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Cereals' Technical Itinerary for Territorial and Environmental Sustainability in Ouargla Region: Evolution, Mutations, and Resilience of Cereal Agrosystems

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ABSTRACT: The sustainability of agriculture in the Saharan region is closely linked to the choice of technical practices and suitable cropping systems. In Ouargla, southeast Algeria, cereals are the main crop following date palm cultivation. The cereal farming system is experiencing significant changes due to environmental, social, and technological factors. This study looks at the development, changes, and resilience of pivot-irrigated cereal farming in Ouargla, focusing on its long-term sustainability. For this purpose, surveys were conducted at 18 farms in the Hassi Ben Abdallah area. The findings show that large farms use center-pivot irrigation in a fast-paced industrial model supported by mechanization and dependent on imported inputs. However, average yields vary widely and do not show consistent productivity improvements, affected by issues like weeds, rodents, and soil salinization, which threaten agricultural sustainability. In order to resolve this problem of salinization, a magnetic water desalination process was introduced for irrigation. Evaluations reveal that this technique lowers pH levels, adsorbed sodium index (SAR) and improves plant growth. Yields are significantly higher with magnetized water compared to non-magnetized. The study indicates that this approach could be a viable solution for enhancing the irrigation systems for the whole technical itinerary of cereals in the Sahara, demonstrating economic benefits as well.

INTRODUCTION

In Algeria, cereal cultivation is a primary agricultural activity that forms the basis of the diet and plays a central role in the dietary habits of the population in both rural and urban areas (Boulal et al., 2007).Cereal products occupy a strategic position in the food system and the national economy. Consumption of cereal products stands at approximately 205 kg per capita per year (DJERMOUN, 2009). In fact, they provide more than 60 percent of the caloric intake and 75 to 80 percent of the protein intake in the national diet (Feillet, 2000).

Cereal production growth remains low relative to population growth (Djermoun, 2018).Statistics show that Algeria has imported an average of more than 12 million metric tons of grains per year over the past five years. Annual production has reached approximately 4.2 million metric tons, including 3.5 million metric tons of wheat. (FAO, 2026).

Agrosystems in the Saharan regions of south Algeria represent some of the most ancient and sophisticated forms of human-environment interaction in arid climates. Historically structured around oases, these systems relied on endogenous knowledge, intricate water management, and agroecological complementarities. Still, in recent decades, these traditional systems have experienced accelerated changes under the pressure of demographic growth, climate variability, groundwater depletion, land-use change, and agricultural modernization.

Actually, agrosystems in arid zones have long been shaped by adaptive strategies that reflect deep ecological knowledge and social organization (bonvallot &lacroix, 2012).

The sustainability of Saharan agriculture hinges on the ability to reconcile productivity with resource conservation. Integrated approaches that promote agroecology, participatory water management, and climate-smart agriculture are increasingly recommended (FAO, 2021).

For the last four decades, a large-scale agricultural development program has been implemented in the Saharan regions, leading to the establishment of new cultivation farms focused on food security and economic diversification. In the Ouargla region, and particularly in the Hassi Ben Abdellah area which is considered a key zone for the expansion of agricultural land, cereal farms and production systems that have been established have undergone significant changes that must be analyzed to enable effective government intervention in the agricultural sector.

Cereal cultivation in the Saharan regions, a production chain which suffers from the conditions of difficult environments and the lack of control of technical itinerary adapted to these arid areas. However, with a rough mastery of production techniques and little impregnated with the constraints specific to this production system, moreover in these regions, farms have seen their productivity levels decline from year to year (Zenkhri, 2017) This study aims to assess the evolution, changes, and resilience of cereal agrosystems under center-pivot irrigation systems in order to establish the technical itinerary best suited to the Saharan context for territorial and environmental sustainability, given their interdependence in terms of cropping systems and production practices: possible production practices depend on cropping systems, since crop combinations and crop rotations are decisive in determining which cultivation operations to carry out. Conversely, the choice of cultivation system is influenced by the various possible production practices, giving consideration that experience reveals that cereal cultivation under center-pivot irrigation systems in Ouargla faces serious difficulties that have significantly impacted yield levels, notably soil salinization, over-extraction of fossil water (Chaouch, 2021), strong winds, and technical issues.

Salinity is one of the major challenges in arid and semiarid environments, posing a significant threat to the sustainability of irrigated areas.

The use of groundwater resources In Saharan areas is a necessary practice for any agricultural development activity. However, inefficient irrigation practices have caused significant losses of this precious resource and have resulted in a rise of soil salinization (Ladjici, 2026).

A simple and promising method is gaining popularity in the Algerian Sahara that relies on the use of magnetic technology to treat irrigation water. This physical process involves exposing the water to a static magnetic field, thereby promoting plant growth in a biologically safe and environmentally friendly manner (Hameda, 2014).

This paper also aims to test the effectiveness of this technique and to compare the yields of a center pivot equipped with a water magnetization device with those of a center pivot without such a device, in the same region, using the same variety of soft wheat, under the same climatic conditions, and with the same farming practices.

2.MATERIALS AND METHODS

2.1. Studying area

This research was carried out in the Algerian region of Ouargla. It is situated in the North-Est part of northern Sahara. The limestone plateau of Tinrhert divides the flat, low-altitude Ouarglaregionwhich ranges from -30 to 200 metersfrom the mountainous territory. This Saharan agro-ecological area is distinguished by its dry climate and abundant natural resourcesparticularly subterranean water.It connects its ancient oases, with sustainable development land, especiallyinHassi ben Abdallah district, which was chosen to carry out our study.

According to the Agricultural Services Directorate (2026), There are a total of 9854 hectares of cereals under 361 pivots in the Ouarglaprovince.

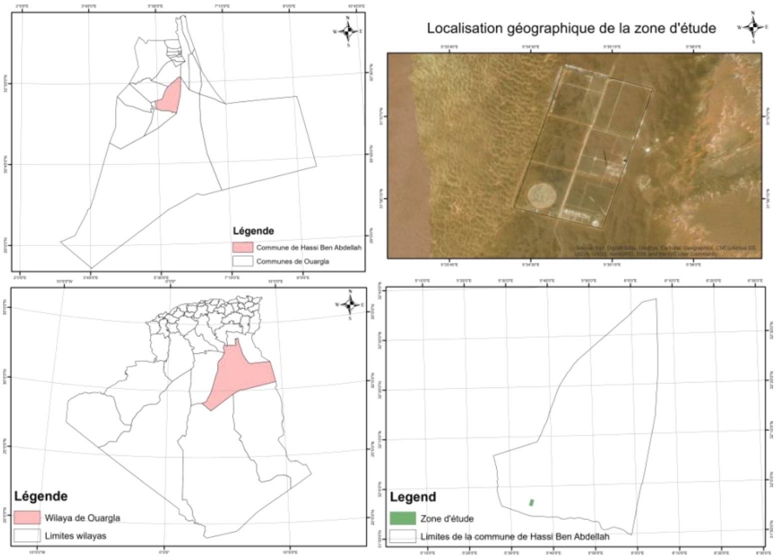

Figure 1. Geographical location of the study area Source: Elaborated by the authors.

2.2. Data Sources

Two data sources were used in this investigation. The first was gathered through a field survey in which cereal producers were interviewed using questionnaires. The second set of data was gathered from relevant sources, including prior research and documents from the State Ministry of Agriculture and Rural Development.

2.3. Sampling and Survey

Reasoned sampling was considered in order to have certain representativeness by area. Surveys were carried out during direct interviews with 18 farmers on their farms in order to know the real situation of the cereal Farms under pivot, to enable us to better understand the problems of the study area.

As for the survey guide, it is based on the bibliographical research and the pre-survey. This survey guide is based on a questionnaire, of the participatory type, which contains information about description of farms, characteristics of farmers and farms, land areas, crops, water sources, irrigation systems, fertilization, sowing, pest control, harvesting. Diagnostic of technical practices: Comparison of practices across crops, regions, and farm sizes and relationship between the type of production system, water source, farm size, technical level, and productivity.

2.4. Experimentation

The experimental design utilized a total randomization approach on flat, homogeneous terrain, featuring two 25-hectare plots under pivot irrigation, each divided into four repetitions. Soil analyses were conducted to a depth of 25 cm, involving physical and chemical assessments after air-drying and sieving. Water from non-magnetized and magnetized boreholes was analyzed for pH, salinity, and ionic balance, including cations and anions. Plant development was monitored at various stages with yield components measured. The magnetic water desalination device, made of stainless steel with a magnetic field of 15,000 gauss, magnetizes water for 72 hours via a magnetic field application.

2.5. Data Analysis

Data collected are processed by the Excel software, SPSS23 and graphic illustrations are produced for a better visualization of the analysis results regarding a study of the desalination effect of irrigation water using magnetism We performed a one-factor analysis of variance between the magnetized and non-magnetized pivot samples for each parameter. This analysis highlights the existence or absence of differences between the variables studied. The software used to process and analyze the results is XLSTAT, version 2016.

To process the water analysis data, we used the hydrochemistry software Diagrams from the Laboratory of Hydrogeology of Avignon, Roland SIMLER, Version 6.48.

3. RESULTS & DISCUSSIONS

3.1. Evolution of agricultural indicators

Table1: Evolution of cereal production indicators under centre-pivot in Ouargla

Indicator	1996	2006	2016	2026	Change 1996-2026
Cultivated area(ha)	2060	230	4000	9845	**+378.3%**
Number of pivots	107	133	85	361	**+237.4%**
Number of investors	25	18	47	112	**+348.0%**
Production(qx)	38067	6300	68906	475000	**+1147.7%**

According to the data, the Ouargla region's irrigated cereal production grew significantly and generally faster between 1996 and 2026. The years that followed were distinguished by significant increases in cultivated area, investment, irrigation infrastructure, and productivity, despite a notable down return between 1996 and 2006. The number of investors climbed from 47 to 112, the number of center pivots expanded from 85 to 361, and the planted area grew from 4,000 to 9,854 ha between 2016 and 2026. Most significantly, production rose from 68,906 to 475,000 over that time, an increase of around 589%.

The table highlights a period of decline between 1996 and 2006, marked by a sharp reduction in cultivated area and production, the structural adjustments adopted in 1994 created strong reluctance among investors (abandonment, sale and resale, as well as the dissolution of the GassiTouil pilot farms, complete abandonment, or a shift toward other crops), cereal-growing areas deteriorated significantly despite attempts at recovery marked by the entry into production of new farms, notably that of Agro-Sud Chaouch (2018).

the region has experienced a gradual recovery since 2006, followed by a remarkable acceleration during the 2016–2026 period. In 2026, the cultivated area reached 9,854 ha, compared to 4,000 ha in 2016, while the number of investors rose from 47 to 112 and the number of pivot irrigators increased from 85 to 361. At the same time, production reaches 475,000 quintals, compared to 68,906 in 2016, representing a yield of 48.2 qx/ha in 2026, compared to 17.2 qx/ha in 2016,an increase of around 589%. This recovery stems both from the expansion of cultivated areas and from improved productivity resulting from the policy to support the “cereals” sector through the provision of interest-free loans, tax exemptions on plant protection products, fertilizer price support, and the programfor the purchase of agricultural equipment.

3.2. Characteristics of farms

The characteristics of the farms studied are shown in Table 2; the farms surveyed are distinguished by a set of criteria, including: establishment, size (or scale), legal status of the land, area devoted to cereals and cereal yield.

Table 2. Farms characteristics

Variable	**Mean**	**SD**	**Median**	**Min**	**Max**	**CV (%)**
Farm creation year	2012.22	5.94	2014.50	1992	2017	0.30
Total farm area (ha)	73.17	50.76	50.00	3	200	69.37
Exploited area (ha)	35	19.81	31.00	3	76	56.29
Cereal area (ha)	23.83	16.02	20.00	1	60	67.20
Cereal yield (qx/ha)	43.00	6.35	45.00	32	54	14.77

The grain farms surveyed were established between 1992 and 2017 as part of the concessions program for 83.3% of farms, while 16.7% were allocated under the APFA, pursuant to law No. 83-18, and thus acquired the status of private property, as provided for by that law.

Regarding their size, the surveyed farms displayed considerable variability. The mean total farm area was 73.17 ha, with a standard deviation of 50.76 ha and a range from 3 to 200 ha. The variation coefficient reached 69.37%, indicating substantial structural heterogeneity.

This heterogeneity is highlighted by the fact that in the arid regions of the Sahara, farms are generally small, ranging from about 1 to 2 ha. However, with the advent of new land enhancement projects, exceptionally large plots ranging from 50 to 1,000 or even more have emerged.

These results indicate that the farms differed substantially in their land resources and the proportion of land devoted to cereals. The effective area under pivot irrigation system ranges from 1 ha to 60 ha; 94% of this area consists of plots averaging between 5 and 60 ha; it is noted that the areas covered by center-pivot systems are not always planted.

In terms of grain yield, however, the results appear relatively more consistent. It ranges from 32 to 54 qx/ha, with an average of 43.00 qx/ha, a standard deviation of 6.35 qx/ha, and a coefficient of variation of 14.77%. This low relative variability

in yield suggests that, despite significant differences in land area among farms, productivity levels remain relatively similar and correlation analysis does not reveal a statistically significant relationship between yield and cereal acreage (Pearson's $r = 0.197$; $p = 0.433$) A positive but non-significant association was observed between production and yield (Spearman's $\varrho = 0.376$; $p = 0.125$).

Variations in cereal yields indicate that distinct factors are at work. Changes in crop management, agricultural practices, and environmental factors can all contribute to variability. Fluctuations in grain yields highlight the need for sustainable agricultural practices, which are essential for long-term soil health and climate resilience.

3.3. Technical itinerary typology

Good management of a farming system constitutes the grassroots of the system's economic, environmental and social sustainability

-Performance by Cereal Crop structure

Durum wheat was the dominant cereal in the sample, representing 72.2% farms followed by Barley with 16.7% and soft wheat by 11.1%.

This distribution indicates a strong orientation toward durum wheat production within the surveyed farms.

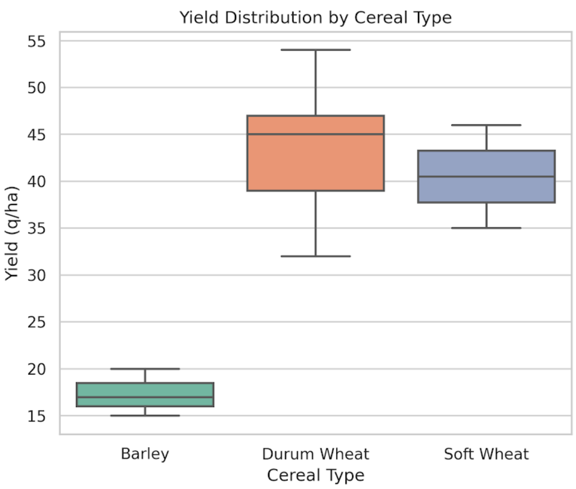

Figure1: Yield Distribution by Cereal Type.

Figure 01 show that Durum wheat produces substantially higher yields (43.31 q/ha) compared to soft wheat (40.50 q/ha) and barley (17.33 q/ha).

The average yields observed on the farms surveyed appear to be higher than those reported by the Ouargla Agricultural Services Directorate , which reports 35 q/ha for durum wheat and 28q/ha for soft wheat, with a very similar figure for barley at 15 qx/ha.(DSA Ourgla,2026).

Tillage

Soil preparation is of the utmost importance and determines the final outcome and, consequently, the profitability of the crop.

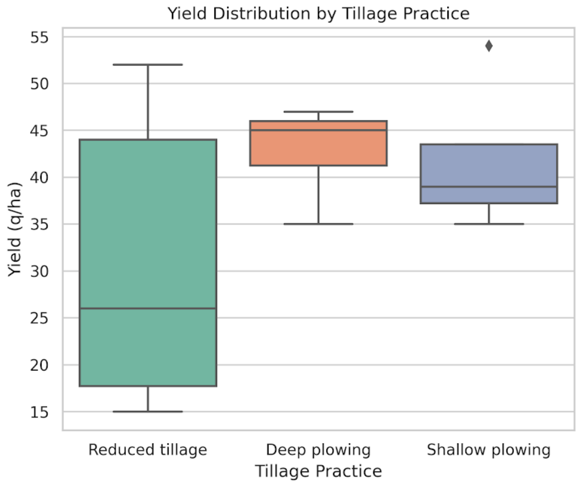

Figure2: yield distribution by tillage practice

According to the results (figure2), three main soil-preparation practices were identified. deep plowing is the most often used tillage method (44.4%), followed by reduced tillage (33.3%) and shallow plowing (22.2%). Analysis of the relationship between tillage and yield revealed that the highest average yield was observed on farms practicing deep ploughing, at an average of 44.38 q ha−1, followed by those using reduced and shallow cultivation.

In general, a decline in grain yield is due to a reduction in the value of one or more components of yield: the number of ears, the grain weight per ear, the weight of 1,000 grains and the number of grains per ear (Woźniak and Soroka 2018). However, the response of cereals to monoculture varies and is limited by environmental conditions, the agronomic practices employed and numerous other factors. Cereal yield is also influenced by tillage systems (Gruber et al. 2012; Zikeli et al. 2013; Montemurro and Maiorana 2015).

Irrigation Source

Irrigation on the farms surveyed relies on two methods: wells and boreholes. Deep boreholes (*forage*) supply 50 % of farms, wells supply 44.4%, and 5.6% utilize a combined system. Consequently, nearly all farms rely almost entirely on groundwater, irrigation water is drawn from the Miocene-Pliocene aquifer at depths of between 100 m and 400 m.

According to (Khadraoui and taleb, 2008), water from the Miocene-Pliocene and Senonian aquifers is generally very hard. The average dry residue is 1.6 to 2.8 g/l, and the chemical composition is generally magnesium-chloride and sodium-chloride.

The irrigation pivots are entirely imported; they cover areas ranging from 1 to 50 ha. The number of pivots varies from 1 to 6. However, 33 per cent of farms have only one pivot, whilst 66% have between 2 and 6. The water requirements of cereals in desert regions are estimated at approximately 6,000 to 7,000 m³ of water

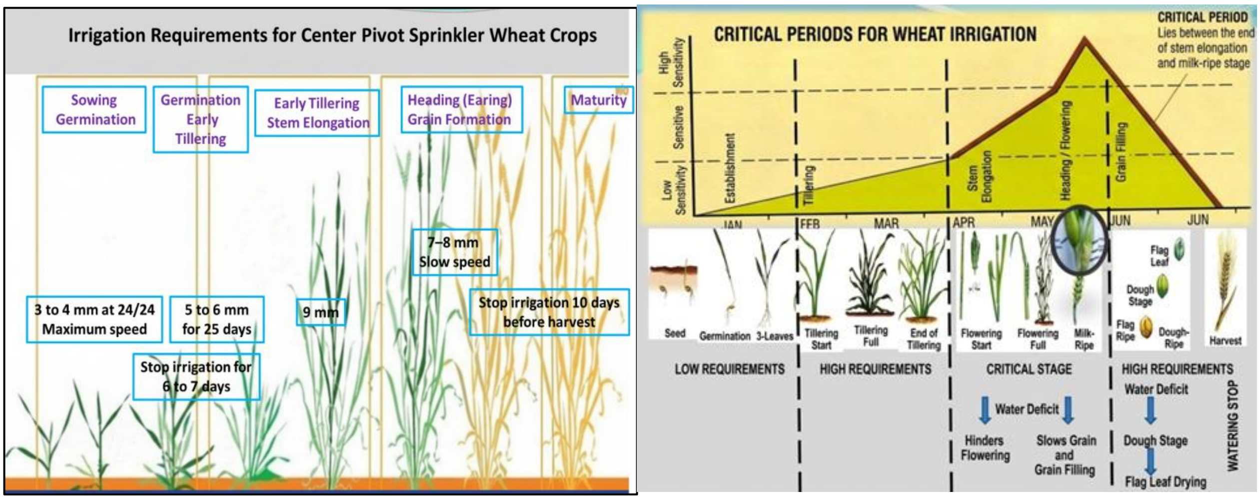

Figure3: Irrigation Requirements for Center Pivot Sprinkler Wheat Crops in arid area

The irrigation program varies according to the climate, soil type and stage of plant growth; with regard to managing irrigation and maintaining centre-pivot systems, the majority of farmers have gaps in their knowledge, which affects grain ear filling and, consequently yields. water requirements and the required irrigation rate for each growth stage are shown in Figure 3, along with the irrigation regime during critical periods, as determined by the researcher as part of the optimization of real irrigation needs for wheat cultivation in arid conditions.

Fertilization

Fertilisation involves applying fertilisers in various forms, either via fertigation or using a fertiliser spreader; according to the collected records, all the farms surveyed use organic soil improvers and mineral fertilisers. Among the fertilisers applied by farmers in the study region are simple nitrogen fertilisers (Urea 46%), Monoammonium phosphate (MAP 12.52.0), Sulphate-based compound fertiliser (NPK 15.15.15), Organic fertilisers (ALGOR, ALGOR+), and suspension fertiliser (NPK 02.52.34).

Mechanization

For cereal farms, the use of agricultural machinery is essential; however, only 38 % of them own their own machinery (tine cultivator with roller, tractor, seed drilling machine and towed equipment). The remaining 62 % hire machinery or use it free of charge to carry out their operations and various tasks. As regards harvesting, the Cereals and Pulses Cooperative (CCLS) is responsible for this operation due to the excessively high cost of combine harvesters relative to the area devoted to cereals per farm. A study carried out by Chaouch et al (2022) reports the same findings regarding mechanization in the region.

Phytosanitary treatments and weed control

phytosanitary treatments is executed by 55.6% of farms but only 44.4% respect the follow dosage guidelines. The difference observed in terms of plant protection treatments and adherence to recommended doses is also worth highlighting. Farms that reported having carried out plant protection treatments and adhered to the recommended doses recorded slightly higher average yields.

Weed control is carried out by 66.7% of farms, the interventions in this process are carried out via the mechanical method, which involves watering the soil before ploughing, followed by ploughing to eradicate them; chemical interventions, which complement by spraying herbicides in accordance with the following conditions as selecting herbicides according to the type of weed, adjusting the sprayer correctly.

In these areas, it is the National Plant Protection Institute that carries out the treatments on the farms, in the fields and according to a clearly defined schedule

Technical Itinerary Index (TII)

The Technical Itinerary Index (TII) measures modern agricultural practice compliance across 6 key operations (Tillage depth, Soil analysis, irrigation, fertilization, Phytosanitary treatment, and Mechanization) on a scale from 0% to 100%. The classification of the farms studied reveals three distinct technical profiles, ranging from traditional, low-input systems to modern commercial cereal farms.

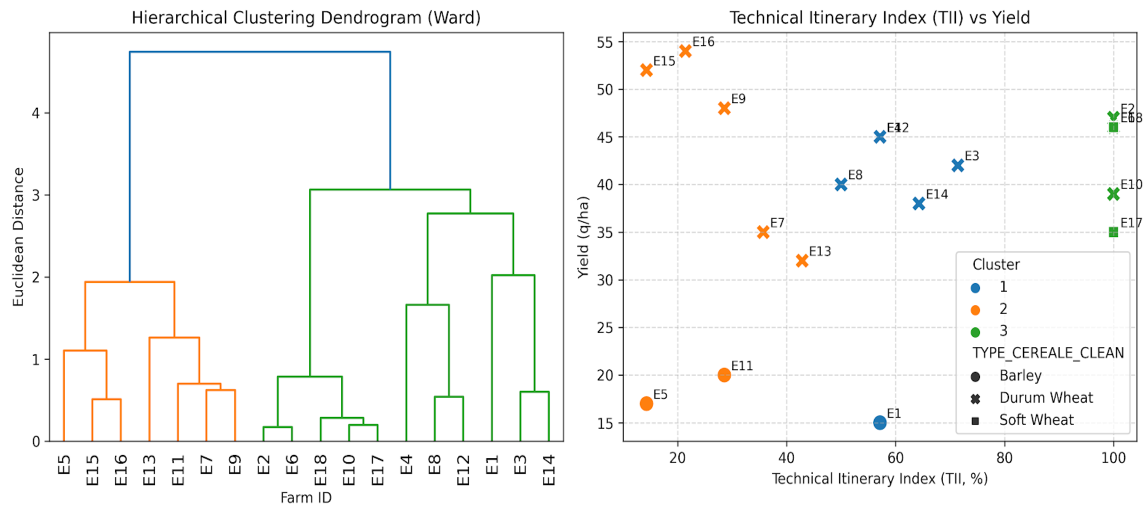

Figure 4: Hierarchical clustering dendrogram (technical itinerary index)

Cluster 3: Intensive Commercial Modern Systems (TII = 100%)

• Technical Rigor: thorough adherence to all contemporary agronomic techniques, such as methodical deep plowing, required soil testing before fertilization, thorough chemical plant protection, precise dose controls, and full machinery integration.
• Crop & Scale Focus: In addition to high-performing Durum Wheat, all Soft Wheat activities are carried out on huge plot sizes (42.0 ha on average).

• Performance Impact: Demonstrates that structural technical compliance ensures consistent productivity at scale by achieving the highest mean yield (45 q/ha) with no crop failures or significant output decreases.

Cluster 1: Semi-Intensive Transition Farms (TII = 60.0%).

• Technical rigor: partial soil preparation and dose controls (60%) combined with the selective use of chemical protection. However, poor soil testing (40%) and low mechanization (20%) impede efficiency.
• Crop & Scale Focus: Durum wheat is the main crop grown on medium-sized farms (19.8 ha on average), with occasional barley.
• Performance Impact: Consistently produces intermediate yield outputs (36.0 q/ha), reflecting smallholders who are actively switching to more advanced technical packages.

Cluster 2: Traditional Low-Input Operations (TII = 30.4%)

• Technical Rigor: Characterized by minimal soil preparation (62.5% reduced tillage), absence of chemical plant protection (0%), complete lack of dosage standardizations, and low mechanization (12.5%). Use organic fertilizer and manual or opportunistic weeding as your main methods.

• Crop & Scale Focus: Traditional Durum Wheat crops are planted alongside all low-performing Barley operations on smaller land allocations (15.0 ha on average).

• Performance Impact: Shows extreme yield instability, with yields ranging from 17 q/ha (E5, Barley) to 54 q/ha (E16, Durum Wheat). A lack of technical uniformity makes these farms extremely susceptible to weed infestation and nutrient depletion over time, even though good soil/water conditions allow isolated high yields without agrochemicals.

-In arid regions like Ouargla area, optimizing cereal production is crucial for agricultural productivity and environmental sustainability. Updating soil preparation to lessen erosion and safeguard soil structures. Implementing precision resource management with soil analysis and automated fertigation minimizes nutrient loss and soil salinization. Enhancing agroecological resilience by using organic amendments helps stabilize yields among climate change. Finally, standardizing sustainable practices across farms safeguards groundwater resources, ensuring economic viability and food security.

3.4. Effect of introducing a desalination technique of water's irrigation by magnetic process on the cereals's technical itinerary

The experimental set-up contains two plots under pivot of 25 hectares each and every plot is divided into four repetitions. The chosen methodological approach enables us to compare the two pivots, based on: soil analyses, water analyses, and calculation of yield components

Soil analysis

The analytical results show that the soil of our study area (the soil of the 02 pivots) is characterized by a totally sandy texture. The soil is very low in organic matter (Mo≤ 1%), with an alkaline pH. Electrical conductivity (EC) values are < 5oo µs/cm, making the soil non-salty according to the Durand (1983) scale.

water analysis

The results obtained from the chemical analysis of our samples are presented in the following table

Table3. Results of water chemical analysis.

N°	Samples	Ca^{++} (meql^{-1})	Mg^{++} (meql^{-1})	Na^{+} (meql^{-1})	K^{+} (meql^{-1})	Cl^{-} (meql^{-1})	SO_4^{--} (meql^{-1})	CO_3^{-} (meql^{-1})	HCO_3^{-} (meql^{-1})	NO_3^{-} (meql^{-1})	pH	CE 25°C (mScm^{-1})	CE 25°C (µScm^{-1})	RS (mgl^{-1})	Salinity (gl^{-1})	SAR	RS (mgl^{-1})
1	Magnetizeddrilling +urea	15,24	20,00	32,18	0,82	32,80	28,90	0,00	2,90	0,00	7,74	6,93	6930	4906	3,80	7,66	4851
2	Non-magnetized+urea	15,22	17,68	33,91	0,80	31,56	29,42	0,00	3,05	0,00	7,77	6,97	6970	4960	3,82	8,36	4879
3	Magnetizeddrilling	15,22	17,68	32,72	0,83	32,97	28,90	0,00	3,00	0,00	7,70	6,94	6940	4900	3,80	8,07	4858
4	Drillingbeforemagnetized	15,72	17,68	33,59	0,83	31,89	28,63	0,00	3,05	0,00	7,74	6,94	6940	4882	3,80	8,22	4858
5	Non-magnetizeddrilling	15,41	20,42	34,78	0,80	36,12	28,11	0,00	3,20	0,00	7,94	6,97	6970	4864	3,82	8,22	4879

The results in the table show the following:

* pH: for the non-magnetized borehole, the pH of the water decreases from 7.94 for pure water to 7.77 after the addition of urea; and for the magnetized borehole, the pH of the water decreases from 7.74 to 7.70 after the magnetization of the water and returns to 7.74 after the addition of urea.

* Electrical Conductivity: 6.97 Mscm^{-1}for the non-magnetized borehole before and after the use of urea; and 6.94 mScm^{-1} for the magnetized borehole before and after magnetization, with a slight decrease after the use of urea (6.93 mScm^{-1}). Water magnetization and fertilizer use therefore have no effect on electrical conductivity.

* Salinity: 3.82 gl^{-1} for the non-magnetized borehole and 3.80 gl^{-1} for the magnetized borehole. Water magnetization and fertilizer use have no effect on salinity.

* SAR: for the non-magnetized borehole, SAR rises from 8.22 to 8.36 after urea application; on the other hand, for the magnetized borehole, it falls from 8.22 to 8.07 after magnetization and rises to 7.66 after urea application.

* RS: for the non-magnetized borehole, there was no change in the RS value after urea use, at 4879 mgl^{-1}. And for the magnetized borehole, the RS value is 4858 mgl^{-1} before and after magnetization, and decreases to 4851 mgl^{-1} after the addition of urea. Thus, the water magnetization process does not have a direct effect on water salinity and electrical conductivity, but it does have an effect on pH, SAR and RS.

After data analysis using the Hydrogeology Laboratory's Diagrams hydrochemistry software, the following graphs were obtained:

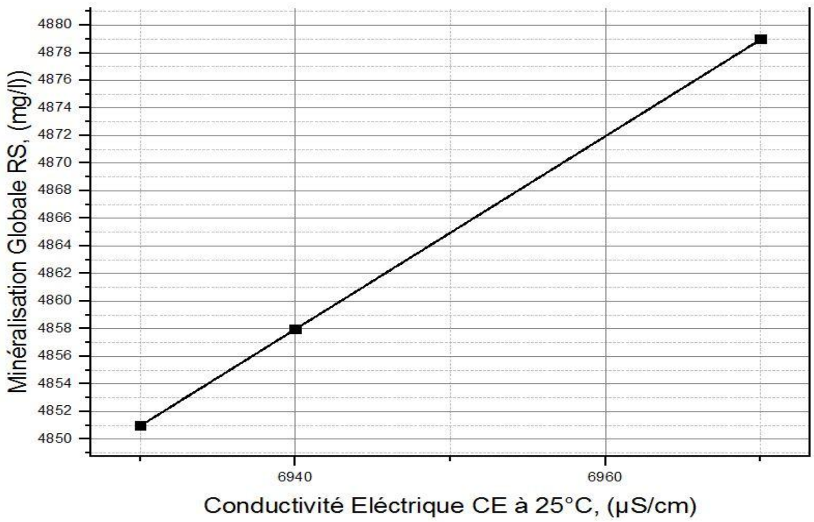

Figure 5. Linear plot of total mineralization RS (mgl^{-1}) versus electrical conductivity EC (µSCm^{-1}) for the 5 samples.

The direct effect of total salinity is to reduce crop growth and production, generally expressed in terms of overall mineralization (or dry residue) or electrical conductivity. The latter is related to dry residue (RS) and osmotic pressure (π) by the following formulas:

RS (mgl^{-1}) = 0,7 * CE (µScm^{-1})

π (atm) = 0,00036 * CE (µScm^{-1})

Soil salinity is made up of all sodium chloride and magnesium sulfate salts, hence the term potential salinity (PS), estimated by (Doneen, 1961) using the following equation:

SP = Cl^{-} + ½ $SO4^{2--}$ (meql^{-1})

Electrical conductivity represents the ability of a solution to conduct electric current, which indirectly represents the measure of total dissolved solids (TDS) in a water sample.

The presence of sodium (Na) has adverse effects on soil structure through clay deflocculation. The calculation of several parameters such as:

- Sodium Adsorption Ration (SAR),

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

-Percentage of sodium (%Na),

%Na = (Na^+ + K) * 1000 / Ca^{++} + Mg^{++} + Na^+ + K^+

- Permeability index:

IP (%) = (Na^+ + $\sqrt{HCO_3^-}$ / Ca^{++} + Mg^{++} + Na^+) x 1000, (meq/l)

- Percentage of sodium exchange :

ESP = 100 * [b * (SAR) – a] / (1 + b * SAR – a), avec a = 0,0126 et b = 0,01475

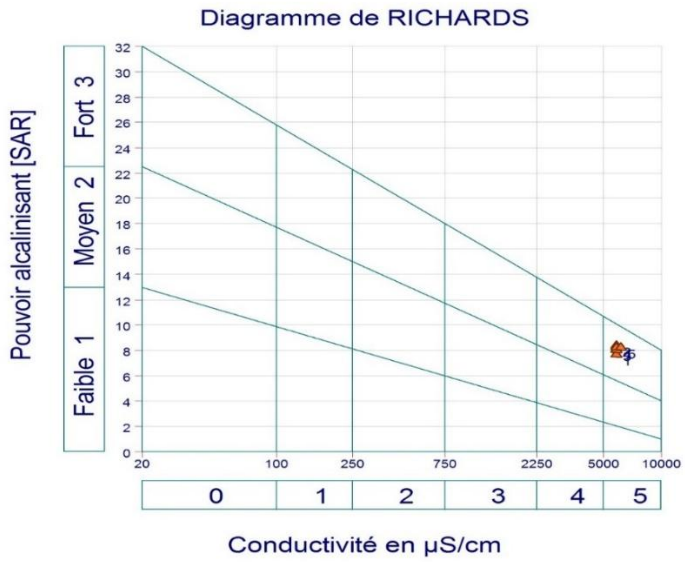

Figure 6. Diagram for classification of irrigation water according to (SAR).

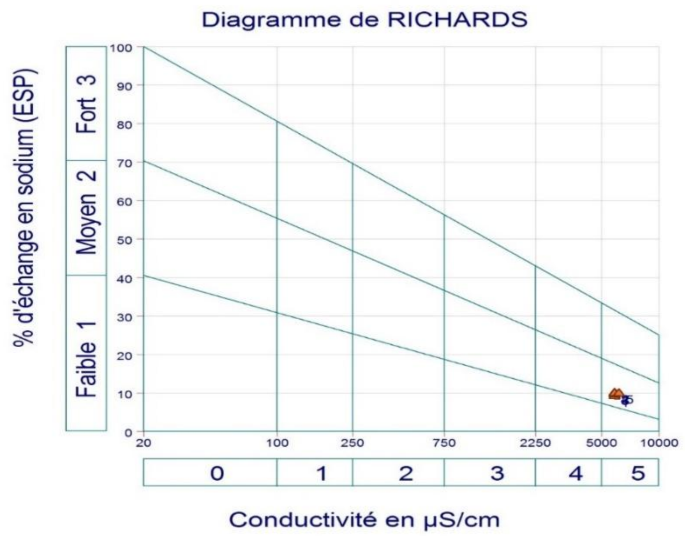

Figure 7. Diagram for the classification of irrigation water according to (ESP).

The RICHARDS diagram assesses soil salinization risk using electrical conductivity and Sodium Adsorption Ratio, dividing it into four salinity and sodization risk classes, based on water salinity and irrigation.

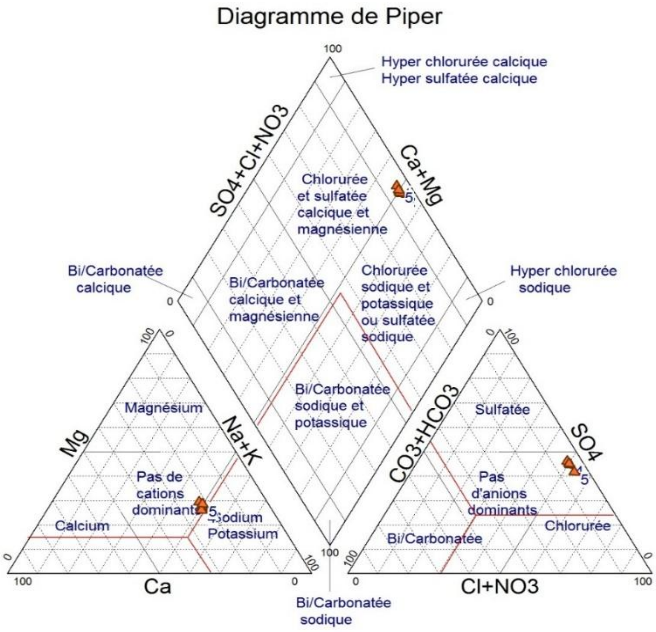

Figure 8. Triangular presentation of sampled waters, PIPER diagram.

The Piper diagram uses major elements to represent different groundwater facies. It can also be used to illustrate the evolution of water from one facies to another, through time-spaced analysis or analysis of samples taken at different locations. The Piper diagram is very useful for representing all other kinds of analysis groups. The Piper diagram consists of two triangles and a diamond. The two triangles (one carrying the cations, the other the anions) are filled in first, followed by the rhombus. The values used are expressed in %.meq.L^{-1}.

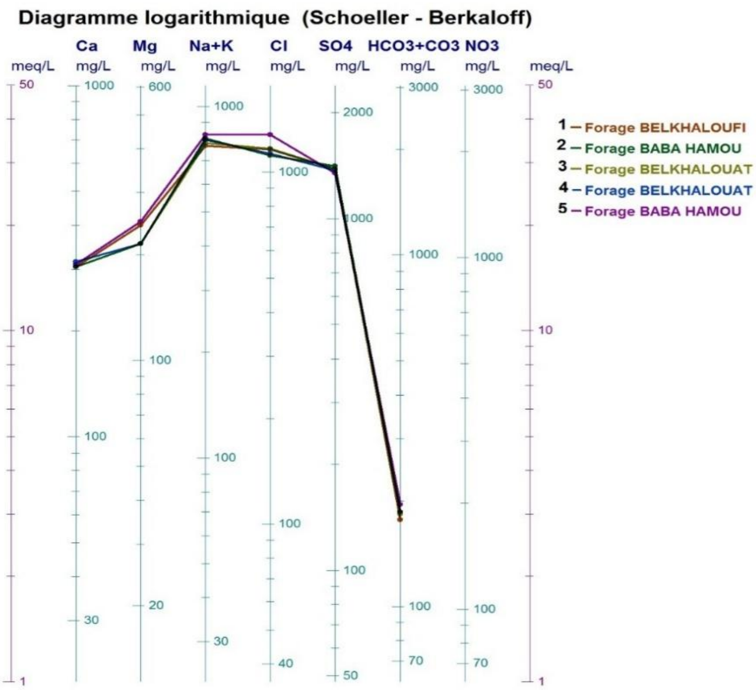

Figure 9. Logarithmic diagram of sampled waters, Scholler-Berkaloff diagram.

The Scholler-Berkaloff diagram is a simple way of identifying groundwater facies, using the concentrations of major elements and plotting them on a column graph with logarithmic scales.

These diagrams illustrate the characterization of sampled waters classified as C5S3, showing the relationship between alkalizing capacity (SAR) and electrical conductivity (EC). Chloride and magnesium-calcium sulfate facies, these waters have a very high salinizing power and a very high alkalizing power. C5 S3: very poor quality, to be used only in exceptional circumstances.

To determine the chemical facies of the water used for irrigation in our experiment, we used Piper and Scholler-Berkaloff diagrams to classify the facies of our water, which is chloride, calcium sulfate and magnesium sulfate. The results of our 5 analyses highlight this case very positively, with the dominant water facies being chloride-calcium and sulfate-calcium-magnesium, balanced waters (with no dominant anion), as illustrated by the PIPER diagram.

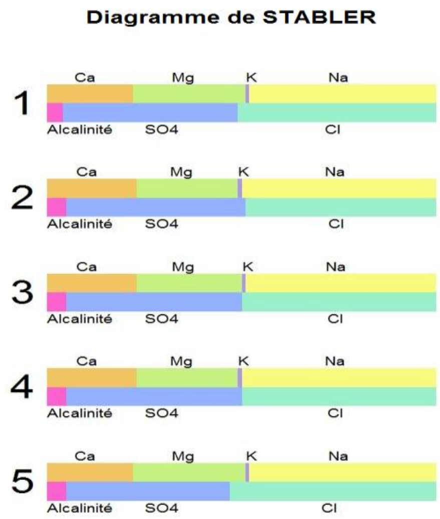

Figure 10. Collins or Stabler diagram.

The Collins diagram is used to determine water titers (alkalimetric titers, salts of strong acids and hydrotimetric titers) by plotting anion and cation concentrations on equal-length bars or columns. Titrations are determined visually. In our case, the 5 samples showed similar trends, with SO42- changing after urea use and Na+ decreasing after magnetization. Magnetic water treatment shows promise as a tool for improving irrigation in arid conditions (El aoud et al, 2017).

Yield calculation parameters

Number of plants / m² (Emergence stage)

The density of seedling in our experiment is 2.2 Qx/ha. The seed density used per m² is: 0.022 kg / m² (22 g / m²) with an average weight of 1000 grains of 33.05 g (the weight of a grain is: 0.03305 g), that the seeding density in grains per m² is: 665.65 grains / m² ~ 666 grains / m²).

The germination rate of our seed is 94.64% for the non-magnetized pivot and 96% for the magnetized pivot. The expected number of seedlings/m² is 630 for the non-magnetized pivot and 639 for the magnetized pivot. However, the magnetized pivot recorded a higher number of plants/m2 at the emergence stage.

Our outcomes which show a better germination rate in grains watered by magnetized water and a higher number of plants / m² for the magnetized pivot, correspond with the results obtained by Marweni (2015) and Gacem and Abdelnebi (2017), their results indicate the positive action of water magnetization on the germination rate. According to Majd and Shabrangi (2009), these results are due to the positive effect of magnetization on increasing the germination rate of grains. This can be attributed to an increase in water absorption following magnetic treatment. For statistical analysis $P > 0.05$, so no significant difference and the values of the number of plants / m² do not differ significantly.

Number of tillers / m² (Tillering stage)

About the number of tillers per m² at the tillering stage. It is 566 tillers for the non-magnetized pivot and 610 tillers for the magnetized pivot.

The magnetized pivot showed higher values than the non-magnetized pivot, but these were low compared to the number of plants/m2 and the variety's morphological characteristics. The importance of tillering depends on: variety, seeding density, weed density and nitrogen nutrition (Belaid, 1996). The HIDDAB variety had medium to high tillering, but high seeding density affected the low number of tillers/m2. Water magnetization has been shown to increase leaf and root development and total plant biomass (Aladjadjiyan, 2002). For statistical analysis, the P-value being well above the significance level 0.05, thus the hypothesis is null, it can be concluded that there is no significant difference between the values of the number of tillers / m².

Number of tillers / plant (Tillering coefficient)

The tillering coefficient is the ratio number of tillers/plants. The average number of tillers was counted for 10 plants / square, or 40 plants for each pivot.

The tillering coefficient is higher for magnetized pivot plants, but both values remain low due to climatic disturbances, temperature drops, and water deficits. Temperature affects nitrification and vegetative activity (Soltner, 1999), while water deficits increase the rate of tiller disappearance (Bouziane, 2001). In our case, both pivots suffered an electrification failure for 05 days, and another pump failure of magnetized pivot for 07 days. Statistical analysis of the tillering coefficient indicates that there is no significant difference for this parameter.

Number of ears / m² (Heading stage)

The tillering rate directly influences this component, with average values being low for magnetized pivots. Ear tillering in isolated or semi-clear plants is influenced by factors like better match of needs to photosynthesis (Meziani, 1985). The number and size of ears in plants are influenced by the efficiency of photosynthesis from floral initiation, and this increases with fertilizer inputs (Bouziane, 2001). Tillers at stage B of the "master strand" give an ear to cover plant needs, reducing the number of ears. High stands can penalize tillers per ear, causing a negative relationship (Grignac, 1965). Statistical analysis for this parameter concluded that these values did not differ significantly ($P > 0.05$).

Number of grains / ear (Maturity stage)

The number of grains per ear is a varietal characteristic highly influenced by the number of ears/m². It acts directly on the number of grains/m² (Couvreur, 1985).

The development of this component, affecting yield and variability, is influenced by grain density per m², with grain number per ear influenced by water availability (Bouziane, 2001). The number of grains per ear at harvest is closely linked to water availability during the vegetative phase. Fertility of the ear is determined over time, with ovule numbers fixed after the mount, potentially leading to abortion in extreme cases ((Bouziane, 2001).; (Triboie, 1986)). Constraining nitrogen and water feeding conditions as well as low light energy will affect photosynthetic activity and consequently penalize spikelet fertility (Mekliche, 1983).

The experimental case reveals a significant difference in grain/ear number values between magnetized and unmagnetized pivots, with a statistical analysis maintaining the null hypothesis.

Yield

Yield is the result of successive phases of growth and development, including the establishment of organs and the process of their increase in size directly related to the energy intercepted and the availability of water and mineral elements absorbed by the root system (Bebba, 2011).

The calculation of the theoretical yield was carried out according to the formula:

Yield (g/m²) = Number of ears/m² × Number of grains/ear × weight of one grain (g)

The calculation of the practical yield was carried out after sampling and manually harvesting the ears of 04 samples of 1m² of each pivot. After manual threshing, we weighed each sample separately, determined their average and deducted the yield per hectare.

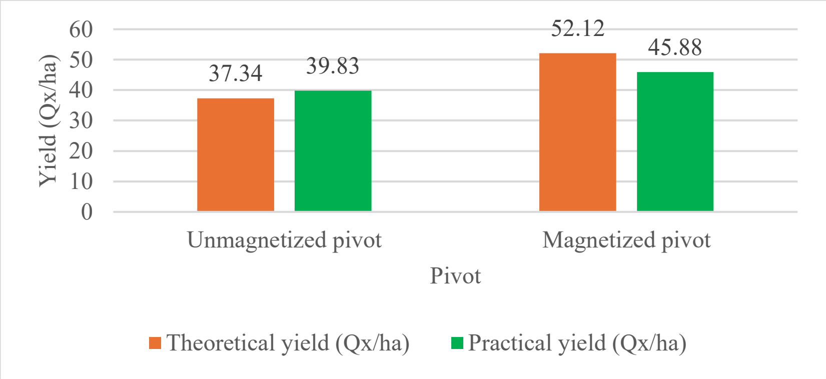

Figure 11. Theoretical and practical yield.

According to Figure 11, the calculated yields (theoretical and practical) are higher for the magnetized pivot than for the non-magnetized one, which shows the effect of water magnetization on cereal yield. The authors Gacem and Abdelnebi (2017), obtained in their experimental work higher yields in plants irrigated by magnetized water.

However, for the magnetized pivot the practical yield is lower than the theoretical yield (the theoretical yield is 52.12 Qx/ha and the practical yield 45.88 Qx/ha). This regression is due to hydric stress caused by the pump failure, and the lack of control of fertigation and crop management; which has given rise to some problems on fields such as the appearance of Fusarium disease, and the yellowing of plants in some parts of the pivot which is caused by excess moisture and the nature of poorly drained soil in some places. On the other hand, the non-magnetized pivot yields higher due to better knowledge and fewer crop year problems. The magnetized pivot yields 6.05 Qx/ha or 151.25 Qx/25ha, and farmers can amortize it after 2-3 crop years. Sherif et al, (2020) report that using magnetic technology for groundwater treatment in arid regions would increase the possibility of using saline water for safe irrigation on the long-run, suggesting integration into comprehensive cereal production systems.

CONCLUSION

The transition from traditional oasis agriculture to modern, large-scale pivot-irrigated cereal farming significantly boosted local grain production under the state's agricultural development programs. However, the technical applied by modern farmers have undergone major mutations due to severe local constraints.

The results revealed substantial heterogeneity in farm structure, particularly in total farm area and cereal area, while cereal yield was comparatively homogeneous but remain low compared to seed performances and available production factors.

Based on our analysis of the current situation in grain cultivation using center-pivot irrigation, we have found a clear discrepancy in the implementation of most agricultural practices within the technical protocol for this crop, as well as significant weaknesses in the management of inputs and outputs. We attribute this primarily to a lack of guidance and training, in addition to other obstacles like failures of water pumps and electrical receivers at certain critical stages, soil salinization and water salinity, more cumbersome procedures for obtaining a bank loan and hinder the operation of farms.

even more serious than these, there are major problems that threaten the sustainability of this agroecosystem, particularly the issue of groundwater depletion resulting from overexploitation. high energy consumption, lack of competitiveness and motivation. The fact that the cereal and legume cooperative has historically been the exclusive buyer, regardless of product quality, marginalizes a quality-focused approach, despite government support for this sector aimed at increasing cereal production to reduce the import costs.

cereal farming contributes to regional food security and economic activity, its long-term regional sustainability remains under threat. The study concludes that true resilience requires moving away from input- and water-intensive practices in favor of an agroecological transition, as well as greater socioeconomic resilience and territorial integration through improved agricultural extension services for local farmers and multi-stakeholder governance aimed at protecting the particularly fragile Saharan aquifers. Resilience and sustainability in Ouargla depend heavily on adaptative technical practices, including:

-Water Management by adapting center-pivot irrigation schedules to mitigate extreme evaporation rates, groundwater depletion, and high soil salinity.

-Crop Protection & Inputs through optimizing fertilizer applications and seed varieties specifically adapted to thermal stress and sandy desert soils.

-Soil fertility and salinity dynamics in the management of risks of salinization and soil degradation resulting from intensive irrigation with mineralized groundwater. To address this concern, we implemented a solution involving desalination of irrigation water using a magnetic process. The evaluation of the efficiency of this technique, show that the magnetization of water leads to a decrease in pH and the adsorbed sodium index (SAR). Regarding plants, germination rate and plant development are slightly improved by irrigating with magnetized water, while the average yield considering its parameters (emergening, tillering and stinging) is significantly enhanced with the use of magnetized water. Moreover, the best average yield is that recorded under magnetized pivot with a theoretical yield of 52.12 Qx/ha and a practical yield of 45.88 Qx/ha, against a theoretical yield of 37.34 Qx/ha and a practical yield of 39.83 Qx/ha recorded under non-magnetized pivot. The economic feasibility study confirms the profitability of this technique, by a gain of 6.05 Qx/ha, or 151.25 Qx/25 ha. Our findings offer a practical alternative for integrating this magnetic process of desalinating irrigation water for the whole technical itinerary of cereals under pivot of the Saharan regions

However, it should be noted that these results are valid only for the region studied, with its distinctive soil characteristics and climatic conditions, and that the sustainability of the center-pivot-irrigated cereal agrosystem in the Algerian Sahara depends on its management and adherence to an appropriate technical schedule.

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CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest in this study.

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