A) B)

Figure S1. Equipment before modernization: (A) pump set and (B) central pivot control panel.

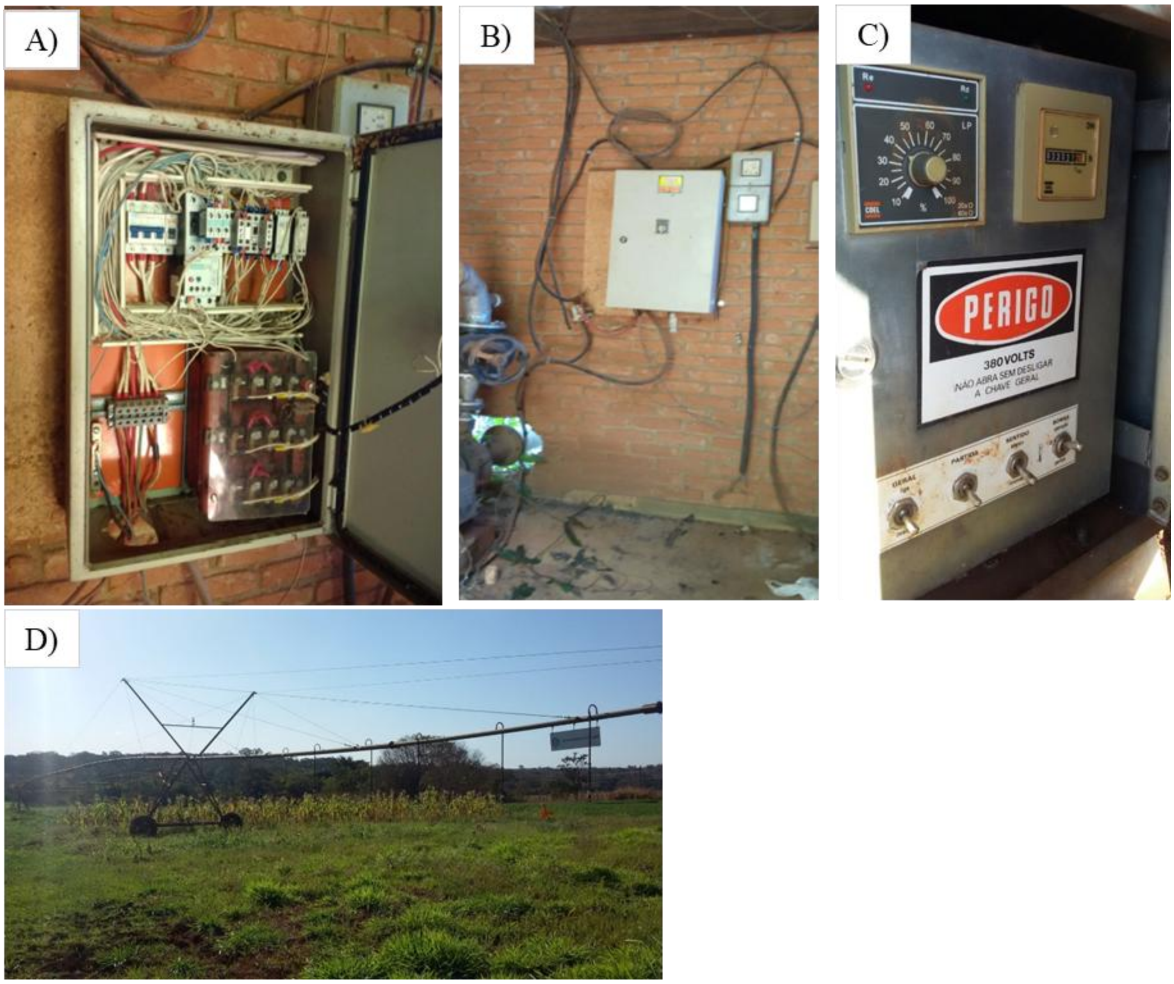


Figure S2. Conventional motor starter switch (parallel series) with open (A) and closed (B) control panel, side view of the central tower, mobile tower, and central pivot overhang (C), and analog control panel on the central tower of the pivot (D).

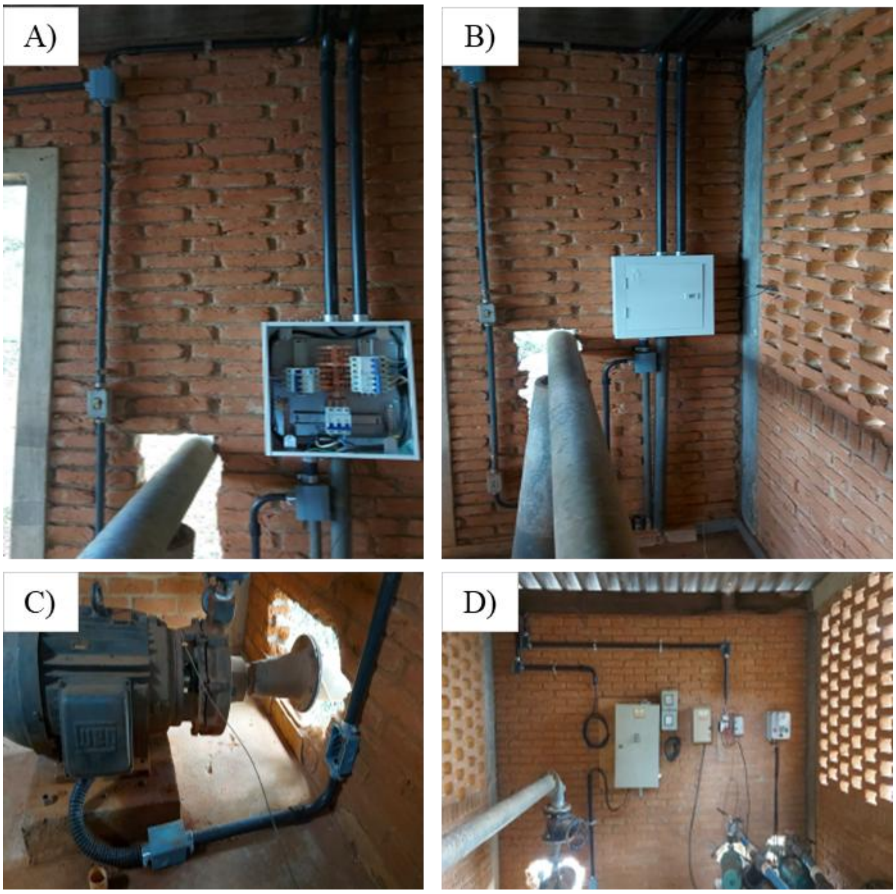


Figure S3. Assembled distribution panel and PVC conduit (A). Installation detail (B). External electrical installation of the motor (C). General view of the back wall of the pump house (D).

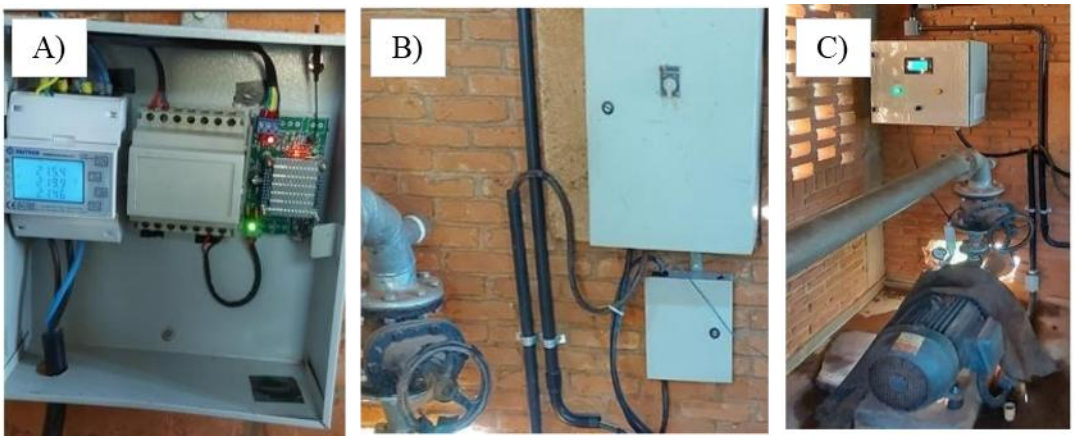


Figure S4. Three-phase power meter (A). Motor control panel (B). Pump set with frequency inverter (C).

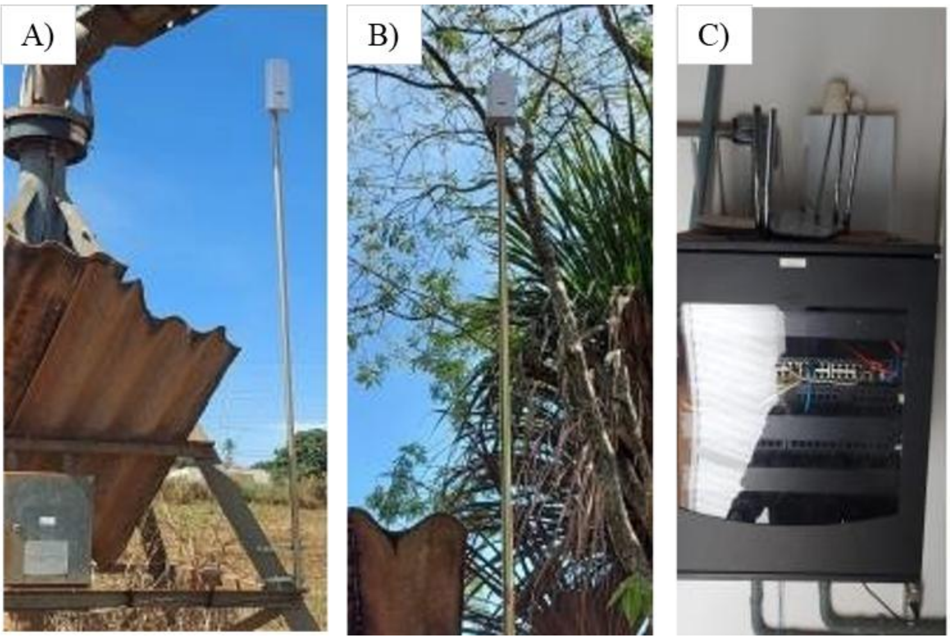


Figure S5. Internet for management and telemetry. Antenna on the central pivot (A). Antenna at the pump house (B). Internet communication modem (C).

Figure S6. Physical adaptations in the pump house. Adjustable metal support on the suction line (A). Support points with metal structure on the discharge line (B).

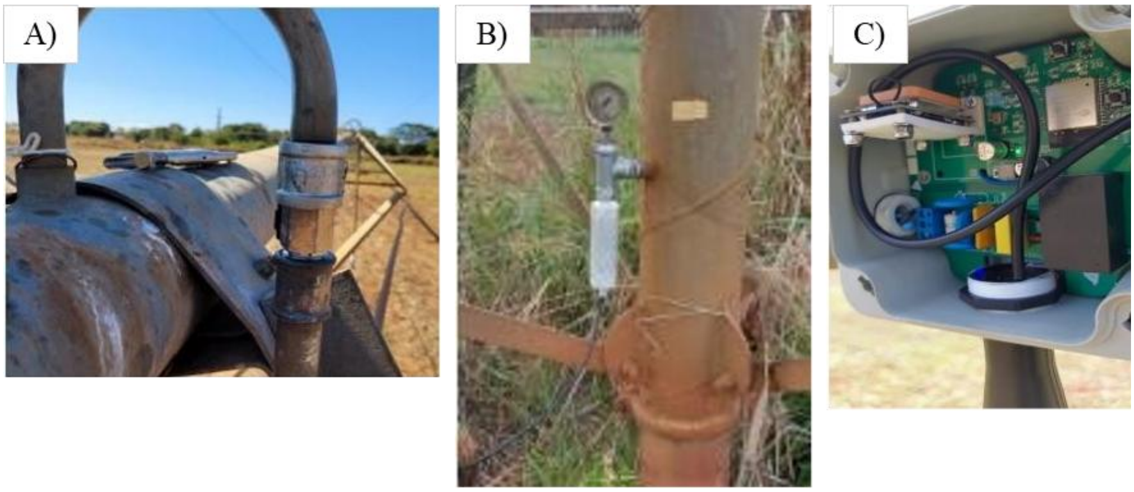


Figure S7. Pressure and flow transducers at the end of the bend in the drop tube for each sprinkler (A); in the riser pipe at the central tower (B); on the pivot lateral tower and at the end of the overhang span (C).

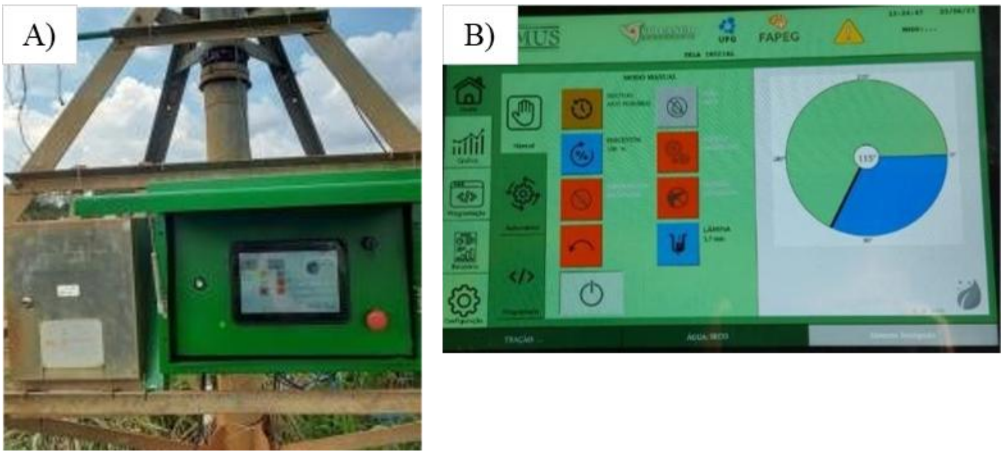


Figure S8. Control panel developed and installed on the central tower of the pivot. Control board and digital panel – external view with the door open (A). Menu and operational functions on the central pivot control panel (B).

Table S1. Physical-chemical attributes of the soil in the experimental area, Goiânia, GO, Brazil

	pH	OM	Ds	P	K^+	Ca^{2+}	Mg^{2+}	Al	H+Al
	$CaCl_2$	g dm^{-3}	1,09	mg dm^{-3}	-------------- cmolc dm^{-3}--------------				
	5.60	16.0		7.0	0.246	12.4	0.7	0.0	1.5
Sand	Silt	Clay		Cu	Fe	Mn	SB	CTC	V
	g kg^{-1}						cmolc dm^{-3}		%
450	80	470		3,2	92.0	47.0	3.34	4.85	70.0

Note: pH: hydrogen potential; MO: organic matter; Ds: soil bulk density; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; Al: aluminum; H+Al: soil potential acidity; $CaCl_2$: calcium chloride; Cu: copper; Fe: iron; Mn: manganese; SB: sum of bases; CEC: cation exchange capacity; V: base saturation.

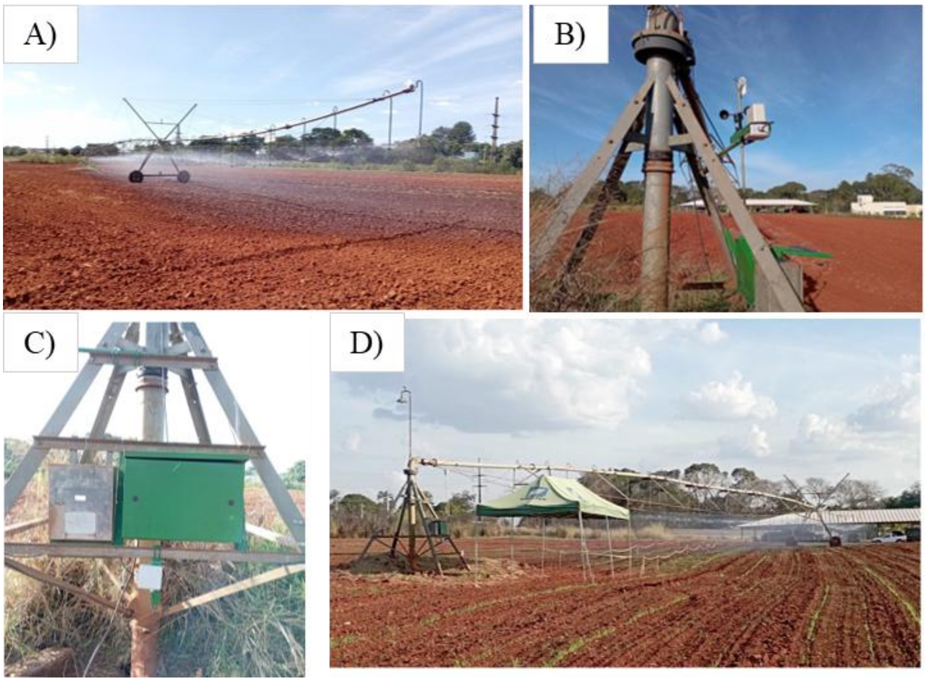
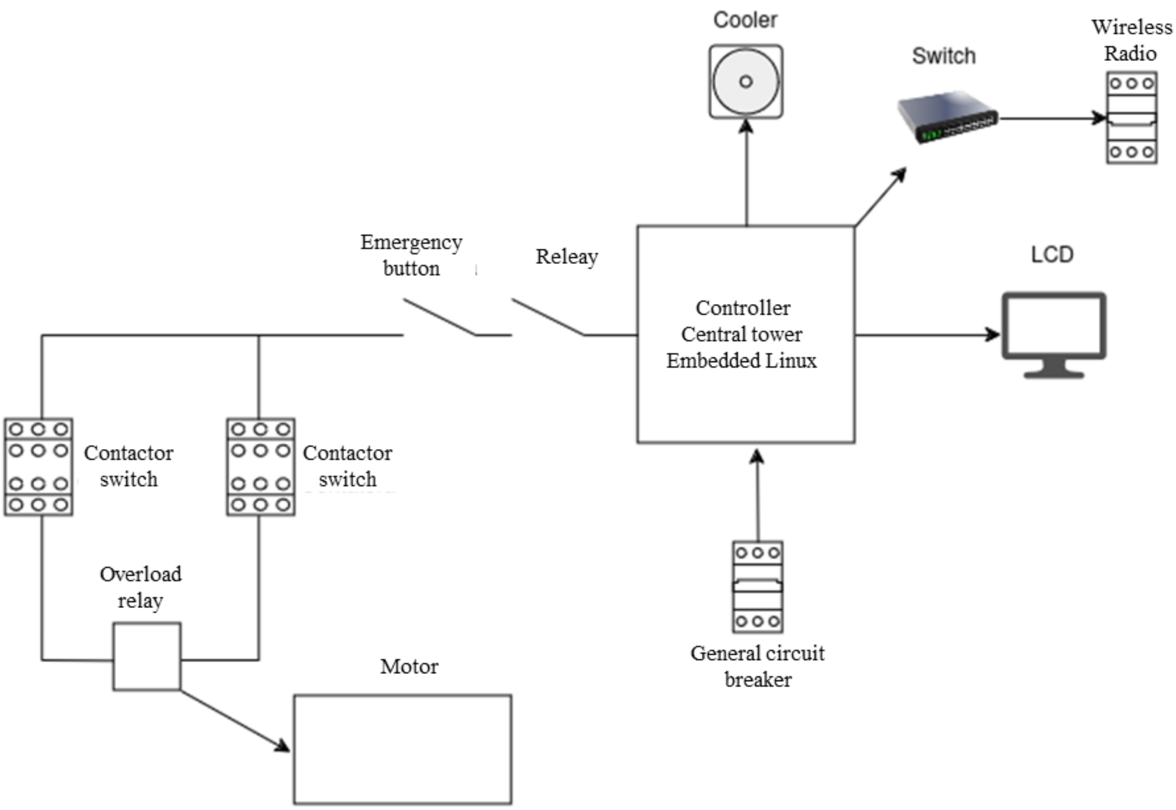


Figure S9. Modernized center pivot in operation (A). Central tower (B). Digital and analog panels (C). View of the central base and pivot tower (D).

Central Tower Controller Design



Main circuit breaker: three-phase, 10 A, curve C, Steck brand.
Controller: Embedded Linux, Broadcom quad-core processor.
LCD: 7 inches.
Cooler: 5V, 25x25 cm.
Relay: 5V.
Emergency button: 10A.
Contactor switch: 10A, Schneider brand.
Overload relay: 2 to 7 A.
Motor: 1hp three-phase.

Figure S10. Potamus system installed on the digital control panel at the central tower of the pivot.

PID Algorithm

Defining u(t) as the output signal, the PID algorithm can be defined by:

$$\mathrm{u}(t) = K_p e(t) + K_i \int_0^t e(\tau)\,d\tau + K_d \frac{de(t)}{dt}$$

onde

K_p: Proportional gain

K_i: Full gain

K_d: Derivative gain

e: Error

t: Time

τ: Integration time

Applying the Laplace transform:

$$L(s) = K_p + K_i/s + K_d s$$

where

s: Complex frequency

Figure S11. PID algorithm used for controlling the electric motor speed via the frequency inverter.

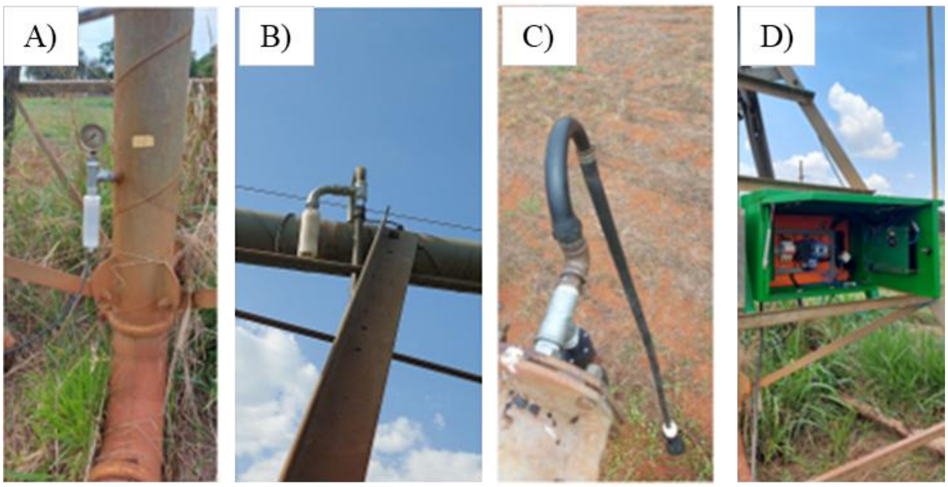


Figure S12. Pressure sensors at the central tower (A), mobile tower (B), and overhang section (C). RK3328 microcontroller board inside the central pivot control panel (D).

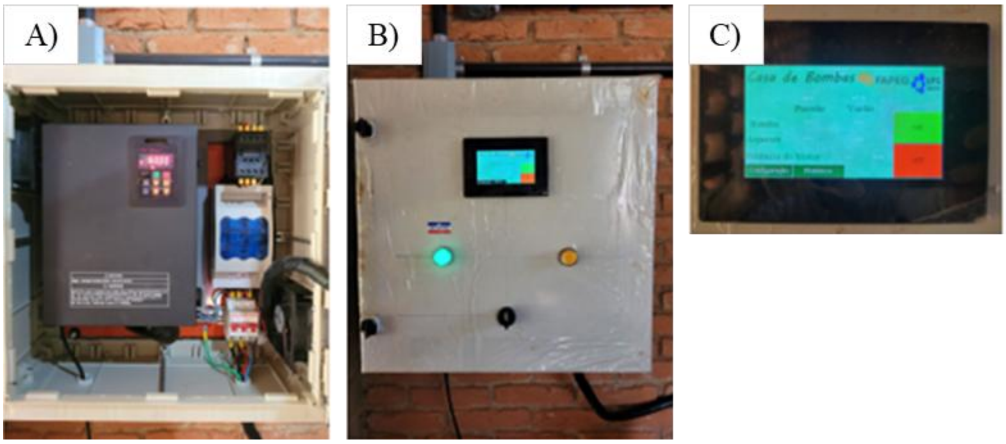


Figure S13. Frequency inverter at the pump house: detail of the internal part of the control panel (A), detail of the external part (B), HMI interface for frequency inverter control (C).

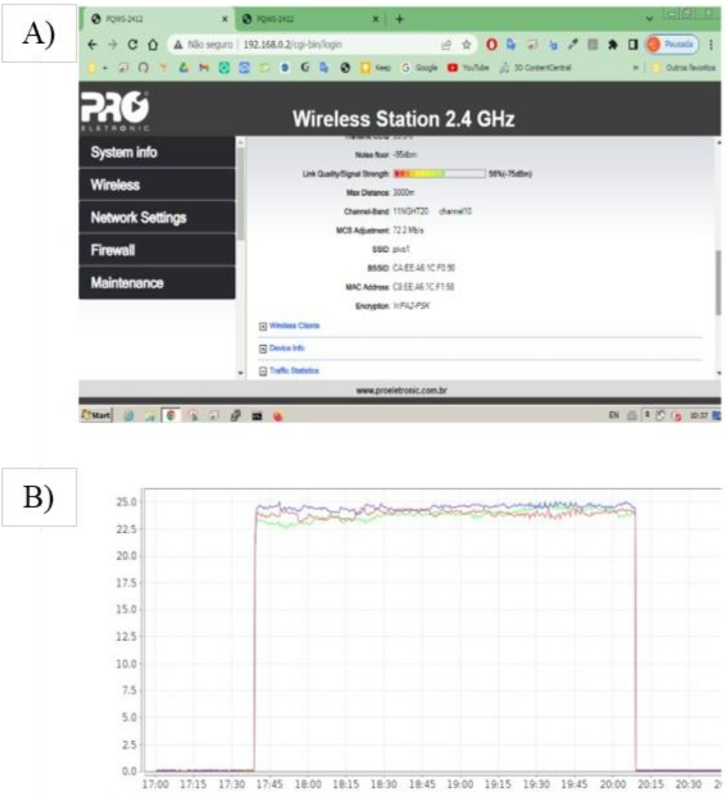


Figure S14. Radio transmission for communication and control. Wi-Fi link quality and signal strength monitoring screen (A). Graph of electric currents in the motor (B).

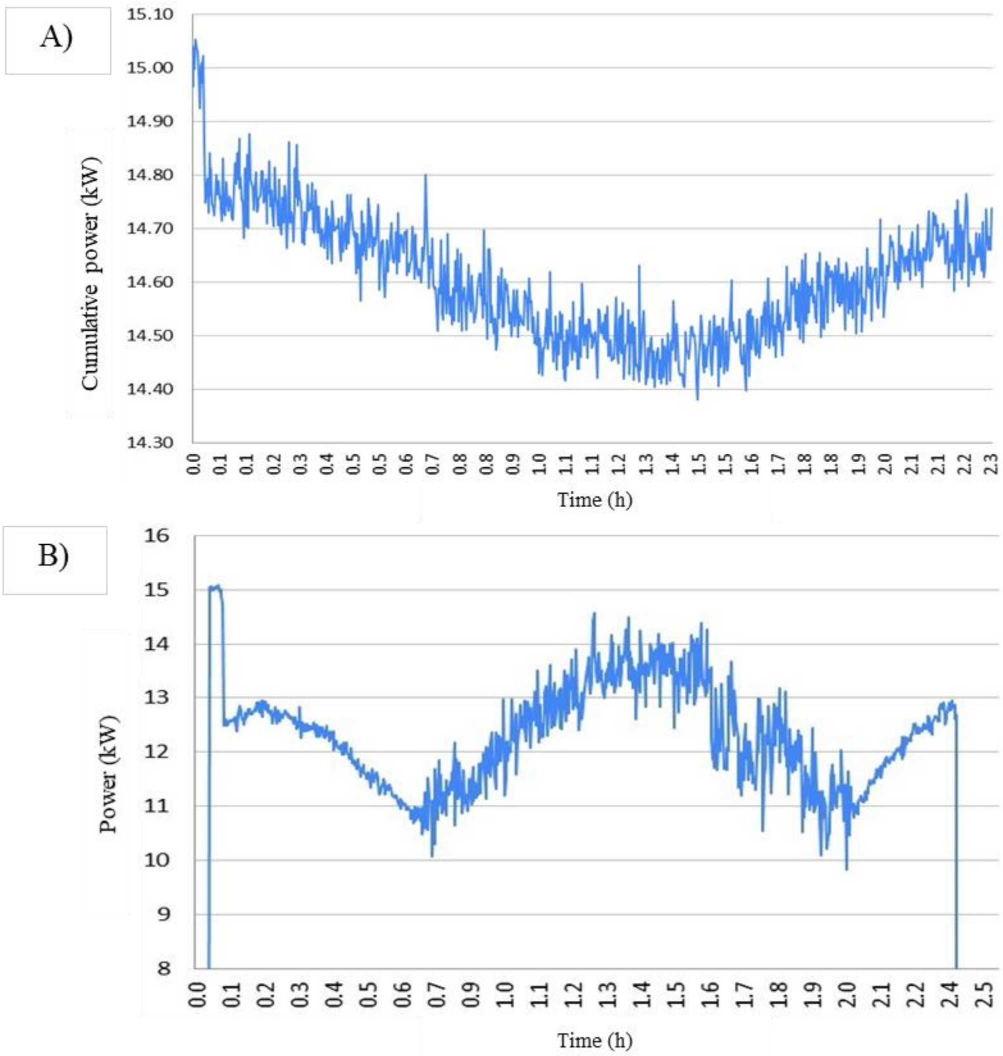


Figure S15. Electric energy consumption during the operation of Pivot 1, EA-UFG, Goiânia-GO, in 2023 (25 CV motor). Electrical power without motor speed control (A). Electrical power with motor speed control via frequency inverter (B).

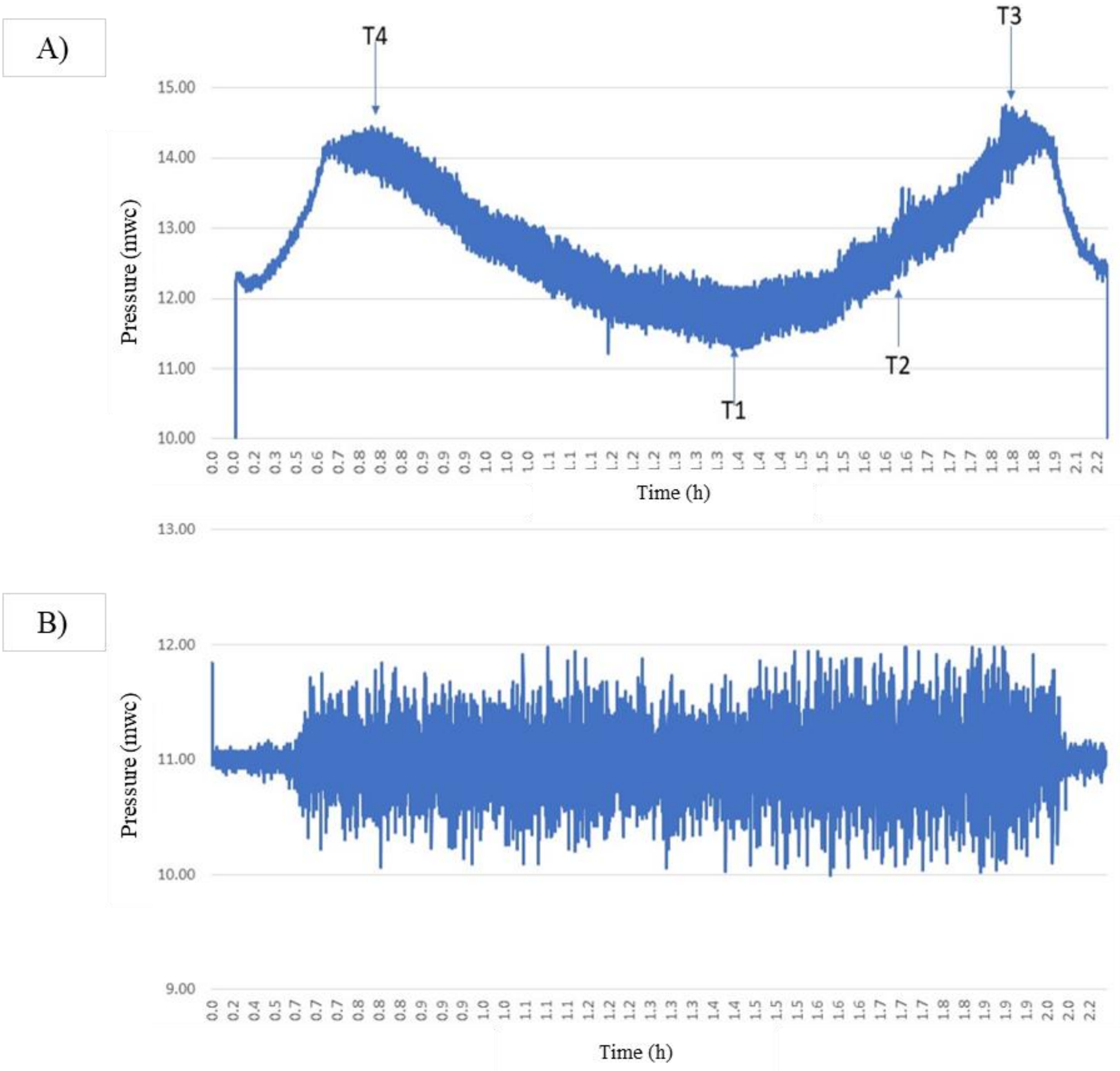


Figure S16. Pressure along the lateral line of the center pivot. Pressure fluctuating due to terrain slope (A). Pressure stabilized with motor speed control via frequency inverter (B).

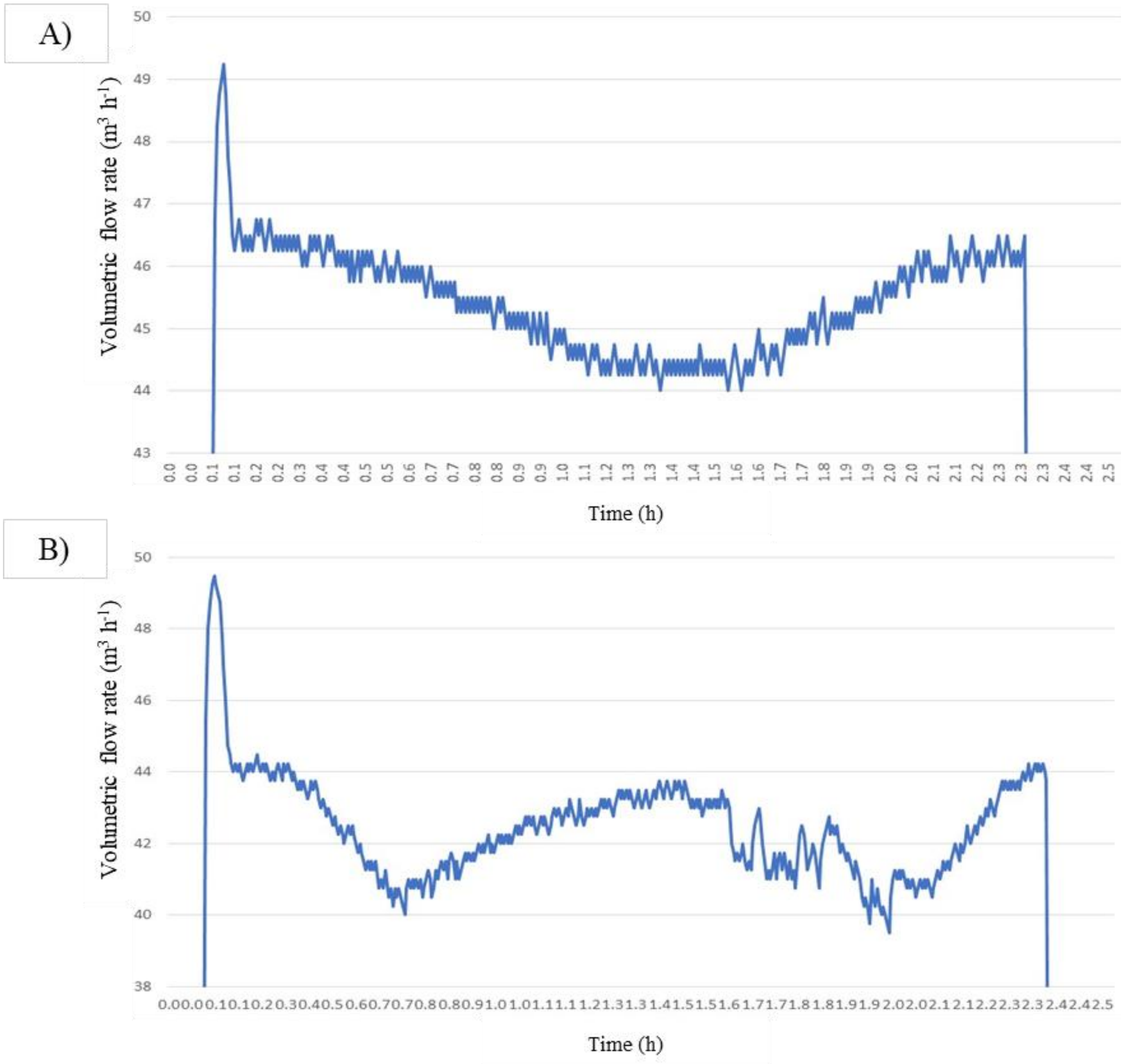


Figure S17. Flow rate in the pivot without pump motor speed control (A) and flow rate with pump motor speed control using a frequency inverter (B).

Table S2. Costs of modernization and automation, including control and telemetry, of the central pivot at the experimental area in Goiânia, Goiás, Brazil.

	Description	Unit	Unit value (R$)	Total value (R$)
Pivot modernization (Alternative system)	Inverter	01	20,000,00	20,000.00
	Pump room controller	01	3,000,00	3,000.00
	Ultrasonic flow sensor	01	1,500,00	1,500.00
	Pressure sensor	01	1,200,00	1,200.00
	Multimeter	01	1,400,00	1,400.00
	Controller in the central tower	01	7,500,00	7,500.00
	Network equipment	01	1,500,00	1.500,00
	Sprinkler sensor	36	260.00	9,360.00
	Pressure sensor	04	1,200,00	4,800.00
	Weather station	01	1,500,00	1,500.00
	Electrical wires and cables	--	1,000,00	1,000.00
	Specialized labor for installation	--	8,000,00	8,000.00
			Total	60,760.00
Pivot modernization (Commercial company)	Electrical equipment, wires and cables	2.5	38,500.00	96,250.00
			Total investment	96,250.00

Note: US$ 1.00 = R$ 5.43; Total investment: US$ 17,737.3581. Exchange rate of 31 August 2025.