unit of evapotranspiration) [1-4]. Self-propelled sprinkler irrigation (center pivot or lateral move) has irrigated over 12.5 million hectares, replacing traditional techniques like flood and other methods [5-9]. Since center pivot irrigation systems account for most of the sprinkler irrigated agricultural land in Iraq [10], they will be the primary focus of the application of VRI in this paper. However, lateral motion systems and even certain solid set systems can use VRI. Variable water application along pivot improves center pivot irrigation system effectiveness in changing soil or crop conditions [11, 12]. Retail sales of commercial VRI systems began in 2004 [13-26]. Engineering-wise, VRI sprinkler systems function mechanically similar to CRI sprinkler systems in terms of uniformity of application, precision of applied depth, planned irrigation quantities, and application of uniformity within management zones [11, 27-56]. While adoption of these systems is less than expected, more farmers and researchers are becoming aware of potential benefits of VRI [15].

The benefits of VRI are location-specific and heavily reliant on temporal and geographical variation within the field [1, 14, 16, 17]. A network of manifolds under moveable sprinkler systems that delivered variable irrigation rates was one of the early concepts for VRI systems [18-20]. The self-propelled irrigation system's high degree of automation offers a solid assurance for the use of VRI [21, 22].

A typical gauge of efficiency is the measurement of system uniformity since under watered areas (i.e., from non-uniform irrigation application) will require overwatering to maintain acceptable crop yield and quality, thus resulting in inefficiency. Uniformity of center pivot and linear move systems is influenced by nozzle type and wind [57-98]. In addition, poor uniformity in the distribution of water flow can result in the non-uniform distribution of agricultural chemicals, which increase the likelihood that chemicals will be leached from the root zone [99-103]. Variable-rate irrigation control systems are being developed for center pivot systems that enable them to supply water precisely at optimal rates relative to the needs of individual areas along the system [99]. The agricultural water demands fluctuate geographically and temporally during an irrigation season in many areas, thus concentrating efforts on technologies for optimizing sprinkler irrigation scheduling utilizing VRI systems might have far-reaching positive benefits [104, 105]. The variability may be caused by natural variations in terrain, soil salinity, and texture, as well as inadvertent management errors such inconsistent planting rates and erroneous fertilizer and herbicide treatments. It may also be brought on by outbreaks of disease and insect infestation. A field might be kept from being overwatered in some places and underwatered in others by combining irrigation scheduling with VRI technology [106-108].

Since VRI technology is still in its infancy, there are still a lot of practical concerns that need to be resolved. Does the overall application uniformity of an irrigation system change as a result of the ON and OFF cycling of sprinklers to achieve varied application rates, for instance? For irrigation to be effective, a high quality of application uniformity is necessary, hence VRI systems should offer at least as excellent uniformity as CRI ones.

Therefore, the goals of this research were to identify advantages and disadvantages of VRI technology for moving sprinklers, provides current examples on such aspects. The specific objective was to assess application uniformity of Variable (VRI) Versus Constant Rate Irrigation (CRI). The motivation behind comparing these two irrigation methods is rooted in the urgent need to provide a basis information about if VRI can be used to develop more uniform irrigation schedules in the future in arable fields as this is critical for water-saving irrigation management. VRI, as a precision irrigation technique, has emerged as a promising avenue to achieve this delicate balance. Dissemination of updated information is important as it serves to educate other researchers, producers, and policy makers involved in water resources.

109 papers published in conferences and journals between the years 1982 and 2023 are considered in this review. These papers are categorized according to VRI equipment systems, advantages and disadvantages related to VRI technologies, and Evaluation of uniformity of irrigation as shown in Figure 1.

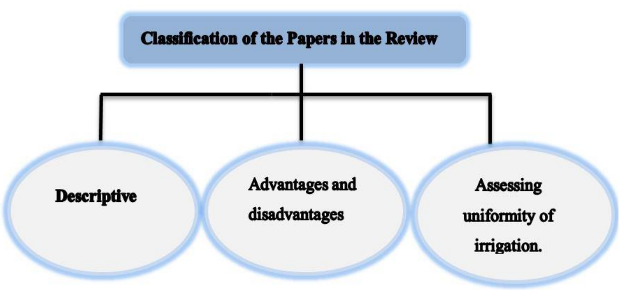

Figure 1. The layout of the review

The outline of the paper's structure consists of an introduction that presents a general overview of the VRI and CRI, Data collections that present how the data was collected, the discussion provides interpretations of the results and compares them with previous studies, the conclusion summarizes the main findings and their implications, and references.

2. DATA COLLECTIONS

The researcher obtained articles on VRI system by searching three (3) areas: types of VRI equipment systems, advantages and disadvantages related to VRI technologies, and Uniformity testing of both variable rate (VRI) and constant rate (CRI) irrigation control systems. The time window of this review is between the years 1982 to 2023.Searches on digital libraries thru internet access, such as journals, websites, articles, and papers. Elsevier, springer, Wiley, and MDPI have several published essay articles, papers, that can aid the research review. Figure 2 shows the distribution of the papers that is covered by this study based on the published year. Figure 3 describes the distribution of publications based on journals.

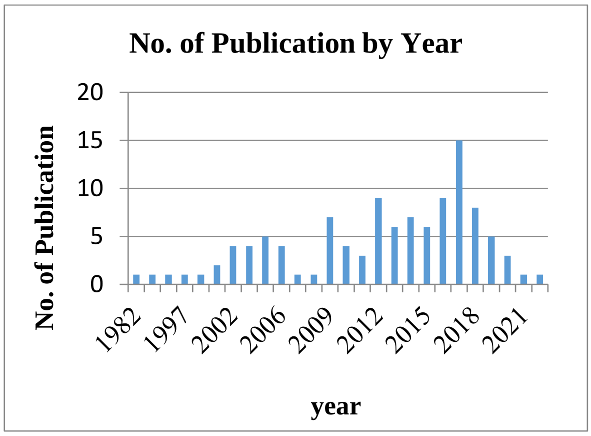

Figure 2. Research study published with year

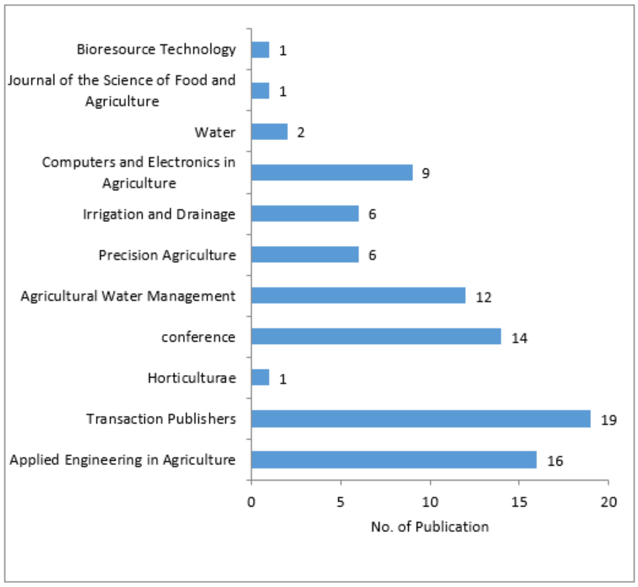

Figure 3. Distribution of publication based on journals

3. DISCUSSION

3.1 Descriptive

This section presents the descriptive of the papers that are presented in this review. In general, the papers prove the successful applications of the Variable Rate Irrigation (VRI) sprinklers on mechanical move irrigation systems (center pivot or lateral move). Identifying advantages, disadvantages and challenges are considered a major part of (VRI) technologies and hence most studies were focused on it. It is found that there are sixty-seven papers of researches discussion it. Twenty-five articles present investigation was to test the irrigation systems with VRI by assessing its irrigation uniformity.

Table 1. Types of VRI systems

Type	Description	Consideration	Example Uses
Speed Control	• Changing the pivot's speed varies the application rate. • Pie-slice shaped irrigation management zones are used.	• Many pivot panels can be used without further investment, making them rather cheap. • The sprinklers don't have any unique hardware.	• If spatial variation matches "pie slices" effectively. • Modifying application in response to topography (e.g., applying less in low regions) if it creates "pie slices." • One pivot serving a variety of crops. • On-farm research.
Zone Control	• Sprinklers cycle on and off in pulses, and pivot speed can change as well. • Zones for irrigation control can be of any width or size.	• Highest degree of application flexibility. • More expensive. • May need more management and maintenance work.	• Avoid applying to water surfaces or un-cropped areas with irregular shapes. • To improve productivity and profits, adjust irrigation on management zones with irregular shapes as necessary.

Table 2. Types of VRI irrigation prescriptions

Type	Description	Consideration	Example Uses
Statics	• Throughout a season, the prescription remains constant or just seldom changes.	• Comparatively easy to apply. Does not take seasonal variations in spatial variability into consideration.	• Avoiding irrigation on un-cropped areas. • Mining differences in Static soil available water capacity. • Different rates of chemigation.
Dynamic	• Throughout the season, the prescription may change for each irrigation event.	• May be challenging and demand more management work. • May offer maximum gross advantage.	• Modifying areas as needs change throughout the season and varying irrigation to each portion of the field as necessary. • Different rates of chemigation.

In this research, the review covered and focused only on advantages and disadvantages of Variable Rate Irrigation (VRI) sprinklers on mechanical move irrigation systems (center pivot or lateral move), additionally and evaluated the uniformity of irrigation of them versus Constant Rate Irrigation (CRI) see Figure 1.

It is possible to accomplish various application rates when employing self-propelled devices by 1) adjusting the system's ground speed, which changes how fast water is applied in the irrigation's direction as it travels. Variable speed irrigation is fairly economical because the only modifications to the pivot are to the pivot digital controls, notwithstanding the apparent limits to alterations only in pie-shaped wedges. 2) Zone control, which applies a variety of irrigation rates along the lateral pipe and in the system's direction of travel. Zone control irrigation is considerably costlier than intermittent speed irrigation since the pivot needs to be equipped with more hardware and innovative control systems.

Zone control can take many different forms, some of which involve altering the ON time of a single or bank of spray nozzles [70] or modifying the sprinkler nozzle hole by pulsing a foldable concentric pin in the nozzle hole during particular duty cycles. Moving sprinkler VRI controls are all offered by the top five sprinkler irrigation manufacturers (Valmont, Zimmatic, T-L, Reinke, and Pierce) [1].

The list (Table 1 and Table 2) includes a summary of the many types of VRI equipment systems, prescriptions (the road plan that instructs the system how to apply the water), and prospective applications.

A substantial field-scale investigation is required to ascertain the proportion of fields that will be responsive to this technology because certain fields benefit from VRI while others do not. Compared to zone control VRI, speed control VRI has fewer initial costs, which causes an earlier return on capital. speed restriction VRI can also help farmers overcome soil absorption challenges while still guaranteeing proper water delivery by rotating the sprinkler back and forth over the problematic region to avoid runoff and give the delivered water time to absorb [70]. Speed control is also utilized when producers are forced to use several crops in a single year or fallow a section of the circle because of limited watering resources [84]. To enable a deeper application in a more consistent way, zone control VRI on a corner arm may be used. Microprocessor-based control technology coupled to the sprinkler's navigation system has increased uniformity along the corner arms, which were previously noticeably out of uniformity. This improvement is the result of enhanced position identification, altered machine speed, and speedier system component communication. The water application rate on the spot soil could be decreased using VRI [69].

3.2 Identifying advantages, disadvantages and challenges of (VRI) technologies

We classified both advantages and disadvantages as prospective based on the reviewed studies. The main areas of VRI technology's advantages and disadvantages are given in (Table 3). The VRI technology has the potential to improve the water and energy use and increase economic efficiencies by optimally matching agricultural inputs to yield in pre-defined management zones. Evidence from studies of VRI supported that water saving of up to 50% can be achieved. Using self-propelled sprinkler irrigation system with variable-rate irrigation (VRI) can boost crop yields by up to 20% while lowering water use and achieving considerable water savings. Producers employ managed drought, a practice of controlled soil water-deficit irrigation, to enhance crop water productivity and reduce water usage. Variable Rate Irrigation (VRI) offers a valuable solution for managed deficit irrigation in field crops with varying soil and topography conditions, as well as for site-specific planting with different densities. VRI can potentially reduce energy consumption by around 18%. The review results imply that the VRI technique is not economically viable under the current conditions. The price of the variable irrigation system will need to be substantially less than the existing investment costs in order to be competitive with the CRI. While VRI technology may have some environmental advantages, it is not possible for it to be an economically viable technology with a positive economic net return due to its high initial investment costs and the fact that grain yields have not increased enough to cover these costs. This may help to explain why manufacturers now engaged in large-scale production are only very slowly adopting these technologies. Despite the upfront investment, the potential long-term advantages in terms of increased crop yields and water conservation may well justify these initial expenses.

3.3 Uniformity of Variable Rate Irrigation (VRI) systems versus Constant Rate Irrigation (CRI)

Many testing techniques for the uniformity of self-propelled systems with constant application rates have been provided by ISO 11545-2009 [95], and ASAE S436.1 [96]. However, there are currently no accepted techniques that can be used to VRI systems. Commonly used criteria include catch-can testing and ASABE Standard S436.1. Understanding the practical constraints on using a VRI system for irrigation depends on quantifying the variability or changes in uniformity of application imposed by the system. Make sure that the sprinkler irrigation system is applied evenly before utilizing it, and address any problems before the start of the growing season. VRI sprinkler systems can be impacted by the same variables that have an impact on constant rate irrigation sprinkler systems, including weather, sprinkler type, sprinkler spacing, the condition of irrigation system elements, and system pressure at work [32]. Despite the fact that there isn't much published study of application uniformity data for variable rate irrigation systems, it is helpful. Study [84] created an equation for the ponding time, calculated the number of on/off cycles using Horton and Kostiakov's infiltration equations, and compared the estimated and observed ponding times. A type of sprinkler having a variable water rate that may be employed with center-pivot and linear movement irrigation systems was researched by study [85]. The size of the spray nozzle was reduced to a certain extent by the employment of a retracting concentric pin in the nozzle hole. This method has problems, such as a 10%–15% reduction in sprinkler wetting diameter. The uniformity and precision of application water depths are crucial for self-propelled VRI systems [1, 20, 34, 88]. The total benefits of VRI systems are connected with crop growth, production, and quality as well as application uniformity [89].

Similar to standard irrigation systems, the sprinkler VRI system's application uniformity and precision are influenced by a variety of factors, including mechanical components, production scheduling, and weather fluctuations [11, 20, 32, 90, 91]. Factors such as sprinkler types, Variable Rate Irrigation (VRI) systems' application uniformity and accuracy are only marginally impacted by cycle times (the total of a solenoid valve's ON and OFF timings), duty cycles (the length of time the valve is on during a cycle), and % timer settings of ground speed. Adjusting the system's timer setting and the solenoid valve's duty cycle was frequently necessary to maintain the irrigation depths of the various zones. Under VRI situations, changes in cycle periods, duty cycles, and timer settings had no impact on the irrigation accuracy for the same management zone. Contrarily, there was a strong correlation between uniformity and irrigation accuracy.

The irrigation precision of the three-span center pivot VRI system with cycle periods of (20, 30, 35, and 50 s) was assessed by studies [92, 93]. They found that adjusting the solenoid valve cycle timings might improve the accuracy of the water application, but there was still a dearth of knowledge on irrigation uniformity. Study [4] developed the variable pulse irrigation algorithm, which is based on the pulsing mechanism, to reduce runoff losses while accounting for the sprinkler watering rate, soil infiltration potential, and surface storage capacity. The results were positive since they reduced runoff by at least 90.7% while producing a good and appropriate irrigation depth with efficient distribution uniformity. By pulsating the flow of water turning on and off as the sprinkler moves through soils with a high percentage of clay or a steep slope, for example, zone control VRI may maintain sprinkler travel speed. Runoff will be decreased as a result of the decreased spraying rate [70].

The specific objective was to assess application uniformity of Variable (VRI) Versus Constant Rate Irrigation (CRI). Summary of literature review of the uniformity of water distribution of self-propelled systems with Variable Rate Irrigation (VRI) versus Constant Rate Irrigation (CRI) was discussed and showed in (Table 4). The values of uniformity coefficient of all studies were assessed and compared well with the each other and was found a good uniformity performance of VRI. The application uniformity was found to be equal to or greater than 90%. Additionally, VRI systems achieve at least comparable uniformity of irrigation to systems operating under CRI.

Finally, when comparing our review study with other reviews, we find that we evaluated VRI technologies, considering their benefits, drawbacks, challenges, and the performance of Variable (VRI) versus Constant Rate Irrigation (CRI). Study [109] reviewed the advances in VRI research, including the connotation, architecture and construction, identification of management zones, decision support system and economic benefits for VRI system with continuously moving sprinkler machines. Study [1] reviewed the potential advantages and potential disadvantages of VRI technology for moving sprinklers, provides updated examples on such aspects, suggests a protocol for designing and implementing VRI technology and reports on the recent advancements.

The implications of the results involve providing a basis for information about whether VRI can be used to develop more uniform irrigation schedules in the future in arable fields, as this is critical for water-saving irrigation management. Dissemination of updated information is important as it serves to educate other researchers, producers, and policymakers involved in water resources.

Table 3. Main classifications of advantages and disadvantages related to VRI technologies

Advantages	Author(s)	Disadvantages	Author(s)
Economic • Minimize water waste • Reduce the cost of pumping. • Increase water efficiency	[13, 21, 23, 24, 27-29, 35-38, 106]	*High initial cost* • Longer payback time • Lack of funding for improvements • It can be challenging to put benefits into a monetary context.	[38, 39, 97]
Environmental • Increased land utilization for the disposal of dairy or cattle waste. • Reduce the root zone's leaching • Runoff and non-point source pollution should be decreased.	[40-49]	*Other factors raised costs.* • Variable frequency drives should be taken into account. • Data collecting from aerial photos and precision irrigation of utilizing sprinkler sensing in the field or on ground level. • Mapping of the ECa field or topography	[50-52]
Agronomic • Decrease supplies of nutrients, pesticides, and water. • Efficiencies in entire-field agricultural yields of water. • Give farmers a way to execute precision irrigation	[37, 53-64]	*Additional hardware* • Makes troubleshooting and repair more labor-intensive • Fewer alarms to warn of faults • Extends the time needed for maintenance	[65, 66, 81-83]
The management of risk • Deal with erratic or inadequate water supplies • Continue irrigation agriculture	[67-70]	*Complexity* • Initial learning curve is steep, and implementation takes more time. • Watering rates that are matched to the crop's changing spatiotemporal needs • Possibility of a decrease in crop quality or quantity	[71-80]

Table 4. Overview of the uniformity of water distribution in self-propelled systems with (VRI) versus (CRI) techniques

Information Resource	Irrigation Method	Irrigation Uniformity (Average CU_H)	Discussion
[11]	(CRI) (VRI)	95% 93%	• Similar to constant rate irrigation, variable rate irrigation maintains uniformity. • VRI system provides consistent irrigation uniformity regardless of cycle periods, duty cycles, or timer settings.
[30]	(CRI) (VRI)	94% 90%	• Rotator and fixed plate low pressure sprinklers had an impact on uniformity. • The pulsing technique has a minimal negative impact on system uniformity and nozzle flow rate.
[32]	(CRI) (VRI)	90% 88%	• Similar to constant rate irrigation, variable rate irrigation maintains uniformity. • VRI system provides consistent irrigation uniformity regardless of cycle periods, duty cycles, or timer settings.
[20]	(CRI) (VRI)	95% 85%	• The uniformity of CRI and VRI was unaffected by the travel speed of the irrigation machine. • Water uniformity along pivot line direction was higher than lateral pipe direction.
[34]	(CRI) (VRI)	86.47% 84.3%	• Control zone uniformity is affected by sprinkler coverage.
[92]	(CRI) (VRI)	91.25% 88.05%	• Similar to constant rate irrigation, variable rate irrigation maintains uniformity.
[93]	(CRI)	91.05% (R3000) 79.35% (D3000)	• Rotator and fixed plate low pressure sprinklers had an impact on uniformity. • Similar to constant rate irrigation, variable rate irrigation maintains uniformity. • VRI system provides consistent irrigation uniformity regardless of cycle periods, duty cycles, or timer settings. • Uniformity of application was affected by control zone placement and width.

4. CONCLUSION

This reviewed article discussed the classification, benefits, and challenges of using VRI technologies. The reviewed indicates that although the use of VRI technology has improved, it is still not very common because of its high costs. Self-propelled sprinkler irrigation systems with variable rates have been demonstrated to improve crop water productivity up to 20%, while reduce energy consumption by around 18%. Evidence from studies of VRI supported that water saving of up to 50% can be achieved. Such systems could be great tools for adopting comprehensive water management practices to cut down on waste and pollution while also supporting irrigation scheduling while taking into account regional and temporal variations in crop water needs. The study demonstrates that the uniformity of water distribution along the lateral pipe or in the pivot's travel direction to each management zone was unaffected considerably by either the cycle time or the predicted irrigation depths. The application uniformity of VRI was found to be equal to or greater than 90%. Additionally, VRI systems achieve at least comparable uniformity of irrigation to systems operating under CRI. The outcomes recommend future VRI projects should consider using a time cycle of 60 s to lower the solenoid valve's switching frequency. On the other hand, the influence of sprinkler spacing, the pressure of the VRI system, and the dimensions and location of the management zone on the application uniformity need further studies.

REFERENCES

[1] O'Shaughnessy, S.A., Evett, S.R., Colaizzi, P.D., Andrade, M.A., Marek, T.H., Heeren, D.M., Lamm, F.R., LaRue, J.L. (2019). Identifying advantages and disadvantages of variable rate irrigation: An updated review. Applied Engineering in Agriculture, 35(6): 837-852. https://doi.org/10.13031/aea.13128

[2] Boserup, E. (2011). The Conditions of Agricultural Growth: The Economics of Agrarin Change under Population Pressure. Transaction Publishers. https://doi.org/10.4324/9781315070360

[3] NASS, U. (2013). 2012 census of agriculture, farm and ranch irrigation survey.

[4] Al Al-Baaj, A.A., Lewis, A. (2019). Variable pulsed irrigation algorithm (VPIA) to reduce runoff losses under a low-pressure lateral move irrigation machine. Horticulturae, 5(1): 10. https://doi.org/10.3390/horticulturae5010010

[5] Spears, T.D. (2003). Irrigating efficiently to feed the world in 2050. In Proceedings of the 2003 Irrigation Association International Exposition and Technical Conference, pp. 411-422.

[6] Yonts, C.D. (2000). Performance of in-canopy sprinklers. In Central Plains Irrigation Short Course and Exposition Proceedings, Colby, Kansas.

[7] Lamm, F.R., Bordovsky, J.P., Howell Sr, T.A. (2019). A review of in-canopy and near-canopy sprinkler irrigation concepts. Transactions of the Asabe, 62(5): 1355-1364.

[8] Nakawuka, P., Okwany, R.O., Peters, T.R., Desta, K., Sadeghi, S.H. (2014). Efficacy of boom systems in controlling runoff under center pivots and linearmove irrigation systems. Applied Engineering in Agriculture, 30(5): 797-801. https://doi.org/10.13031/aea.30.10540

[9] Turral, H., Svendsen, M., Faures, J.M. (2010). Investing in irrigation: Reviewing the past and looking to the future. Agricultural Water Management, 97(4): 551-560. https://doi.org/10.1016/j.agwat.2009.07.012

[10] Al-Kayssi, A.W., Mustafa, S.H. (2016). Modeling gypsifereous soil infiltration rate under different sprinkler application rates and successive irrigation events. Agricultural Water Management, 163: 66-74. https://doi.org/10.1016/j.agwat.2015.09.006

[11] Dukes, M.D., Perry, C. (2006). Uniformity testing of variable-rate center pivot irrigation control systems. Precision Agriculture, 7(3): 205-218. https://doi.org/10.1007/s11119-006-9020-y

[12] Perry, C., Vellidis, G., Thomas, D., Pocknee, S., Hart, E., Wells, N., Kvien, C. (2003). Precision pivot irrigation. In Proceedings of the 6th International Conference on Precision Agriculture and Other Precision Resources Management, Minneapolis, MN, USA, pp. 1049-1063.

[13] Hedley, C.B., Yule, I.J., Tuohy, M.P., Vogeler, I. (2009). Key performance indicators for simulated variable-rate irrigation of variable soils in humid regions. Transactions of the ASABE, 52(5): 1575-1584. https://doi.org/10.13031/2013.29146

[14] Daccache, A., Knox, J.W., Weatherhead, E.K., Daneshkhah, A., Hess, T.M. (2015). Implementing precision irrigation in a humid climate–Recent experiences and on-going challenges. Agricultural Water Management, 147: 135-143. https://doi.org/10.1016/j.agwat.2014.05.018

[15] Gonzalez Perea, R., Daccache, A., Rodriguez Diaz, J.A., Poyato, C.E., Knox, J.W. (2018a). Modelling impacts of precision irrigation on crop yield and in-field water management. Precision Agriculture, 19: 497-512. https://doi.org/10.1007/s11119-017-9535-4

[16] LaRue, J., Evans, R.G. (2012). Considerations for variable rate irrigation. In 24th Annual Central Plains Irrigation Conference, Colby, Kansas, pp. 111-116.

[17] Serrano, J., Shahidian, S., Marques da Silva, J., Paixão, L., Moral, F., Carmona-Cabezas, R., Garcia, S., Palha, J., Noéme, J. (2020). Mapping management zones based on soil apparent electrical conductivity and remote sensing for implementation of variable rate irrigation—Case study of corn under a Center Pivot. Water, 12(12): 3427. https://doi.org/10.3390/w12123427

[18] Bordovsky, J.P., Lyle, W.M., Lascano, R.J., Upchurch, D.R. (1992). Cotton irrigation management with LEPA systems. Transactions of the ASAE, 35(3): 879-884. https://doi.org/10.13031/2013.28673

[19] Omary, M., Camp, C.R., Sadler, E.J. (1997). Center pivot irrigation system modification to provide variable water application depths. Applied Engineering in Agriculture, 13(2): 235-239. https://doi.org/10.13031/2013.21604

[20] Zhao, W., Li, J., Yang, R., Li, Y. (2014). Field evaluation of water distribution characteristics of variable rate center pivot irrigation system. Transactions of the Chinese Society of Agricultural Engineering, 30(22): 53-62.

[21] Sui, R., Yan, H. (2017). Field study of variable rate irrigation management in humid climates. Irrigation and Drainage, 66(3): 327-339. https://doi.org/10.1002/ird.2111

[22] Andrade, M.A., O'Shaughnessy, S.A., Evett, S.R. (2020). ARSPivot, a sensor-based decision support software for variable-rate irrigation center pivot systems: Part A:

Development. Transactions of the ASABE, 63(5): 1521-1533. https://doi.org/10.13031/trans.13907
[23] Liu, J., Gull, U., Putnam, D.H., Kisekka, I. (2021). Variable-rate irrigation uniformity model for linear-move sprinkler systems. Transactions of the ASABE, 64(4): 1295-1302. https://doi.org/10.13031/trans.14313
[24] Liu, J., Yuan, S., Li, H., Zhu, X. (2013). A theoretical and experimental study of a variable-rate complete fluidic sprinkler. Applied Engineering in Agriculture, 29(1): 17-25. https://doi.org/10.13031/2013.42529
[25] Liu, J., Zhu, X., Yuan, S., Fordjour, A. (2019). Modeling the application depth and water distribution uniformity of a linearly moved irrigation system. Water, 11(4): 827. https://doi.org/10.3390/w11040827
[26] Milton, A.W., Perry, C.D. (2006). Status of variable-rate irrigation in the southeast. In 2006 ASAE Annual Meeting. American Society of Agricultural and Biological Engineers.
[27] Perry, C., Pocknee, S. (2003). Precision pivot irrigation controls to optimize water application. In Understanding & Addressing Conservation and Recycled Water Irrigation, the Proceedings of the 2003 Irrigation Association Meeting, San Diego, CA, pp. 86-92.
[28] King, B.A., Wall, R.W., Kincaid, D.C., Westermann, D.T. (2005). Field testing of a variable rate sprinkler and control system for site-specific water and nutrient application. Applied Engineering in Agriculture, 21(5): 847-853. https://doi.org/10.13031/2013.19712
[29] Pierce, F.J., Chavez, J.L., Elliott, T.V., Matthews, G.R., Evans, R.G., Kim, Y. (2006). A remote real-time continuous move irrigation control and monitoring system. ASABE Paper No. 062162. St. Joseph, MI: ASABE. https://doi.org/10.13031/2013.20732
[30] Han, Y.J., Khalilian, A., Owino, T.O., Farahani, H.J., Moore, S. (2009). Development of Clemson variable-rate lateral irrigation system. Computers and Electronics in Agriculture, 68(1): 108-113. https://doi.org/10.1016/j.compag.2009.05.002
[31] Kim, Y., Evans, R.G. (2009). Software design for wireless sensor-based site-specific irrigation. Computers and Electronics in Agriculture, 66(2): 159-165. https://doi.org/10.1016/j.compag.2009.01.007
[32] O'Shaughnessy, S.A., Urrego, Y.F., Evett, S.R., Colaizzi, P.D., Howell, T.A. (2013). Assessing application uniformity of a variable rate irrigation system in a windy location. Applied Engineering in Agriculture, 29(4): 497-510. https://doi.org/10.13031/aea.29.9931
[33] Chavez, J.L., Pierce, F., Elliott, T.V., Evans, R.G., Kim, Y., Iversen, W.M. (2010). A remote irrigation monitoring and control system (RIMCS) for continuous move systems. Part B: Field testing and results. Precision Agriculture, 11(1): 11-26. https://doi.org/10.1007/s11119-009-9110-8
[34] Sui, R., Fisher, D.K. (2015). Field test of a center pivot irrigation system. Applied Engineering in Agriculture, 31(1): 83-88. https://doi.org/10.13031/aea.31.10539
[35] Yari, A., Madramootoo, C.A., Woods, S.A., Adamchuk, V.I. (2017). Performance evaluation of constant versus variable rate irrigation. Irrigation and Drainage, 66(4): 501-509. https://doi.org/10.1002/ird.2131
[36] King, B.A., Wall, R.W., Karsky, T.F. (2009). Center-pivot irrigation system for independent site-specific management of water and chemical application. Applied Engineering in Agriculture, 25(2): 187-198. https://doi.org/10.13031/2013.26334
[37] Lo, T.H., M. Heeren, D., Martin, D.L., Mateos, L., Luck, J.D., Eisenhauer, D. (2016). Pumpage reduction by using variablerate irrigation to mine undepleted soil water. Transactions of the ASABE, 59(5): 1285-1298. https://doi.org/10.13031/trans.59.11773
[38] Sharma, V., Irmak, S. (2020). Economic comparisons of variable rate irrigation and fertigation with fixed (uniform) rate irrigation and fertigation and pre-plant fertilizer management for maize in three soils. Agricultural Water Management, 240: 106307. https://doi.org/10.1016/j.agwat.2020.106307
[39] Schaible, G.D., Aillery, M.P. (2012). Water Conservation in irrigated agriculture: Trends and challenges in the face of emerging demand. Economic Information Bull. No. 99. Washington, DC: USDA. https://doi.org/10.2139/ssrn.2186555
[40] Schaible, G.D., Aillery, M.P. (2017). Chapter 2.1.1 – Challenges for U.S. irrigated agriculture in the face of emerging demands and climate change. In J.R. Ziolkowska, & J.M. Peterson (Eds.), Competition for Water Resources, pp. 44-79. https://doi.org/10.1016/B978-0-12-803237-4.00004-5
[41] Swaney, D.P., Howarth, R.W., Hong, B. (2018). Nitrogen use efficiency and crop production: Patterns of regional variation in the United States, 1987-2012. Science of The Total Environment, 635: 498-511. https://doi.org/10.1016/j.scitotenv.2018.04.027
[42] McDowell, R.W. (2017). Does variable rate irrigation decrease nutrient leaching losses from grazed dairy farming? Soil Use and Management, 33(4): 530-537. https://doi.org/10.1111/sum.12363
[43] McDowell, R.W., van der Weerden, T.J., Campbell, J. (2011). Nutrient losses associated with irrigation, intensification and management of land use: A study of large scale irrigation in North Otago, New Zealand. Agricultural Water Management, 98(5): 877-885. https://doi.org/10.1016/j.agwat.2010.12.014
[44] Davenport, J.R., Hattendorf, M.J. (2000). Using site-specific approaches to advance potato management in irrigated systems. HortTechnology, 10(3): 452-457. https://doi.org/10.21273/HORTTECH.10.3.452
[45] Liu, Z., Grabow, G.L., Huffman, R.L., Osborne, J., Evans, R.O. (2012). Factors affecting uniformity of irrigation-type manure application systems. Applied Engineering in Agriculture, 28(1): 43-56. https://doi.org/10.13031/2013.41285
[46] Hedley, C.B. (2015). The role of precision agriculture for improved nutrient management on farms. Journal of the Science of Food and Agriculture, 95(1): 12-19. https://doi.org/10.1002/jsfa.6734
[47] Szabó, A., Tamás, J., Nagy, A. (2021). An irrigation homogenity assessment of a variable rate sprinkler irrigation. Acta Horticulturae et Regiotecturae, 24(s1): 8-11. https://doi.org/10.2478/ahr-2021-0002.
[48] USEPA. (2014). Regulatory Flexibility Act Section 610 Review of the National Pollutant Discharge Elimination System (NPDES) Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFLs). USEPA, Washington, DC.
[49] Bolan, N.S., Laurenson, S., Luo, J., Sukias, J. (2009). Integrated treatment of farm effluents in New Zealand's dairy operations. Bioresource Technology, 100(22):

5490-5497. https://doi.org/10.1016/j.biortech.2009.03.004
[50] Brar, D., Kranz, W.L., Lo, T.H., Irmak, S., Martin, D.L. (2017). Energy conservation using variable-frequency drives for centerpivot irrigation: Standard systems. Transactions of the ASABE, 60(1): 95-106. https://doi.org/10.13031/trans.11683
[51] Henry, C.G., Merritt McDougall, W., Allen, C.D., Reba, M.L., Carman, D.K. (2014). Can variable frequency drives reduce irrigation costs for rice producers? In American Society of Agricultural and Biological Engineers, Montreal. https://doi.org/10.13031/aim.20141928170
[52] Zhu, H., Sorensen, R.B., Butts, C.L., Lamb, M.C., Blankenship, P.D. (2002). A pressure regulating system for variable irrigation flow controls. Applied Engineering in Agriculture, 18(5): 533-540. https://doi.org/10.13031/2013.10157
[53] Peters, R.T., Desta, K., Nelson, L. (2013). Practical use of soil moisture sensors and their data for irrigation scheduling. Washington State University Ext.
[54] O'Shaughnessy, S.A., Evett, S.R. (2010). Canopy temperature based system effectively schedules and controls center pivot irrigation of cotton. Agricultural Water Management, 97(9): 1310-1316. https://doi.org/10.1016/j.agwat.2010.03.012
[55] Evans, R.G., LaRue, J., Stone, K.C., King, B.A. (2013). Adoption of site-specific variable rate irrigation systems. Irrigation Science, 31: 871-887. https://doi.org/10.1007/s00271-012-0365-x
[56] Yang, C., Everitt, J.H., Murden, D., Robinson, J.R. (2002). Spatial variability in yields and profits within ten grain sorghum fields in south Texas. Transactions of the ASAE, 45(4): 897-906. https://doi.org/10.13031/2013.9936
[57] Allaire, S.E., Cambouris, A.N., Lafond, J.A., Lange, S.F., Pelletier, B., Dutilleul, P. (2014). Spatial variability of potato tuber yield and plant nitrogen uptake related to soil properties. Agronomy Journal, 106(3): 851-859. https://doi.org/10.2134/agronj13.0468
[58] Stone, K.C., Sadler, E.J. (2016). Assessing spatial variation of corn response to irrigation using a bayesian semiparametric model. 2015 ASABE / IA Irrigation Symposium: Emerging Technologies for Sustainable Irrigation - A Tribute to the Career of Terry Howell, Sr. Conference Proceedings. https://doi.org/10.13031/irrig.20152142961
[59] O'Shaughnessy, S.A., Evett, S.R., Colaizzi, P.D. (2015). Dynamic prescription maps for site-specific variable rate irrigation of cotton. Agricultural Water Management, 159: 123-138. https://doi.org/10.1016/j.agwat.2015.06.001
[60] O'Shaughnessy, S.A., Evett, S.R., Colaizzi, P.D., Howell, T.A. (2012). Grain sorghum response to irrigation scheduling with the time-temperature threshold method and deficit irrigation levels. Transactions of the ASABE, 55(2): 451-461. https://doi.org/10.13031/2013.41395
[61] Zhao, W., Li, J., Yang, R., Li, Y. (2017). Crop yield and water productivity responses in management zones for variable-rate irrigation based on available soil water holding capacity. Transactions of the ASABE, 60(5): 1659-1667. https://doi.org/10.13031/trans.12340
[62] Li, X., Zhao, W., Li, J., Li, Y. (2018). Crop yield and water use efficiency as affected by different soil-based management methods for variable-rate irrigation in a semi-humid climate. Transactions of the ASABE, 61(6): 1915-1922. https://doi.org/10.13031/trans.13036
[63] Maestrini, B., Basso, B. (2018). Drivers of within-field spatial and temporal variability of crop yield across the US Midwest. Scientific Reports, 8(1): 14833. https://doi.org/10.1038/s41598-018-32779-3
[64] Workneh, F., O'Shaughnessy, S., Evett, S., Rush, C.M. (2017). Relationships between early wheat streak mosaic severity levels and grain yield: Implications for management decisions. Plant Disease, 101(9): 1621-1626. https://doi.org/10.1094/PDIS-02-17-0176-RE
[65] Vellidis, G., Tucker, M., Perry, C., Kvien, C., Bednarz, C. (2008). A real-time wireless smart sensor array for scheduling irrigation. Computers and Electronics in Agriculture, 61(1): 44-50. https://doi.org/10.1016/j.compag.2007.05.009
[66] Levidow, L., Zaccaria, D., Maia, R., Vivas, E., Todorovic, M., Scardigno, A. (2014). Improving water-efficient irrigation: Prospects and difficulties of innovative practices. Agricultural Water Management, 146: 84-94. https://doi.org/10.1016/j.agwat.2014.07.012
[67] Lo, T.H. (2015). Quantification of variable rate irrigation benefits and spatial variability in root zone water holding capacity. MS thesis, Lincoln: University of Nebraska-Lincoln, Department of Biological Systems Engineering.
[68] Miller, K.A., Luck, J.D., Heeren, D.M., Lo, T., Martin, D.L., Barker, J.B. (2018). A geospatial variable rate irrigation control scenario evaluation methodology based on mining root zone available water capacity. Precision Agriculture, 19: 666-683. https://doi.org/10.1007/s11119-017-9548-z
[69] Smith, A.K. (2012). Matching application to the varying speed and geometry of center pivot swing arm corner systems. ASABE Paper No. 121336824. St. Joseph, MI: ASABE. https://doi.org/10.13031/2013.41706
[70] Peters, R.T., Flury, M. (2017). Variable rate irrigation on center pivots. What is it? Should I invest? Proc. Western Alfalfa & Forage Symp. Producing Quality Forages in the West. UC California: Alfalfa & Forage Systems Workgroup & Cooperative Extension Services.
[71] Khot, L.R., Sankaran, S., Carter, A.H., Johnson, D.A., Cummings, T.F. (2016). UAS imaging-based decision tools for arid winter wheat and irrigated potato production management. International Journal of Remote Sensing, 37(1): 125-137. https://doi.org/10.1080/01431161.2015.1117685
[72] Hoffmann, H., Jensen, R., Thomsen, A., Nieto, H., Rasmussen, J., Friborg, T. (2016). Crop water stress maps for an entire growing season from visible and thermal UAV imagery. Biogeosciences, 13(24): 6545-6563. https://doi.org/10.5194/bg-13-6545-2016
[73] Zhang, N., Wang, M., Wang, N. (2002). Precision agriculture: A worldwide overview. Computers and Electronics in Agriculture, 36(2): 113-132. https://doi.org/10.1016/S0168-1699(02)00096-0
[74] Camilli, A., Cugnasca, C.E., Saraiva, A.M., Hirakawa, A.R., Correa, P.L.P. (2007). From wireless sensors to field mapping: Anatomy of an application for precision agriculture. Computers and Electronics in Agriculture, 58(1): 25-36. https://doi.org/10.1016/j.compag.2007.01.019
[75] Moral, F.J., Terron, J.M., Silva, J.R. (2010). Delineation of management zones using mobile measurements of soil

apparent electrical conductivity and multivariate geostatistical techniques. Soil and Tillage Research, 106(2): 335-343. https://doi.org/10.1016/j.still.2009.12.002
[76] Gili, A., Alvarez, C., Bagnato, R., Noellemeyer, E. (2017). Comparison of three methods for delineating management zones for site-specific crop management. Computers and Electronics in Agriculture, 139: 213-223. https://doi.org/10.1016/j.compag.2017.05.022
[77] Schepers, A.R., Shanahan, J.F., Liebig, M.A., Schepers, J.S., Johnson, S.H., Luchiari Jr., A. (2004). Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. Agronomy Journal, 96(1): 195-203. https://doi.org/10.2134/agronj2004.1950
[78] Haghverdi, A., Leib, B.G., Washington-Allen, R.A., Buschermohle, M.J., Ayers, P.D. (2016). Studying uniform and variable rate center pivot irrigation strategies with the aid of site-specific water production functions. Computers and Electronics in Agriculture, 123: 327-340. https://doi.org/10.1016/j.compag.2016.03.010
[79] Andrade, M.A., O'Shaughnessy, S.A., Evett, S.R. (2017). ARSPivot, a sensor based decision support tool for the integrated irrigation management of VRI center pivot systems for center pivot irrigation systems. In Proceeding of the 28th Annual Central Plains Irrigation Conference, Kansas, pp. 5-14.
[80] Liakos, V., Porter, W., Liang, X., Tucker, M.A., McLendon, A., Vellidis, G. (2017). Dynamic variable rate irrigation: A tool for greatly improving water use efficiency. Advances in Animal Biosciences, 8(2): 557-563. https://doi.org/10.1017/S2040470017000711
[81] Vellidis, G., Liakos, V., Andreis, J.H., Perry, C.D., Porter, W.M., Barnes, E.M., Morgan, K.T., Fraisse, C., Migliaccio, K.W. (2016). Development and assessment of a smartphone application for irrigation scheduling in cotton. Computers and Electronics in Agriculture, 127: 249-259. https://doi.org/10.1016/j.compag.2016.06.021
[82] Yang, Y., Sun, L., Hu, J., Porter, D., Marek, T., Hillyer, C. (2017). A reliable soil moisture sensing methodology for agricultural irrigation. In 2017 IEEE International Symposium on Parallel and Distributed Processing with Applications and 2017 IEEE International Conference on Ubiquitous Computing and Communications (ISPA/IUCC), Guangzhou, China, pp. 1342-1349. https://doi.org/10.1109/ISPA/IUCC.2017.00204
[83] Barker, J.B., Heeren, D.M., Neale, C.M.U., Rudnick, D.R. (2018). Evaluation of variable rate irrigation using a remotesensing- based model. Agricultural Water Management, 203: 63-74. https://doi.org/10.1016/j.agwat.2018.02.022
[84] Gencoglan, C., Gencoglan, S., Merdun, H., Ucan, K. (2005). Determination of ponding time and number of on–off cycles for sprinkler irrigation applications. Agricultural Water Management, 72(1): 47-58. https://doi.org/10.1016/j.agwat.2004.08.001
[85] King, B.A., Kincaid, D.C. (2004). A variable flow rate sprinkler for site-specific irrigation management. Applied Engineering in Agriculture, 20(6): 765. https://doi.org/10.13031/2013.17724
[86] Al-Kufaishi, S., Blackmore, S., Sourell, H., Maletti, G. (2005). Assessment of two variable rate irrigation controllers used on a centre-pivot. International Commission of Agricultural Engineering.
[87] Zhou, Z., Tao, S., Mo, J. (2018). Simulation of spraying process in lateral VRI sprinkler system based on PWM. MATEC Web of Conferences, 246: 03012. https://doi.org/10.1051/matecconf/201824603012
[88] Takács, S., Bíró, T., Helyes, L., Pék, Z. (2019). Variable rate precision irrigation technology for deficit irrigation of processing tomato. Irrigation and Drainage, 68(2): 234-244. https://doi.org/10.1002/ird.2299
[89] Irmak, S., Odhiambo, L.O., Kranz, W.L., Eisenhauer, D.E. (2011). Irrigation efficiency and uniformity, and crop water use efficiency. University of Nebraska–Lincoln Extension, Lincoln, NB.
[90] Ortíz, J.N., Tarjuelo, J.M., Juan, J. (2009). Characterisation of evaporation and drift losses with centre pivots. Agricultural Water Management, 96(11): 1541-1546. https://doi.org/10.1016/j.agwat.2009.06.015
[91] Zhang, L., Merkley, G.P., Pinthong, K. (2013). Assessing whole-feld sprinkler irrigation application uniformity. Irrigation Science, 31(2): 87-105. https://doi.org/10.1007/s00271-011-0294-0
[92] Yari, A., Madramootoo, C.A., Woods, S.A., Adamchuk, V.I. (2017). Performance evaluation of constant versus variable rate irrigation. Irrigation Drainage, 66(4): 501-509. https://doi.org/10.1002/ird.2131
[93] Hui, X., Lin, X., Zhao, Y., Xue, M., Zhuo, Y., Guo, H., Xu, Y., Yan, H. (2022). Assessing water distribution characteristics of a variable-rate irrigation system. Agricultural Water Management, 260: 107276. https://doi.org/10.1016/j.agwat.2021.107276
[94] Zhao, W., Li, J., Yang, R., Li, Y. (2015). Field evaluating system performance of a variable rate center pivot irrigation system. In 26th Euro-Mediterranean Regional Conference and Workshops. Innovate to Improve Irrigation Performances, pp. 12-15.
[95] ISO Standards. (2009). ISO 11545–2009: Agricultural irrigation equipment-Centre-pivot and moving lateral irrigation machines with sprayer or sprinkler nozzles – determination of uniformity of water distribution. ISO, Geneva, Switzerland.
[96] ASABE Standards. (2016). ASAE S436.1: Test procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles. ASAE, St. Joseph, MI, USA.
[97] Kranz, W.L., Evans, R.G., Lamm, F.R., O'Shaughnessy, S.A., Peters, R.T. (2012). A review of mechanical move sprinkler irrigation control and automation technologies. Applied Engineering in Agriculture, 28(3): 389-397. https://doi.org/10.13031/2013.41494
[98] Perry, C., Pocknee, S., Hansen, O. (2003). A variable rate pivot irrigation control system. In Proceedings of the Fourth European Conference in Presicion Agriculture, pp. 539-544.
[99] Dukes, M.D. (2006). Effect of wind speed and pressure on linear move irrigation system uniformity. Applied Engineering in Agriculture, 22(4): 541-548. https://doi.org/10.13031/2013.21222
[100] Hanson, B.R., Orloff, S.B. (1996). Rotator nozzles more uniform than spray nozzles on center pivot sprinklers. California Agriculture, 50(1): 32-35. https://doi.org/10.3733/ca.v050n01p32
[101] Tarjuelo, J.M., Montero, J., Carrion, P.A., Honrubia, F.T., Calvo, M.A. (1999). Irrigation uniformity with medium size sprinklers part II: Influence of wind and

other factors on water distribution. Transactions of the ASAE, 42(3): 677-689. https://doi.org/10.13031/2013.13229
[102] Li, J., Li, B., Rao, M. (2005). Spatial and temporal distributions of nitrogen can crop yield as affected by nonuniformity of sprinkler fertigation. Agricultural Water Management, 76(3): 160-180. https://doi.org/10.1016/j.agwat.2005.01.017
[103] Brito, R.A.L., Willardson, L.S. (1982). Sprinkler irrigation uniformity requirements for the elimination of leaching. Transactions of the ASAE, 25(5): 1258-1261. https://doi.org/10.13031/2013.33709
[104] Padhi, J., Misra, R.K., Payero, J.O. (2012). Estimation of soil water deficit in an irrigated cotton field with infrared thermography. Field Crops Research, 126: 45-55. https://doi.org/10.1016/j.fcr.2011.09.015
[105] Cohen, Y., Alchanatis, V., Saranga, Y., Rosenberg, O., Sela, E., Bosak, A. (2017). Mapping water status based on aerial thermal imagery: Comparison of methodologies for upscaling from a single leaf to commercial fields. Precision Agriculture, 18: 801-822. https://doi.org/10.1007/s11119-016-9484-3
[106] Sadler, E.J., Evans, R.G., Stone K.C., Camp, C.R. (2005). Opportunities for conservation with precision irrigation. Journal of Soil and Water Conservation, 60(6): 371-379.
[107] Evett, S.R., Colaizzi, P.D., Schwartz, R.C., O'Shaughnessy, S.A. (2014). Soil water sensing - Focus on variable rate irrigation. In Proceedings of the 26th Annual Central Plains Irrigation Conference, Burlington, Colorado, pp. 99-109.
[108] Szabó, A., Tamás, J., Kövesdi, Á., Nagy, A. (2023). Evaluation of new pivoting linear-move precision irrigation machine. Irrigation and Drainage, 72(4): 922-933. https://doi.org/10.1002/ird.2850
[109] Zhao, W., Li, J., Li, Y. (2016). Review on variable rate irrigation with continuously moving sprinkler machines. Transactions of the Chinese Society of Agricultural Engineering, 32(13): 1-7.