RECIUJES
Revista Científica da Universidade José Eduardo dos Santos
e-ISSN: 3006-9688 | Edição Especial AC-2025 | Vol. 06 | n.º 01 | 2026

ENGINEERING CHALLENGES IN THE DIMENSIONING OF THE 360 RAIN PRECISION IRRIGATION SYSTEM

DESAFIOS DE ENGENHARIA NO DIMENSIONAMENTO DO SISTEMA DE REGA DE PRECISÃO 360 RAIN

Adriano B. Bingobingo

Faculty of Agricultural Sciences of José Eduardo dos Santos University, Chianga, Huambo, Angola. Email for correspondence: adrianobingobingo@gmail.com, Adriano.bingobingo@ujes.ao

ABSTRACT

Increasing climate variability and growing pressure on water resources have intensified the demand for more efficient and automated irrigation technologies. Among recent innovations, the 360 RAIN system has emerged as a mobile localized irrigation technology capable of applying water directly near the crop root zone while operating autonomously under GNSS guidance. This study evaluated the main hydraulic and operational challenges associated with the sizing of the 360 RAIN irrigation system under wheat production conditions. Hydraulic simulations were performed to analyze irrigation depth requirements, machine travel speed, head losses along the flexible supply hose, and pumping power demand. The results demonstrated that machine travel speed is one of the most critical operational variables, since small speed variations substantially affect the applied irrigation depth. In addition, hydraulic head losses increased considerably with hose length, directly influencing pumping requirements and energy demand. Despite presenting lower hydraulic complexity than conventional center pivot systems, the 360 RAIN system requires careful hydraulic

RESUMO

O aumento da variabilidade climática e a crescente pressão sobre os recursos hídricos têm intensificado a procura por tecnologias de rega mais eficientes e automatizadas. Entre as inovações recentes, destaca-se o sistema 360 RAIN, uma tecnologia móvel de rega localizada capaz de aplicar água directamente próximo da zona radicular das culturas, operando de forma autónoma com orientação por sistemas GNSS. O presente estudo avaliou os principais desafios hidráulicos e operacionais associados ao dimensionamento do sistema de rega 360 RAIN em condições de produção de trigo. Foram realizadas simulações hidráulicas para analisar as necessidades hídricas da cultura, a velocidade de deslocamento da máquina, as perdas de carga ao longo da mangueira flexível de alimentação e as necessidades de potência do sistema de bombagem. Os resultados demonstraram que a velocidade de deslocamento da máquina constitui uma das variáveis operacionais mais críticas, uma vez que pequenas variações na velocidade afectam significativamente a lâmina de rega aplicada. Adicionalmente, as perdas de carga aumentaram consideravelmente com o comprimento da mangueira, influenciando directamente as necessidades de bombagem e o consumo energético. Apesar de apresentar menor complexidade hidráulica em comparação com sistemas convencionais de pivô central, o sistema 360 RAIN requer um dimensionamento hidráulico rigoroso sizing to ensure adequate pressure conditions, irrigation uniformity, and efficient water application. The study highlights the importance of integrating hydraulic and operational analyses to optimize the performance of localized mobile irrigation systems under precision agriculture conditions.

Keywords: climate change, mobile irrigation system, hydraulic design, precision irrigation, pumping system, head losses, wheat irrigation.

para garantir condições adequadas de pressão, uniformidade de aplicação e eficiência no uso da água. O estudo evidencia a importância da integração entre análises hidráulicas e operacionais para optimizar o desempenho de sistemas móveis de rega localizada em condições de agricultura de precisão.

Palavras-chave: alterações climáticas, Sistema de rega móvel, dimensionamento hidráulico, rega de precisão, Sistema de bombagem, perda de carga, rega do trigo.

Introduction

Irrigation is one of the main factors influencing agricultural productivity, particularly in regions characterized by irregular rainfall distribution and increasing water scarcity. Under these conditions, improving irrigation efficiency has become essential to enhance crop productivity while reducing pressure on water resources. Consequently, modern irrigation systems have increasingly focused on precision water application and energy efficiency (Lakhiar et al., 2024).

Recent advances in precision agriculture have promoted the development of innovative irrigation technologies capable of improving water distribution uniformity and reducing operational losses. Among these technologies, the 360 RAIN system, developed by 360 Yield Center, has emerged as an alternative to conventional sprinkler irrigation systems by integrating machine mobility, localized water application, and digital operational control (360 Yield Center, 2024).

Unlike traditional center pivot systems, the 360 RAIN technology applies water directly near the crop root zone through drag hoses positioned along the crop rows. This configuration significantly reduces evaporation, wind drift, and canopy interception losses, potentially increasing water application efficiency and improving irrigation management under deficit water conditions (Jadhav & Jadhav, 2024).

Despite its operational advantages, the hydraulic and operational design of the 360 RAIN system presents several engineering challenges that differ from those observed in conventional pressurized irrigation systems. These challenges are mainly associated with:

- determination of the optimal machine travel speed;
- estimation of the applied irrigation depth;

- hydraulic sizing of the pumping unit;
- pressure loss management along the lateral lines and drag hoses;
- maintenance of pressure uniformity throughout the irrigation operation.

In addition, the intermittent movement of the system and the localized application pattern introduce complexities in hydraulic behavior, requiring more accurate sizing methodologies to ensure adequate system performance and water distribution uniformity.

Therefore, understanding the hydraulic constraints and operational requirements of the 360 RAIN system is essential for improving its design efficiency and supporting its adoption under different agricultural and environmental conditions.

Development

Characterization of the 360 RAIN system

The 360 RAIN system is a self-propelled irrigation technology designed to perform localized water application along crop rows. The equipment moves autonomously across the field using Global Navigation Satellite System (GNSS) guidance, allowing precise control of irrigation operations and remote monitoring through digital platforms (Bocu et al., 2025; Precision Agri Services, 2024).

The system is hydraulically connected to the water supply source through a flexible polyethylene hose, which is automatically unwound during the forward movement of the machine and reeled during its return movement. This operational configuration enables continuous irrigation while minimizing manual intervention (Elshikha, 2025; Naik et al., 2025).

According to specifications provided by 360 Yield Center, the main operational characteristics of the system include:

- hose diameter of approximately 76 mm;
- maximum hose length close to 900 m;
- operating flow rate ranging from 34 to 45 $m^3 h^{-1}$;
- operating pressure between 7 and 8 bar;
- irrigation capacity exceeding 60 ha from a single water supply point.

Water application occurs through drag hoses positioned between crop rows, similarly to the Y-Drop nutrient application concept, promoting localized irrigation near the root zone. This configuration reduces evaporation and wind drift losses compared with conventional sprinkler irrigation systems.

A distinctive operational characteristic of the 360 RAIN system is that water application occurs during both forward and return machine movements (360 Yield Center, 2024). Consequently, irrigation depth estimation and travel speed determination must account for the cumulative effect of the two application passes.

Hydraulic Sizing Principles

The hydraulic sizing of irrigation systems generally involves the estimation of crop water requirements, determination of irrigation depth, and hydraulic design of the pumping and distribution systems (Alves, 2023; Tamele, 2007).

For the 360 RAIN system, several hydraulic parameters are predefined by the manufacturer, including hose diameter, emitter configuration, nominal operating pressure, and discharge capacity (Precision Agri Services, 2024). Therefore, hydraulic design efforts are primarily focused on determining the appropriate machine travel speed and sizing the pumping system.

Determination of Irrigation Depth

Crop evapotranspiration was estimated according to the FAO-56 methodology proposed by Allen et al. (1998):

Equation 1. Determination of crop evapotranspiration

$$ET_c = K_c \times ET_o$$

Where:

- ETc is crop evapotranspiration (mm day^{-1});
- Kc is the crop coefficient;
- ETo is reference evapotranspiration (mm day^{-1}).

The gross irrigation depth was determined as:

Equation 2. Determination of the gross irrigation depth

$$IR_b = \frac{ET_c}{E_a}$$

Where:

- IRb is gross irrigation depth (mm);
- Ea is application efficiency.

The accurate estimation of irrigation depth is essential because excessive irrigation may increase deep percolation losses, whereas insufficient application may reduce crop productivity.

Travel Speed Determination

In the 360 RAIN system, the applied irrigation depth is directly dependent on machine travel speed. Therefore, speed control represents one of the main operational variables affecting irrigation uniformity and application efficiency.

The irrigation depth applied during a single machine pass can be estimated as:

Equation 3. Determination of the blade applied by the system

$$IR_b = \frac{Q}{V \times W}$$

where:

- Q is system flow rate ($m^3\ s^{-1}$);
- V is machine travel speed ($m\ s^{-1}$);
- W is wetted width (m).

Because irrigation occurs during both forward and return movements (360 Yield Center, 2024), the total irrigation depth becomes:

Equation 4. Determination of the total depth applied by the system

$$IR_t = 2 \times IR_b$$

Thus, the required travel speed for a target irrigation depth can be estimated by:

Equation 5. Determination of the travel speed required

$$V = \frac{2Q}{IR_t \times W}$$

Small variations in travel speed may produce substantial changes in applied irrigation depth, particularly under low-speed operating conditions. Consequently, accurate speed regulation is essential to maintain irrigation uniformity and avoid water application deficits or excesses.

Pumping System Design

The pumping system was sized based on the total dynamic head required for system operation (Alves, 2023):

Equation 6. Determination of the total head

$$H_t = H_s + H_d + H_f + H_p$$

where:

- H_s is suction head;
- H_d is discharge head;
- H_f represents head losses;
- H_p is the operating pressure required by the irrigation equipment.

Hydraulic power demand was calculated as:

Equation 7. Determination of the hydraulic power

$$P_h = \rho g Q H_t$$

where:

- ρ is water density (1000 kg m^{-3});
- g is acceleration of gravity (9.81 m s^{-2})

The required pump power was then estimated by:

$$P = \frac{P_h}{\eta}$$

where:

- η is overall pump efficiency.

Due to the long flexible hose used in the system, head losses may become significant, especially under high flow rates and extended operating distances. Consequently, hydraulic losses along the hose represent one of the main engineering constraints in the design of the 360 RAIN system.

Main Hydraulic and Operational Challenges

Although the 360 RAIN system presents a relatively simple operational configuration, its hydraulic sizing involves several technical challenges, including:

- accurate estimation of crop water requirements;

- precise determination of machine travel speed;
- consideration of cumulative irrigation depth during forward and return movements;
- adequate pump sizing under variable operating conditions;
- management of head losses along the supply network.

Furthermore, spatial variability in soil hydraulic properties, crop development, and field topography may require continuous operational adjustments to maintain irrigation efficiency and water application uniformity.

Hydraulic Simulation and Operational Analysis

Simulation Conditions

A hydraulic and operational simulation was performed to evaluate the main design constraints of the 360 RAIN irrigation system under field conditions for wheat cultivation. The simulation considered a hypothetical commercial production scenario representative of semi-arid agricultural regions.

The operational and hydraulic parameters adopted in the simulation are presented in Table 1.

Table 1. Operational and hydraulic parameters used in the simulation

Parameter	**Value**
Crop	Wheat (*Triticum aestivum* L.)
Irrigated area	60 ha
Reference evapotranspiration (ETo)	5.2 mm day^{-1}
Crop coefficient (Kc)	1.15
Application efficiency (Ea)	90%
Operating flow rate	40 m^3 h^{-1}
Hose length	900 m
Hose diameter	76 mm
Operating pressure	7.5 bar
Wetted width	18 m
Pump efficiency	75%

The adopted crop coefficient corresponds to the mid-season growth stage of wheat, characterized by maximum water demand (Allen et al., 1998).

Bingobingo, A. B. (2026). Engineering challenges in the dimensioning of the 360 rain precision irrigation system. RECUJES Edição Especial Angola 50 Anos - Agosto Científico: Huambo. e-ISSN: 3006-9688, Vol. 06, n.º 01 – 2026, p.2443-255.

Irrigation Depth and Travel Speed Analysis

Crop evapotranspiration was estimated using the FAO-56 methodology:

$$ET_c = K_c \times ET_o$$

Considering $K_c = 1.15$and $ET_o = 5.2$mm day^{-1}:

$$ET_c = 1.15 \times 5.2 = 5.98 \text{ mm day}^{-1}$$

The gross irrigation depth required to satisfy crop water demand was calculated as:

$$IR_b = \frac{ET_c}{E_a}$$

$$IR_b = \frac{5.98}{0.90} = 6.64 \text{ mm}$$

Because the 360 RAIN system applies water during both forward and return movements, the machine travel speed was determined using:

$$V = \frac{2Q}{IR_t \times W}$$

where the total irrigation depth (IR_t) corresponds to the cumulative depth applied during the two operational passes. Table 2 presents the estimated travel speeds required for different irrigation depths.

Table 2. Relationship between irrigation depth and machine travel speed

Total irrigation depth (mm)	**Travel speed (m h^{-1})**
4	1111
6	741
8	556
10	444
12	370

The results demonstrate a strong inverse relationship between travel speed and applied irrigation depth. Small reductions in machine speed substantially increased water application, indicating that accurate speed control is essential for maintaining irrigation uniformity and preventing excessive water application.

Under wheat production conditions, excessive irrigation depths may increase risks of nutrient leaching and temporary soil saturation, particularly in fine-textured soils.

Hydraulic Head Loss Analysis

Hydraulic head losses along the flexible supply hose were estimated using the Darcy-Weisbach equation (Abdulameer et al., 2022):

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

Simulations were performed for different hose lengths while maintaining constant flow rate and pipe diameter conditions.

Table 3. Estimated head losses as a function of hose length

Hose length (m)	Head loss (m)
300	7.8
600	15.6
900	24.1

The results indicate that hydraulic losses increased proportionally with hose length. Under the maximum operational distance of 900 m, pressure losses became considerable, potentially compromising the operating pressure required by the irrigation equipment.

These findings demonstrate that hose length represents one of the main hydraulic constraints of the 360 RAIN system, particularly under high-flow operating conditions.

Pumping Power Requirements

The total dynamic head required by the system was estimated considering suction head, discharge head, pressure losses, and operating pressure requirements:

$$H_t = H_s + H_d + H_f + H_p$$

Hydraulic power demand was calculated using:

$$P_h = \rho g Q H_t$$

The required pump power was then determined as:

$$P = \frac{P_h}{\eta}$$

Table 4 presents the estimated pumping power requirements for different total head conditions.

Table 4. Pump power requirements under different hydraulic conditions

Total dynamic head (m)	Required pump power (kW)
60	8.7
75	10.9
90	13.1

The increase in total dynamic head significantly affected energy demand (Loureiro et al., 2024; Moreno et al., 2010), demonstrating that hydraulic optimization of the supply network is essential to reduce operational costs and improve energy efficiency.

Moreover, high operating pressures combined with long hose distances may increase pumping costs, especially in large-scale irrigation operations.

Operational Implications for Wheat Irrigation

The hydraulic simulation demonstrated that the operational performance of the 360 RAIN system is strongly dependent on machine travel speed and hydraulic pressure stability.

For wheat cultivation, maintaining adequate irrigation depth is particularly important during critical phenological stages such as tillering, stem elongation, and grain filling, when water deficits may significantly reduce crop productivity (Ma et al., 2025; Zhao et al., 2025).

The localized application pattern adopted by the 360 RAIN system may contribute to reducing evaporation losses and improving water use efficiency compared with conventional sprinkler irrigation systems (Ali et al., 2025; Ali, 2025; Gopal et al., 2025). However, improper travel speed adjustment may lead to non-uniform water distribution and reduced irrigation performance. Additionally, the long flexible hose used by the system introduces substantial hydraulic head losses, requiring careful pump sizing to guarantee adequate operating pressure throughout the irrigation cycle.

Overall, the results indicate that hydraulic design and operational management are fundamental factors for maximizing the agronomic and hydraulic performance of the 360 RAIN irrigation system under wheat production conditions.

Conclusions

The hydraulic simulation demonstrated that the operational performance of the 360 RAIN irrigation system is strongly influenced by machine travel speed and hydraulic head losses along the flexible supply hose.

The results showed that small variations in travel speed significantly affect the applied irrigation depth, making speed control one of the main operational challenges of the system. In addition, hydraulic losses increased with hose length, directly influencing pumping power requirements and operational efficiency.

For wheat irrigation conditions, the system showed potential to improve water application efficiency through localized irrigation and reduced evaporation losses. However, proper hydraulic sizing is essential to ensure adequate pressure, uniform water application, and efficient system operation.

Overall, the study demonstrates that hydraulic and operational analyses are fundamental for optimizing the performance of the 360 RAIN system under precision irrigation conditions.

References

360 Yield Center. (2024). 360 Rain Irrigation System. https://doi.org/https://www.360yieldcenter.com/products/360-rain/

Abdulameer, L. S., Dzhumagulova, N., Algretawee, H., Zhuravleva, L., & Alshammari, M. H. (2022). Comparison between Hazen-Williams and Darcy-Weisbach equations to calculate head loss through conveyancing treated wastewater in Kerbala city, Iraq. *Eastern-European Journal of Enterprise Technologies*, *1*(1 (115)), 36–43. https://doi.org/https://doi.org/10.15587/1729-4061.2022.251385

Ali, A., Hussain, T., & Zahid, A. (2025). Smart Irrigation Technologies and Prospects for Enhancing Water Use Efficiency for Sustainable Agriculture. *AgriEngineering*, *7*(4), 106.

Ali, M. U. (2025). Water Use Efficiency and Irrigation Innovations in Crop Systems. *International Journal of Environment and Climate Change*, *15*(11), 492–499. https://doi.org/https://doi.org/10.9734/ijecc/2025/v15i115130

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, rome*, *300*(9), D05109. https://doi.org/https://www.avwatermaster.org/filingdocs/195/70653/172618e_5xAGWAx8.pdf

Alves, D. I. M. C. L. (2023). *Elaboração de um projecto de rega localizada para um amendoal intensivo no Alentejo* Universidade de Lisboa].

Bocu, D., Panti, A., Suru, A.-I., Domuța, C. G., & Donca, G. (2025). Ai-driven irrigation: the path towards smart irrigation systems to ensure agricultural sustainability. *Annals of the University of Oradea, Fascicle: Ecotoxicology, Animal Science and Food Science and Technology*. https://doi.org/https://protmed.uoradea.ro/nou/images/Publicatii/Ecotox/2025A/Agriculture/02._Bocu.pdf.

Elshikha, D. E. (2025). Smart Irrigation Solutions for Today's Farms. *University of Arizona Cooperative Extension. az2109*.

Gopal, R., Singh, N., Ashoka, P., Mohanty, L. K., Panotra, N., Shashidhar, K., Kumar, J., Anand, P., & Pathania, D. (2025). Precision Irrigation Techniques for Optimizing Water Use Efficiency in Agriculture. *Archives of Current Research International*, *25*, 347–362. https://doi.org/10.9734/acri/2025/v25i121675

Jadhav, M. M. A., & Jadhav, M. Y. J. (2024). The drip irrigation system. *International Journal of Scientific Research in Engineering and Management*, *8*(4), 1–5. https://doi.org/https://www.academia.edu/123967812/The_Drip_Irrigation_System

Lakhiar, I. A., Yan, H., Zhang, C., Wang, G., He, B., Hao, B., Han, Y., Wang, B., Bao, R., Syed, T. N., Chauhdary, J. N., & Rakibuzzaman, M. (2024). A Review of Precision Irrigation Water-Saving Technology under Changing Climate for Enhancing Water Use Efficiency, Crop Yield, and Environmental Footprints. *Agriculture*, *14*(7), 1141. https://doi.org/https://www.mdpi.com/2077-0472/14/7/1141

Loureiro, D., Beceiro, P., Fernandes, E., Alegre, H., & Covas, D. (2024). Energy efficiency assessment in collective irrigation systems using water and energy balances: methodology and application. *Irrigation Science*, *42*(4), 745–768. https://doi.org/https://doi.org/10.1007/s00271-023-00891-6

Ma, J., Shang, C., Zhang, X., Yin, B., & Zhen, W. (2025). Optimized Agronomic Management in North China Plain to Maintain Wheat (Triticum aestivum L.) Yield While Reducing Water and Fertilizer Inputs. *Agronomy*, *15*(5), 1053.

Moreno, M. A., Córcoles, J. I., Tarjuelo, J. M., & Ortega, J. F. (2010). Energy efficiency of pressurised irrigation networks managed on-demand and under a rotation schedule. *Biosystems Engineering*, *107*(4), 349–363. https://doi.org/https://doi.org/10.1016/j.biosystemseng.2010.09.009

Naik, T. V., Dhanush, G., Dayanandanaik, S., Babybai, H., & Lokesh, T. (2025). MECHANIZATION AND AUTOMATION IN AGRICULTURAL SYSTEMS. *RESILIENT AGRICULTURE*, 204.

Precision Agri Services. (2024). 360 Rain Irrigation System Overview. https://doi.org/https://precisionagriservices.com/brands/360-yield-center/360-rain.

Tamele, C. M. A. (2007). Dimensionamento de um Sistema de Rega por Gotejamento para uma Área de 50 ha no Distrito de Chókwè. *Projecto Final, Universidade Eduardo Mondlane*. https://doi.org/https://cgspace.cgiar.org/server/api/core/bitstreams/358e3290-1dc8-4f87-aa99-492ca5688935/content.

Zhao, Z., Li, Q., Xia, F., Zhang, P., Hao, S., Sun, S., Cui, C., & Zhang, Y. (2025). Optimized Water Management Strategies: Evaluating Limited-Irrigation Effects on Spring Wheat Productivity and Grain Nutritional Composition in Arid Agroecosystems. *Agriculture*, *15*(10), 1038.