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Geostatistical Modeling of the Spatial Distribution of Physico-Chemical Properties of Soil Cultivated with Cereals Under a Pivot Irrigation System in the Algerian Sahara: A Case Study in Biskra, Algeria

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Dedication

To my dearest mother and father,

Your unwavering love, endless support, and boundless encouragement have been the guiding light throughout my academic journey. Your sacrifices, selflessness, and belief in my potential have shaped me into the person I am today. This thesis stands as a testament to your faith in me and the values you instilled in me from the very beginning.

To my beloved brothers, Bilal and Aymen,

My forever strength and companionship

To my cherished sister, Nermine,

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lina

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Abstract

Assessing the sustainability of agricultural production systems in irrigated regions demands meticulous examination of soil quality, particularly within cereal-cultivated areas under pivot irrigation systems. This study investigates the intricate spatial dynamics of soil properties within two distinct regions: Ourlal and El Outaya, both situated in Biskra, Algeria. Through systematic sampling and analysis spanning four years of cereal cultivation, we rigorously assessed key parameters including irrigation water quality, granulometry, pH, electrical conductivity (EC), organic matter (OM), and equivalent calcium carbonate (total limestone).

In Ourlal, granulometry analysis revealed sandy loam soil dominance, with pH values ranging from moderately alkaline in cultivated soils to slightly alkaline in the reference soil. Notable salinity levels were observed in irrigation water, with EC values indicating high salinity levels in cultivated soils and moderate salinity in reference soils. Total limestone measurements suggested a strongly calcareous character across all sites with low organic matter content. Variogram modeling elucidated Gaussian and Exponential patterns for pH and EC, respectively, underscoring the complex spatial variability of these parameters within cultivated sites.

Similarly, in El Outaya, granulometry analysis showcased sandy loam soil dominance, with pH values exhibiting a similar range as in Ourlal. Salinity levels in irrigation water were also noteworthy, with EC values indicating high salinity in cultivated soils and moderate salinity in reference soils. Total limestone measurements confirmed a strongly calcareous character across all sites, accompanied by low organic matter content. The coefficient of variation highlighted minimal spatial variability in organic matter content but significant fluctuations in EC and total limestone values across study sites.

Overall, these findings underscore the profound impact of agricultural practices on soil characteristics in both Ourlal and El Outaya, emphasizing the necessity for improved management strategies to ensure the long-term sustainability of farming systems in irrigated regions. By leveraging geostatistical techniques and interdisciplinary insights, future endeavors can further elucidate the intricate dynamics shaping soil quality, paving the way for more informed decision-making and sustainable agricultural practices in challenging environments like the Algerian Sahara.

key word : Algerian sahara , Cereal cultivation, Geostatistical techniques, Pivot irrigation system , Sustainability .

الملخص

يتطلب تقييم استدامة أنظمة الإنتاج الزراعي في المناطق المروية فحصًا دقيقًا لجودة التربة، لا سيما في المناطق المزروعة بالحبوب في ظل أنظمة الري المحوري. تبحث هذه الدراسة في الديناميكيات المكانية المعقدة لخصائص التربة في منطقتين متميزتين: أورلال ولوطايا ، وكلاهما يقع في بسكرة، الجزائر. من خلال أخذ العينات والتحليل المنهجي الذي يمتد لأربع سنوات من زراعة الحبوب، قمنا بتقييم المعلمات الرئيسية بدقة بما في ذلك جودة مياه الري، وقياس الحبيبات، ودرجة الحموضة، والتوصيل الكهربائي (EC)، والمواد العضوية (إجمالي OM)، وما يعادلها من كربونات الكالسيوم (الحجر الجيري).

في أورلال، كشف تحليل قياس الحبيبات عن هيمنة التربة الطميية الرملية، حيث تتراوح قيم الأس الهيدروجيني من القلوية المعتدلة في التربة المزروعة إلى القلوية قليلاً في التربة المرجعية. ولوحظت مستويات ملوحة ملحوظة في مياه الري، حيث تشير قيم التوصيلية الكهربائية إلى مستويات ملوحة عالية في التربة المزروعة وملوحة معتدلة في التربة المرجعية كما تشير قياسات الحجر الجيري الإجمالية إلى وجود طابع كلسي قوي في جميع المواقع ذات المحتوى المنخفض من المواد العضوية. أوضحت نمذجة الفاريوقرام الأنماط الغوسية والأسية للأس الهيدروجيني والناقلية الكهربائية ، على التوالي، مما يؤكد التباين المكاني المعقد لهذه المعلمات داخل المواقع المزروعة.

وبالمثل، في لوطايا، أظهر تحليل قياس الحبيبات هيمنة التربة الطميية الرملية، حيث أظهرت قيم الاس الهيدروجيني نطاقًا مماثلاً كما هو الحال في أورلال. وكانت مستويات الملوحة في مياه الري ملحوظة أيضًا، حيث تشير قيم الناقلية الكهربائية إلى ارتفاع الملوحة في التربة المزروعة والملوحة المعتدلة في التربة المرجعية. أكدت قياسات الحجر الجيري الكلي وجود طابع كلسي قوي في جميع المواقع، مصحوبًا بمحتوى منخفض من المواد العضوية كما أبرز معامل التباين الحد الأدنى من التباين المكاني في محتوى المادة العضوية ولكن تقلبات كبيرة في الناقلية الكهربائية وقيم الحجر الجيري الإجمالية عبر مواقع الدراسة.

بشكل عام، تؤكد هذه النتائج على التأثير العميق للممارسات الزراعية على خصائص التربة في كل من أورلال ولوطايا، مما يؤكد ضرورة تحسين استراتيجيات الإدارة لضمان الاستدامة طويلة المدى لأنظمة الزراعة في المناطق المروية. ومن خلال الاستفادة من التقنيات الإحصائية الجغرافية والرؤى متعددة التخصصات.

الكلمات الرئيسية :الصحراء الجزائرية، زراعة الحبوب، تقنيات الجيوإحصاء، نظام الري المحوري، الاستدامة

INTRODUCTION

Introduction

Understanding the diverse spatial nature of soil characteristics is crucial for the sustainability of agricultural practices, as emphasized by numerous studies (Castaldi et al., 2016; Denton et al., 2017; Biswas and Zhang, 2018). Arid regions, in particular, present distinctive traits such as elevated levels of soluble salts, gypsum, and carbonates, posing significant challenges to agricultural productivity. Consequently, assessing soil in arid regions becomes paramount to determine their vulnerability to desertification, land degradation, and their potential suitability for agriculture (Weindorf et al., 2016). Thus, access to soil information becomes indispensable in making informed decisions regarding the management of arid lands. It is noteworthy that spatial variations in soil properties are collectively influenced by factors such as climate, time, parent material, topography, vegetation, and human activities (Umali et al., 2012; Lin et al., 2016; Rodrigo-Comino et al., 2019).

Historically, irrigation agriculture played a pivotal role in ensuring food security for billions of people in arid and semi-arid regions. However, the current state and future prospects of these regions are less promising due to low crop yields and land degradation (Mason, 2002). Unfortunately, the concept of integrated catchment management in dryland areas is often overlooked during agricultural development expansions. Soil productivity is increasingly compromised by unfavorable drainage conditions, improper farming systems, and inappropriate irrigation practices, leading to widespread waterlogging. Consequently, insufficient information about soil characteristics and inadequate soil, irrigation, and drainage management have accelerated land degradation (Khouri, 2003).

The imperative to ensure food security in Algeria's arid northern landscapes, marked by growing populations, declining agricultural productivity, and scarce rainfall, has spurred the exploration of innovative irrigation methods (Piri and Naserin, 2020). Among these innovations, the pivot irrigation system, recently introduced to the Algerian Sahara (Benbrahim, 2018), shows promise. However, effective water and nutrient management in arid regions hinges on a nuanced understanding of soil property distribution under pivot irrigation (Guo and Wang, 2021). This irrigation method evenly distributes water across a circular area, inevitably leading to variations in soil properties. These attributes, encompassing texture, structure, organic matter content, and water-holding capacity, play a crucial role in regulating water and nutrient movement within the soil, thereby significantly impacting crop growth and yield (Guo and Wang, 2021).

Recognizing the importance of pinpointing the spatial distribution of soil properties for tailored irrigation and fertilization strategies (Munjiza and Delic, 2018), techniques such as soil sampling, analysis, and the use of geostatistical approaches have shifted from being optional to essential. Surprisingly, Algeria lags in comprehensive research on the spatial variability of soil properties, particularly in employing geostatistical methods for data interpretation. This study, therefore, undertakes the ambitious goal of evaluating cereal soil properties within the scope of a pivot irrigation system in the Algerian Sahara. Its primary objectives include deciphering the impact of irrigation on soil attributes and understanding how these attributes exhibit spatial variability. This deeper comprehension is a crucial step toward developing effective strategies for managing soil and water resources in arid regions, ultimately leading to increased crop yields (Djenadi et al., 2016).

In the context of increasing global food demands, agriculture's role becomes more significant. However, arid regions like the Algerian Sahara pose formidable challenges due to limited water resources and poor soil quality (Asadi et al., 2020; Hammoudi et al., 2017). Farmers in these areas have adopted the pivot irrigation system as a prudent water-saving approach (Benmamar et al., 2015; Mebarki et al., 2019). Yet, this transition comes at a cost—

alterations in soil properties leading to shifts in salinity and alkalinity levels that adversely affect crop growth and overall soil health (Mokhtari et al., 2019; Hakim et al., 2019). In the heart of Algeria's Biskra region, cereal cultivation holds a significant position, ranking second only to the cultivation of date palms (Phoenix dactylifera L.) (Chadouli, 1991; Kellil, 2010). Despite earnest efforts, cereal yields in Algeria continue to underperform and remain uncertain, ranging from 7 to 15 quintals per hectare depending on the year (where 1 quintal equals 100 kg) (Selmi, 2000; Bessaoud et al., 2019). This lackluster performance can be attributed to adverse pedoclimatic conditions and an inadequate understanding of cultivation techniques, particularly under the ambit of pivot irrigation systems (Hakim et al., 2019).

Wheat, a staple crop in various pockets of Ourlal and El Outaya Biskra, faces its own challenges due to disparities in soil quality within these regions. Variations in pH, limestone composition, electric conductivity, and organic matter content significantly impact crop yields and complicate crop management for farmers (Khanchou et al., 2020; Rachid et al., 2018). Addressing these concerns, geostatistical techniques have assumed a central role. Techniques such as creating interpolation maps through GIS, working with ordinary kriging semi-variograms, and employing statistical analyses have become indispensable for understanding the spatial variability of soil properties and tracking transformations in cereal lands governed by pivot irrigation systems (Hakim et al., 2019). The adoption of geostatistical tools empowers farmers to closely monitor soil properties, identify potential challenges, and make well-informed decisions regarding soil management practices. At its core, this study aims to explore the intricacies of agricultural soil properties in the arid region case of Ourlal and El Outaya region (Algeria). Through a meticulous examination of the effects of pivot irrigation and an investigation into the spatial variability of soil attributes, this study seeks to shed light on the effectiveness of geostatistical techniques in unraveling the dynamic shifts occurring in cereal lands managed by pivot irrigation systems.

This deeper understanding is pivotal for crafting effective strategies for prudent soil and water resource management, ultimately culminating in increased crop yields in these challenging arid landscapes.

Our work will aim to:

- Characterize the spatial variation of several soil properties, including salinity, soil reaction, and total limestone.
- Estimate the intensity of the evolution of these properties through the analysis of annual variation rates (AVRs) and consequently assess the variations caused by agricultural intensification on the studied parameters.

This thesis consists of two parts:

- The first part will cover the materials and methods used for carrying out this work.
- The second part will discuss the results.

THE FIRST PART

BIBLIOGRAPHIC SYNTHESIS

CHAPTER 01:

GENERAL OVERVIEW OF CEREAL CULTIVATION

Chapter 01: General overview of cereal cultivation

1.1. Cereal farming in Algeria

Grains are the staple food in most countries southern Mediterranean. They are therefore considered to be strategic in the food security of populations (Lemeilleur et al., 2009). In Algeria, cereal farming plays a main role in the national economy, it occupies the first place in strategic crops, it is practiced by the majority of farmers. According to statistics from the Ministry of Agriculture, the general agricultural census (RGA) in 2013 gives us around 600,000 cereal growers, i.e. nearly 60% of all agricultural holdings, regardless of fallow. According to the FAOSTAT database (2015), the area occupied by cereals is 8.5 million ha. This agricultural area is very narrow compared to the total area of Algeria which amounts to 238 million hectares of which 191 million are unproductive.

1.2. Agro-ecological requirements and constraints

There are many constraints in cereal farming, including water scarcity, land degradation and climate change.

1.2.1. The water shortage

Water resources are a major concern for Algeria which is a country mostly arid and semi-arid (Rahal-Bouziane, 2018). According to the general management of forests (2003), Algeria is classified among the countries that are below the scarcity threshold of water availability, internationally fixed at 1000 m3 / year / inhabitant. Drought often delays the developmental stages of the plant because of inhibition of growth by water deficit (Blum, 1996 in Hargas, 2007). When the Water deficit appears during the period of herbaceous tillering, the rate of release of tillers decreases and if the deficit increases severely, tillering stops. During the assembly, and especially during the first weeks of the run, water stress greatly accentuates noticeably the rate of tiller regression (Gate, 1995). According to Slafer et al (2005), below the 400 mm isohyet, the production of grain becomes haphazard, as water becomes the main limiting factor. The cereal water requirements are between 450 and 650 mm (Adjabi, 2011). The most critical period vis-à-vis the lack of water is between the 20 days preceding heading until the end of the water level (Bouthiba et al., 2006).

The water deficit is to be feared from the month of May, from which the rains are rare and increasingly high temperatures causing an increase in the demand for water on the part of the plant at a critical phase where the yield is determined (Chennafi et al. al., 2008). The water deficit also influences the average grain weight and shortens the grain filling time (Wardlaw and Moncur, 1995).

1.2.2. Land degradation

Land degradation is in turn defined as the reduction or reduction of loss of biological or economic productivity in drylands (EM, 2005), where the desertification plays a major role in this phenomenon, According to Moulai (2008), Algeria is one of the countries most affected by desertification. With nearly 20 million hectares of steppe routes and 12 million hectares of pre-Saharan rangelands located in semi-arid to arid bioclimatic stage, Algeria thus loses a few thousand hectares every year.

1.2.3. Climate change

In the Maghreb, climate change will lead to a reduction in the availability of water for rainfed and irrigated agriculture caused by the conjunction of three aspects: increased evaporation and evapotranspiration, the likely reduction in precipitation and the increase in its variability and the rise in sea level in relation to with coastal groundwater (Rousset and Arrus, 2004). According to Aziza (2006), Algeria is considered vulnerable to the effects of climate change, it is part of the semi-arid and arid zones exposed to chronic droughts. She anticipates an average reduction in cereal yields of 10% by 2020. Vegetable production will also be strongly affected by the climate change in Algeria, the productivity of which would decrease by 15 to 30% by 2030 (Bindi and Moriondo, 2005 in: Rousset, 2007)

1.3. National production

The cereal production system in Algeria takes the form of small family farms where the average size of each is 6.8 hectares. The means of production without much imitation, especially during the period from 1962 to 1990. Cereal farming occupies an average of 3.4 million hectares each year, of which around 2 million hectares are occupied by wheat. In addition, the cultivation of cereals continues to be associated with fallow (3.2 million hectares on average) in the majority of farms (Hamadache, 2011). (Fig01)

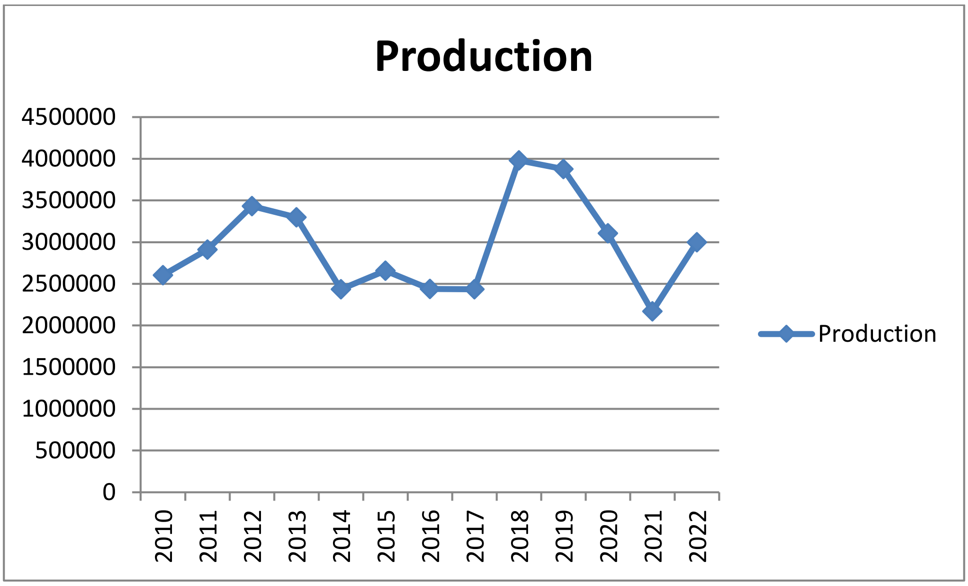


Figure 1: Evolution of Wheat production in Algeria 2010-2022 (Source: FAO, 2024).

Cereal production in Algeria is influenced by several factors, among which climatic hazards which are the key factor in determining profitability from production. This strong correlation between climatic conditions and production causes a very large irregularity in grain yields from year to year other. Indeed, over the last 30 years, we have recorded a difference of 1 to 5 between a disastrous year (9.7 million Qx in 1994) and a year of interesting production (52.5 million Qx in 2009) (figure 02). According to figures from the Minister of Agriculture cited by the official agency (APS, 2016), the national production of cereals (barley, oats, durum wheat and common wheat) fell to 34.750 million quintals during the 2015/2016 season when the rate estimated profitability is 16 quintals per hectare. It was 40 million quintals in 2014/2015, 35 million quintals in 2013/2014 and 49.1 million quintals in 2012/2013. For example, the production for the 2015/2016 season is broken down as follows:

• wheat, 25 million quintals including 5 million quintals soft wheat.

• barley, 09 million quintals.

• oats, 750,000 quintals. Generally.

Durum wheat is the crop best suited to the agro-climatic conditions of Algeria (Rastoin and Benabderrazik, 2014). It remains the predominant product in Due to its high consumption by the inhabitants, the production is estimated at 80% of the total wheat production for the case of the 2015/2016 campaign. Moreover, the average of durum wheat production during the period 2009-2015 is estimated at 21 million quintals against 13.5 million quintals during the 2000-2008 campaign. This product is considered as the basis of food for the Algerian population with consumption average per capital of 230 kg in 2009. In Egypt it is 131 kg / inhabitant / year, in France it is estimated at 98 kg / inhabitant / year (Hervieu et al., 2006). From a nutritional point of view, wheat represents on average an equivalent intake of 1505.5 kcal / person / day, 45.533 grs of protein / person / day and 5.43 grams of lipid / person / day (Djermoun, 2009)

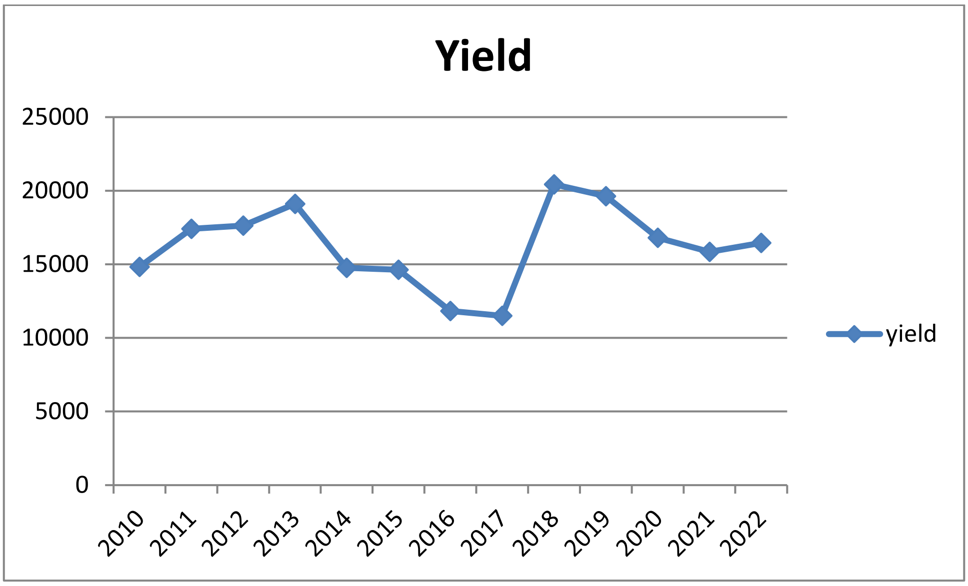


Figure 2: Evolution of Wheat yield in Algeria 2010-2022 (Source: FAO, 2024).

Despite the application of several programs to develop the agricultural sector by Algeria, in particular the national agricultural and rural development plan (PNDAR) in 2001/2002, cereal yields are still low and very irregular: 13.5 q / ha for wheat and 13.2 for barley during the period 2001-2010. These results place us very far behind the productivity of Mediterranean countries, the Magreb and Europe. This observation may be explained by various constraints such as environmental conditions (soil and climate), technical (seeds, cultivation practices) or human (organization and training of producers).

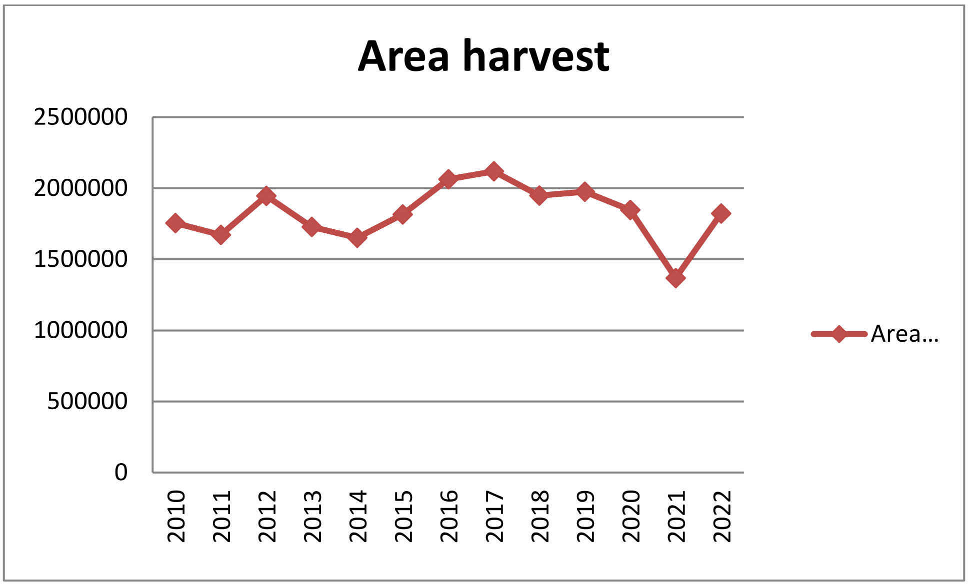


Figure 3: Evolution of areas used for wheat in Algeria 2010-2022. (Source FAO, 2024).

1.4. Challenges and prospects of the cereal sector in Algeria

The increase in cereal production in Algeria was the result of a policy of technical and economic supervision, as well as the climatic conditions favorable in the main cereal regions. In other words, agriculture remains largely dependent on rainfall. System development policy irrigation scheme launched by the Ministry of Agriculture and Rural Development and fishing is important and necessary in order to develop this strategic sector. This option is considered the best suited to secure production without forgetting the research and development efforts to improve performance technical. Indeed, the context of the cereal production security program by irrigation, launched in 2008-2009 at the level of 13 wilayas before its generalization to 43 wilayas begins to bear these fruits (FCE, 2019). As part of the "agricultural and rural renewal" program, launched in 2010 by the Ministry of Agriculture and Rural Development (Anonymous, 2012). According to the Algerian French CCI (2016), the government aims to reach 600,000 hectares of perimeters irrigated for the cereals sector by the 2019 deadline. data to operators, in stitutions and organizations in the sector to start the implementation of this action plan. In this context, agreements have been signed between the Algerian Office Interprofessional of Cereals (OAIC), the National Agricultural Mutual Fund (CNMA), the Technical Institute of Field Crops (ITCG) and the National Institute of Soils, Irrigation and of drainage (INSID) in order to contribute each in his field to the achievement of this In addition, and to encourage the irrigation system, the Algerian state grants cereal producers 50% financial support for the acquisition of equipment and facilities in the form of Ettahaddi-type credit. As part of the intensification of cereal production, the OCI is working on currently ensuring the consolidation of the mechanization of agriculture, the improvement of seeds and fertilizer availability.

1.5. Cereal growing in the Biskra region

The region of Biskra has been known since Roman times as the breadbasket of Europe in grains and other products. Only during the reign of the Turks and the French, we note that phoeniciculture has grown to the detriment of other crops in the Zabans due to its market value. Cereal cultivation has long been practiced on the spreading of wadis floods in the Biskra region during the rainy periods, hundreds of hectares will be plowed each year either:

- By breeders to supplement their herds with fodder and self-consumption.
- By sedentary people for the encouragement of family breeding and self-consumption. Cereal cultivation is concentrated in the eastern Ziban of Biskra, especially in the municipalities of El-Outaya, Sidi Okba, El-Haouch, Aïn-Naga, M'ziraâ, Faïdh, and Zeribet El Oued. (Fig. 04)

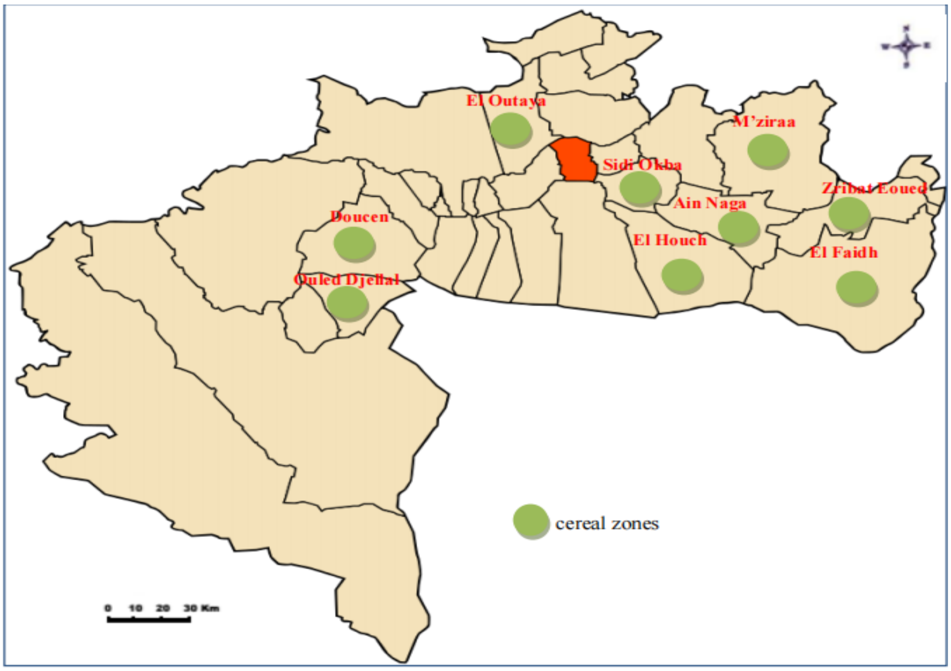


Figure 4: Main cereal areas in Biskra region.(Bakroune. 2021)

1.6. Cereal production

El Outaya Sidi Okba Ain Naga M'ziraa Zribat Eoued El Faidh El Houch Doucen Ouled Djellal cereal zones The wilaya of Biskra has a total agricultural area (SAT) of 1.65 million hectares and a useful agricultural area (UAA) of 185,473 hectares, of which nearly 104,000 irrigated hectares, where cereal cultivation occupies an area of (31,360 hectares) distribute according to the cereal zones. During the 2016/2017 campaign, the area devoted to cereals covers 28,239 hectares including 11,491 hectares reserved for durum wheat, 10,494 hectares for soft wheat, 5.204 ha for barley and 50 ha for oats (Fig.5)

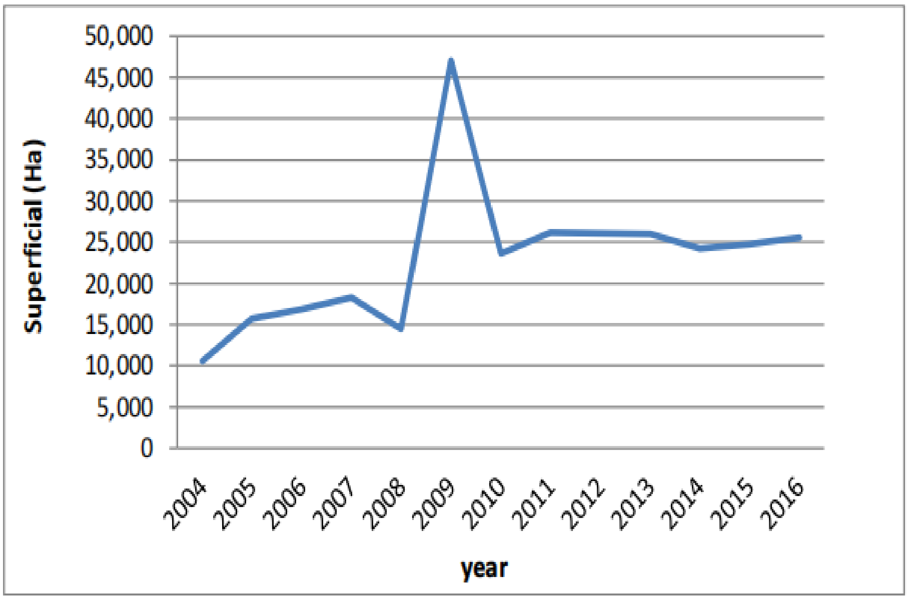


Figure 5: Evolution of the areas used for cereals in Biskra 2004-2016. (Source: D.S.A de Biskra, 2017).

The increase in production is explained by the doubling of cultivated areas, while yields only increased by 14%. Areas devoted to production cereals increased sharply as a result of the conquest of new areas of production, in particular the creation of fifteen (15) new agricultural perimeters totaling an area of 26,900 hectares in the wilaya of Biskra in order to promote large investments (DSA, 2017)

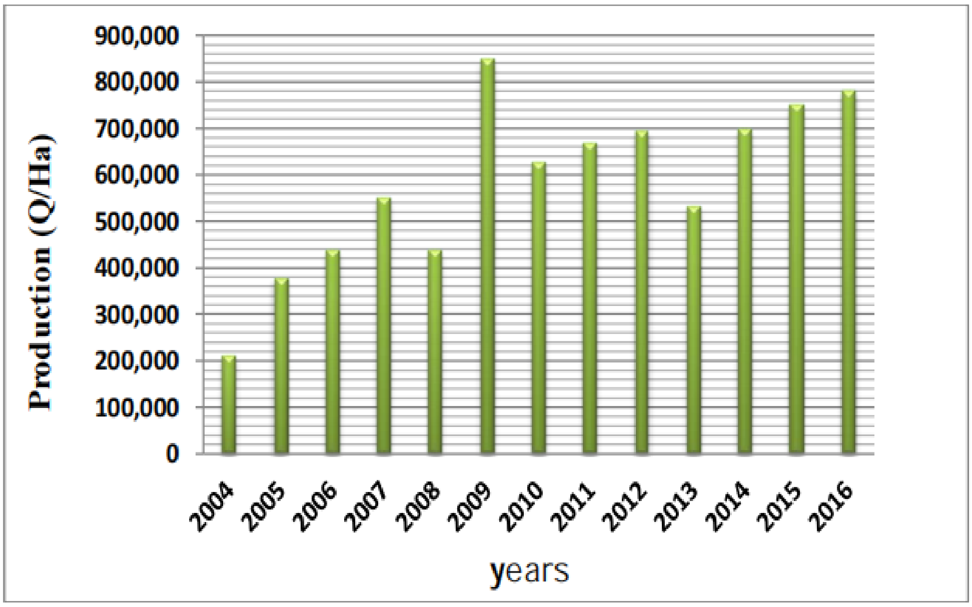


Figure 6: Evolution of cereal production in Biskra 2004-2016. (D.S.A de Biskra, 2017).

CHAPTER 02: Presentation of the study region

Chapter 02: Presentation of the study region

In this chapter, we will deal with the characteristics of the Biskra region, particularly its geographical location and the edaphic, climatic and biological.

2.1. Geographical location and limits of the Biskra region

The Biskra region is located in the South-East of Algeria, at the gates of the Algerian Sahara, in the eastern part of the northern Sahara. It is located at an altitude of 124m, its latitude is 34.48 ° N and a longitude of 05.44 ° E. It is limited to the north by the wilaya of Batna, to North-east by that of M'Sila, to the south by the wilaya of El-Oued and to the southwest by the wilaya of Djelfa (Figure 07). It covers an area of 216712Km².

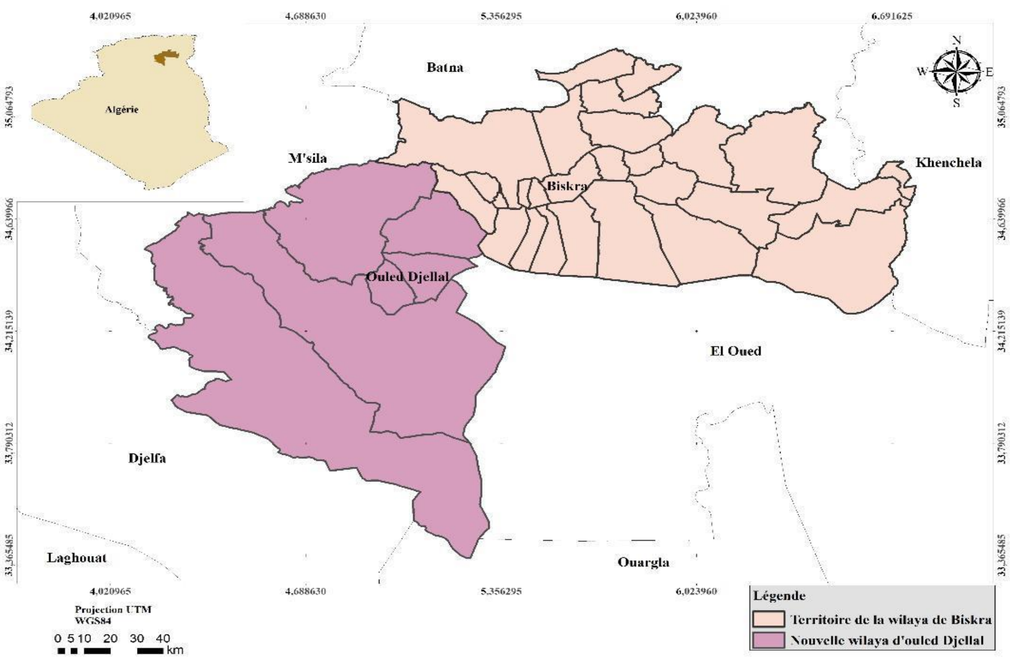


Figure 7: Map of the Biskra region.

2.1.1. Edaphic data

The wilaya of Biskra constitutes the transition between the folded Atlas domains of the North and the flat desert expanses of the Sahara to the South. We go from fairly high relief high and rugged in the north with a plateau topography slightly inclined towards the south.The relief of the wilaya of Biskra is made up of four major geomorphological groups.

- **The mountains:** Located to the north of the wilaya, they are generally bare of any natural vegetation, the highest point is Jebel Taktiout at an altitude of 1924 m
- **The plateaus:** Located largely in the west of the wilaya, they extend over a area of 1,210,848 hectares (or 56% of the area of the wilaya). the vegetation of the plateaus is meager constituted of the privileged sites of course.
- **The plains**: They extend in the East - West axis of the wilaya of Biskra, and cover the almost all of the Daïra of El-Outaya and Sidi-Okba and the commune of Doucen.
- **The depressions:** Are located in the South-East of the wilaya, they constitute a plate where form very thin water tables thus constituting the chotts, the most important of which is the chott Melghir whose level can reach minus 33m below the sea .

2.1.2. Ground

The morphoanalytical study of soils in the Biskra region shows the existence of several types of soil. According to soil studies carried out by Khachai (2001), soils have the following characteristics:

- The southern regions are mainly characterized by salt and gypsum accumulations and limestone.
- The eastern regions are defined by alluvial soils and fertile clay soils.
- The northern areas (or mountain areas) are the site of low soil formation evolved and not very fertile.
- The plain located northwest of Biskra is characterized by clay

– sodic soils irrigated by strongly mineralized waters constitute the character of the pedogenesis of this region.

2.2. Climatic characteristics

According to Lévêque (2001) and Faurie and al (2003), climatic conditions have a great importance on the control and distribution of living beings and the dynamics of ecosystems.

The reactions of living beings to variations in physical and chemical factors of the environment are concerned with morphology, physiology and behavior (Dajoz, 2003). The Saharan climate is characterized in particular by the weakness and irregularity of precipitation, intense light, high evaporation and large temperature variations (Ozenda, 1991). In order to characterize the climate of the study region, we have used climatic data from the National Meteorological Office (NWO) of the wilaya of Biskra.

2.2.1. Temperature

The Biskra region is subject to the thermal influence of deserts which present very high temperatures and large thermal differences due to the purity of their atmosphere and often also their continental position (Ozenda, 1983). monthly averages, maximums and minimums for the decade 2000 to 2023 in the Biskra region are shown in table **01**

Table 1: Monthly average temperatures of the Biskra region during the period 1989-2023 NWO

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	A-a
Max temperature	**17**	**19.1**	**22.85**	**26.8**	**32.4**	**37.5**	**40.8**	**40**	**34.7**	**29**	**22.2**	**17.9**	**28.4**

Min temperature	**6.8**	**8.2**	**11.5**	**15.2**	**20**	**24.4**	**27.9**	**27.7**	**23.4**	**18.2**	**12**	**8.1**	**17**
Medeame temperature	**12**	**13.8**	**17.4**	**20.7**	**26.2**	**31.1**	**34.4**	**33.8**	**28.9**	**23.6**	**17.1**	**13**	**22.7**

A-a: Annual average

Temperature is the second factor after precipitation that conditions the climate of a region (Laib, 2014). The Biskra region is characterized by high temperatures that can reach an annual average of 22.7 ° C. The hottest months during the period (1989- 2023) are June, July and August with a monthly average of 31.1 ° C respectively, 34.4 ° C and 33.8 ° C. The coldest months are December with 13 ° C, the month of January with 12 ° C and the month of February with 13.8 ° C. By way of illustration, Table N   shows monthly average temperatures in the Biskra area.

Table 2: Average monthly wind speed in the Biskra region during the period 1989-2023 (NWO).

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Wind speed	4	4.6	4.9	5.5	5.2	4.6	4	3.7	3.9	3.8	4	3.7

The maximum wind speed was recorded during the month of April with an average of 5.5m / s. On the other hand, the minimum was raised in August and December with 3.7 m / s.

2.2.2. The precipitations

Rainfall remains the most important element on the planet, it constitutes a essential and fundamental ecological factor for the functioning and distribution of terrestrial ecosystems (Ramade, 1984). The Biskra region is characterized by a very low rainfall, varying between 0 and 200 mm per year. The rains fall irregularly and can sometimes be torrential (Fig. 08).

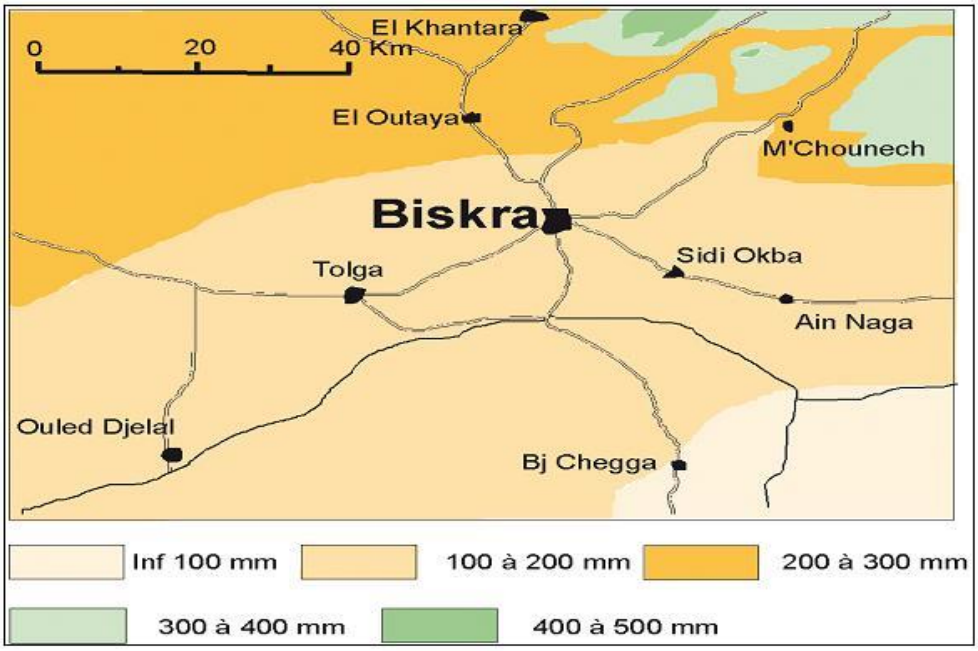


Figure 8: Rainfall distribution map, Biskra region (Extract from the rainfall map of Algeria at 1 / 1500,000, 1971).

Table 3: Average monthly precipitation in the Biskra region during the period 1989-2023 (NWO).

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
precipitatuion	**20.6**	**12.1**	**13.9**	**16.1**	**11.3**	**7.9**	**1.7**	**4.3**	**15.9**	**17.1**	**16**	**13.9**

It appears from table N ° 01 that the total annual precipitation in the region of Biskra is very low and characterized by a remarkable irregularity with maximum drought which was recorded during the month of July with a rainfall of 1.7 mm on the other hand during the wettest month (October), it is 17.1 mm.

2.3. Climate synthesis

The climatic synthesis consists in determining the dry period and the wet period by means of the Gaussen ombrothermic diagram as well as the bioclimatic stage of study regions thanks to the pluviothermal climagramme of Emberger.

2.3.1. Gaussen temperature diagram

GAUSSEN's ombrothermal diagram highlights the notion of wet and dry seasons. Figure ... shows the months on the x-axis and the temperatures (T) and precipitation (P) on the y-axis with a double scale for the former where P = 2 T. GAUSSEN considers that there is a drought when the monthly rainfall expressed in millimeters are less than twice the monthly average temperature expressed in degrees Celsius (Dajoz, 1971).

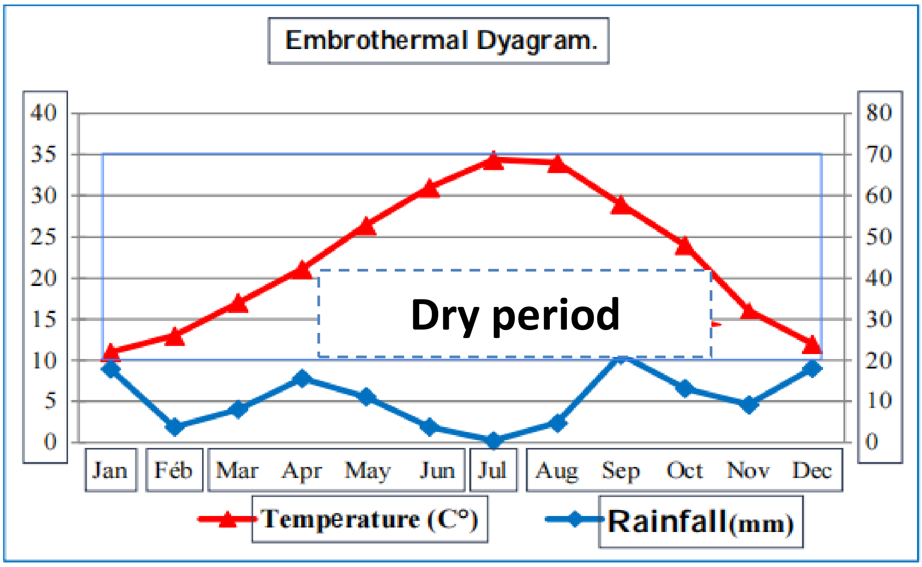


Figure 9: Gaussen's shadow diagram of the Biskra region during the period 2000-2022.

Analysis of the figure tells us that the dry period in the Biskra region during the period 2000 to 2016 lasts almost throughout the year, it is more accentuated in summer.

2.3.2. Emberger climagram Emberger's rainfall

Quotient formula has been modified by STEWART (1969), it is calculated as follows: Q = 3.43 x P / M - m

- P is the annual precipitation in mm.
- M is the average of the maximum temperatures of the hottest month.
- m is the average of the minimum temperatures of the coldest month.

For a bioclimatic approach of the region of Biskra during the period from 2000 to 2010, the values of this quotient are of the order of 11.3 where P is equal at 116.89 mm; My 41.28 ° C and m at 5.81 ° C.

By relating this value to Emberger's climagram (Figure ..), we find that the Biskra region is located in the Saharan bioclimatic stage in winter Embrothermal Dyagram. Temperature (C

°) Rainfall (mm) drty period temperate and characterized by low precipitation, high temperatures, high brightness and intense evaporation.

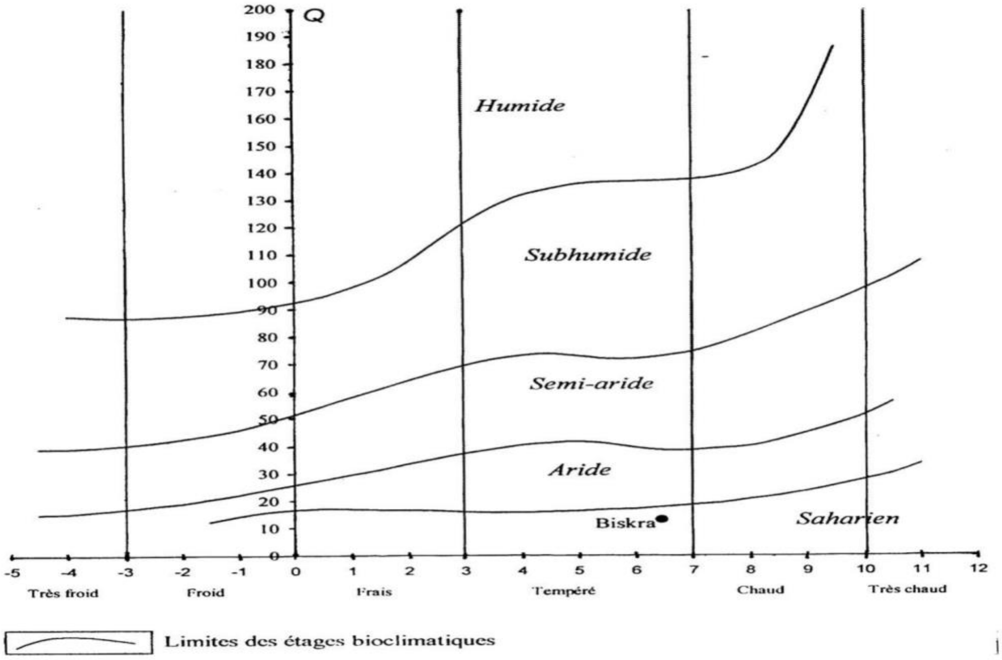


Figure 10: Location of the Biskra region on the Emberger climagram

2.4. Water resources

The Wilaya of Biskra, located in a pivotal area between the Tell and the Sahara, enjoys on the plan water with a double advantage: surface water from the north (Aures, Tellian Atlas) which cover almost the entire territory of the wilaya (Oued Biskra, Oued Djeddi, Oued El Arab, Oued Al Abiod), and the underground waters of the northern Sahara (CI-CT) in addition to the water table. (DRE BISKRA, 2014)

2.5. Quality of water intended for irrigation

The salinity of soil and water is the major problem in many countries around the world. According to DUBOST (1994) cited by MASMOUDI (2012), in the Sahara waters containing less than 0.5g of salts can be considered exceptional and those of less than 1g perfect for human consumption. Up to 2g this is quality irrigation water

excellent for irrigation. Between 2 and 5g, this is salt water and above 5g you can say they are very salty. Their effect on soil and plants is all the more harmful as their use is poorly studied. On the other hand, the demand for fresh water is constantly increasing for different competitive uses (domestic, agriculture, industry) which creates a crucial need use of salt water in agriculture (MASMOUDI, 2012) Resorting to the use of salt water is becoming more and more of an absolute necessity given the absence or scarcity of freshwater resources in certain regions (MASMOUDI, 2011) The lack of good quality water is now a major constraint when wants to create new irrigated perimeters (CHEVRY, 1995). Salt water will be used in addition in the future due to increased demand for irrigation water (VAN HOORN, 1991 in MASMOUDI, 2011).

2.6. General data on the wilaya's irrigation sector

2.6.1. Evolution of irrigated areas 2010/2018 (most recent)

Table 4: The change in irrigated areas 2010/2018 (Source; DSA Biskra, 2018)

Wilaya	Sup irrig 2010 (ha)	Sup irrig 2011 (ha)	Sup irrig 2012 (ha)	Sup irrig 2013 (ha)	Sup Irrig 2014 (ha)	Sup irrig 2015 (ha)	Sup irrig 2016 (ha)	Sup irrig 2017 (ha)	Sup irrig 2018 (ha)
Biskra	98433	100680	102503	104079	105920	108622	109500	111170	116964

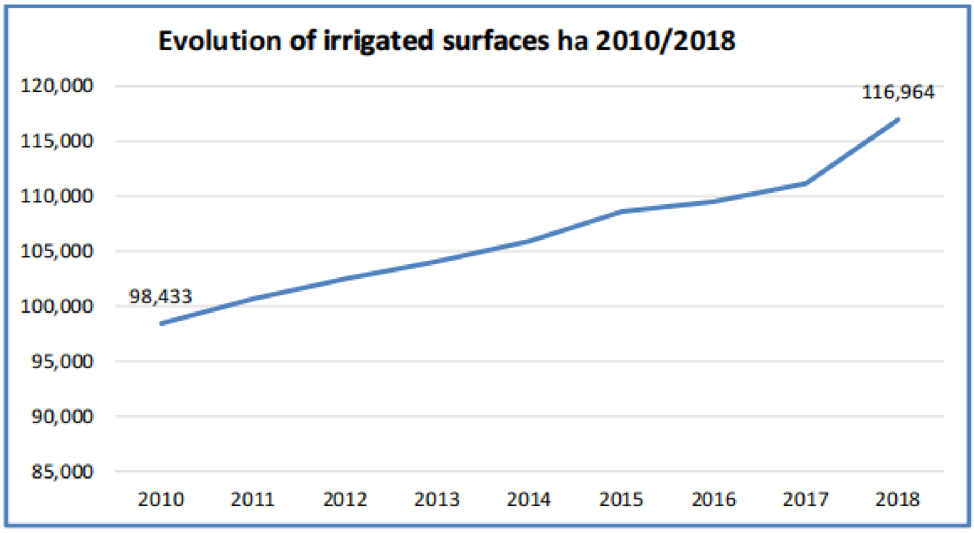


Figure 11: Representative diagram of the evolution of the irrigated area of the Wilaya of Biskra from 2010 to 2018.(Merdaci.S 2021)

2.6.2. The distribution of areas irrigated by irrigation system

Table 5: The distribution of areas irrigated by irrigation system (Source; DSA Biskra 2018)

Systèmes d'irrigation	Gravity	aspersion	pivots	drip drop	total
Superficial (ha)	59269	1565	749	55381	116 964
Pourcentage	51 %	≈ 1 %	≈ 1 %	47 %	100 %

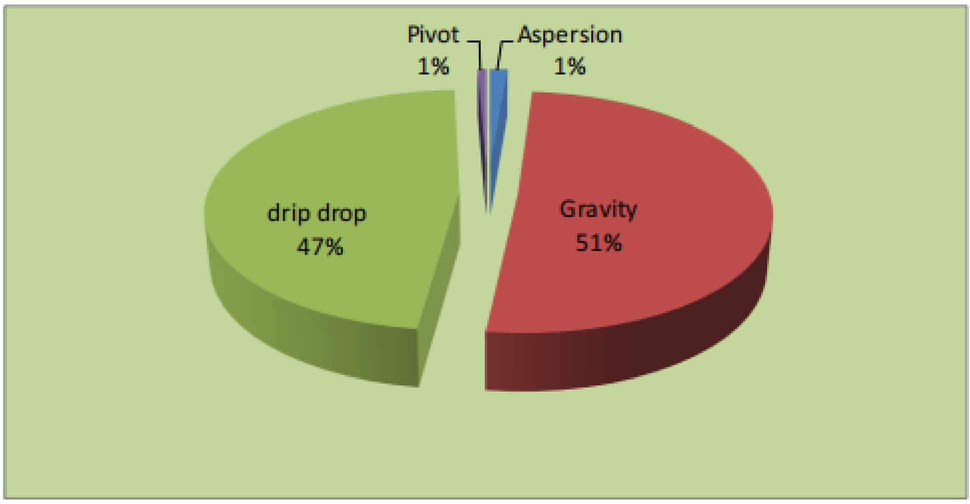


Figure 12: The distribution of IAS by irrigation system (DSA Biskra, 2018)

We notice in table N °05 and figure N °13 that the majority of land is irrigated by traditional systems (51%) and water saving systems occupy (49%) with (47%) drip, 1% sprinkling by conventional kits and (1%) by pivots. These figures confirm that irrigation in the wilaya of Biskra consumes a lot of water by referring to statistics produced by the services of the DRE which indicate that the waters intended for irrigation represent 89% of available water resources, whereas those intended for drinking water supply present 10% and 1% for industry.

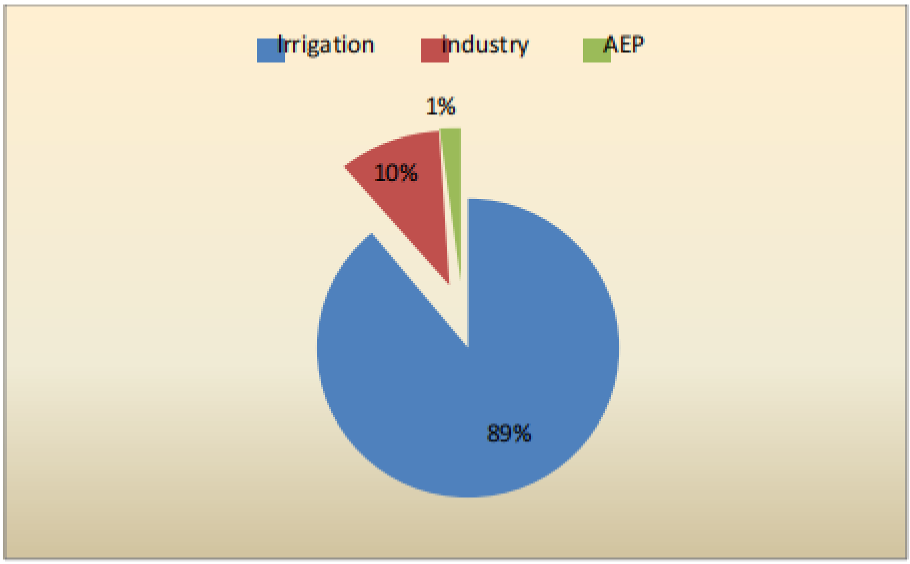


Figure 13: The distribution of water consumption by sector in the wilaya of Biskra (DRE Biskra 2016)

THE SECOND PART

PRACTICAL WORK

CHAPTER 03: MATERIAL AND METHODS

Chapter 03: Material And Methods

3.1. Methodological Approach

Soil quality is an essential element in assessing the sustainability of intensive agricultural development. Sustainable soil management can only be achieved if it maintains or improves soil and water qualities (LARSON and PIERCE, 1992). To assess soil quality, the U.S.D.A. (1999) proposed two evaluation methods:

- Periodically measuring changes or trends in soil quality over time.
- Comparing measured values to a reference soil state or natural ecosystem.

In the absence of initial soil data and studies at the start of development, we have adopted the second method by comparing measured values in pivot plots to the natural ecosystem.

The objective of this work is to evaluate the variations caused by cereal cultivation under pivot irrigation for some soil properties in the Algerian Sahara, analyzing the annual rate of variation and studying their spatial variabilities.

3.2. Selection of Study Sites

To conduct this study, we selected two stations in the Biskra region: El Outaya and Ourlal.

The stations are chosen for the following reasons:

- Four consecutive years of cultivation, a relatively satisfactory period to assess the variations caused by cereal cultivation on the soil.
- Accessibility and cooperation from the farm owner.
- Technical uniformity among selected plots, enabling comparisons between parameter evolution rates.

- Availability of a reference plot of the same size as the cultivated plots and with a similar surface appearance.

Figure 14: Geographical location of study stations

3.3. Presentation of El Outaya Study Area

3.3.1 Station 01 : Dris Amor farm

The study was conducted during august 2021 at CAZDA COSIDER company in Biskra. The experimental plots are located at “Dris Amor farm” south of the commune of El Outaya (about 5 km). The geographical coordinates of thesite are: •X=34°58057 ' N , Y=005°36 939'E, the data projection is GCS-WGS 1984.The site is divided into 27 pivots with the surface of 20.5 Ha for each. These were planted with wheat since 2018,Three pivots were chosen for the work .

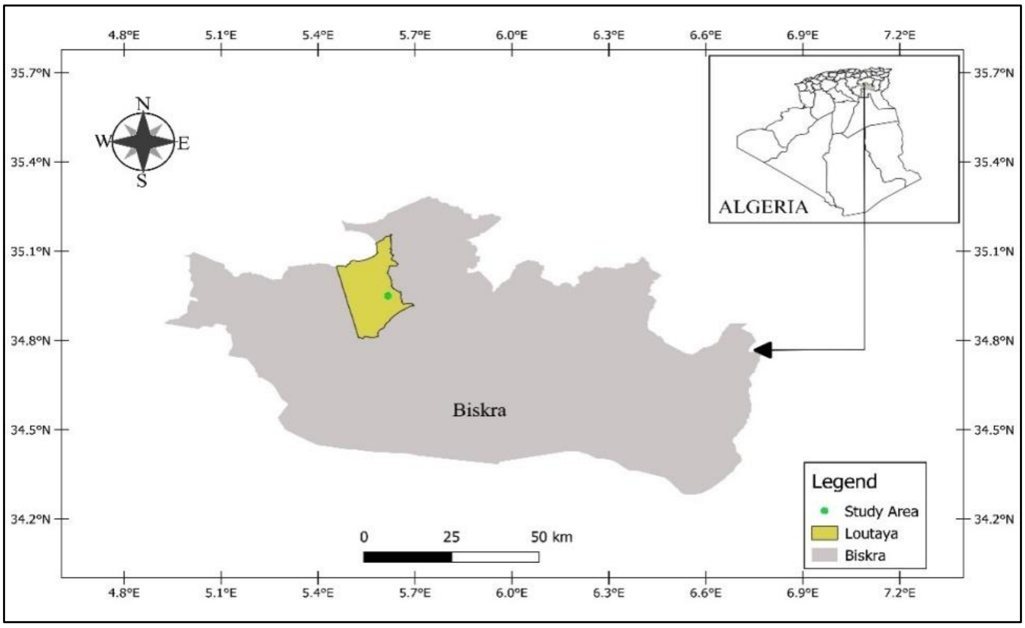


Figure 15: Presentation of the study region and sampling method (El Outaya).

El Outaya is located in the northern Sahara Desert. According to the Köppen-Geiger climate classification system.The weather is very hot and dry, characterized by two seasons: a hot and dry season (from April to September) and a moderate season (from October to March) (Hamel et al., 2022) with extreme heat during the summer months of July and August.

Summer daytime temperatures can reach or exceed 45 °C. During the winter, temperatures can drop to around 5-10 °C at night, with daytime temperatures ranging from 18-22 °C.

The humidity in El Outaya is very low, typically ranging between 10 % and 20%.Throughout the year, rainfall is scarce, with an annual precipitation average of less than 100 mm (Climate-Data.org). it is also characterized by hot and dry winds, with sandstorms and dust storms on occasion(Gaouaoui et al., 2017). Because of the extreme temperatures, low humidity, and lack of rainfall, the climate in El Outaya is difficult for agriculture (Naorem et al., 2023). The region is known for its hot and arid desert conditions, as well as its scarcity of vegetation and natural resources (Boudibi et al., 2021) .

3.3.2 .Soil samples

In order to execute the study, three specific experimental plots were meticulously chosen from within P1 and P2. These plots have been consistently utilized for wheat cultivation over a continuous span of four years. In contrast, the control plot, denoted as (T) remained devoid of any soil exploitation and can be categorized as undisturbed soil.

Table 6: coordinations of study site in El Outaya station .

Study site	Coordinations
Pivot 01	34.947887° 5.590486°
Pivot 02	34°56'37.86''N 5°35'50.30'' E
Reference	34°54'45.65''N 5°33'16.46''E

Sampling activities were conducted at a soil depth ranging from 0 to 30 centimeters, targeting the topsoil layer due to the sandy nature of the soil, which promotes deeper root growth. The spatial separation between each sample was fixed at 30 meters. The collected samples were preserved within labeled plastic bags, marked with the corresponding date of collection. A total of 49 soil samples were procured for each of the experimental pivots, P1 and P2. This position of points is statistically perfect. The results can be presented by all type of cartography and the geostatic exploitation is possible (Belkassem & Lemiere, 2006).

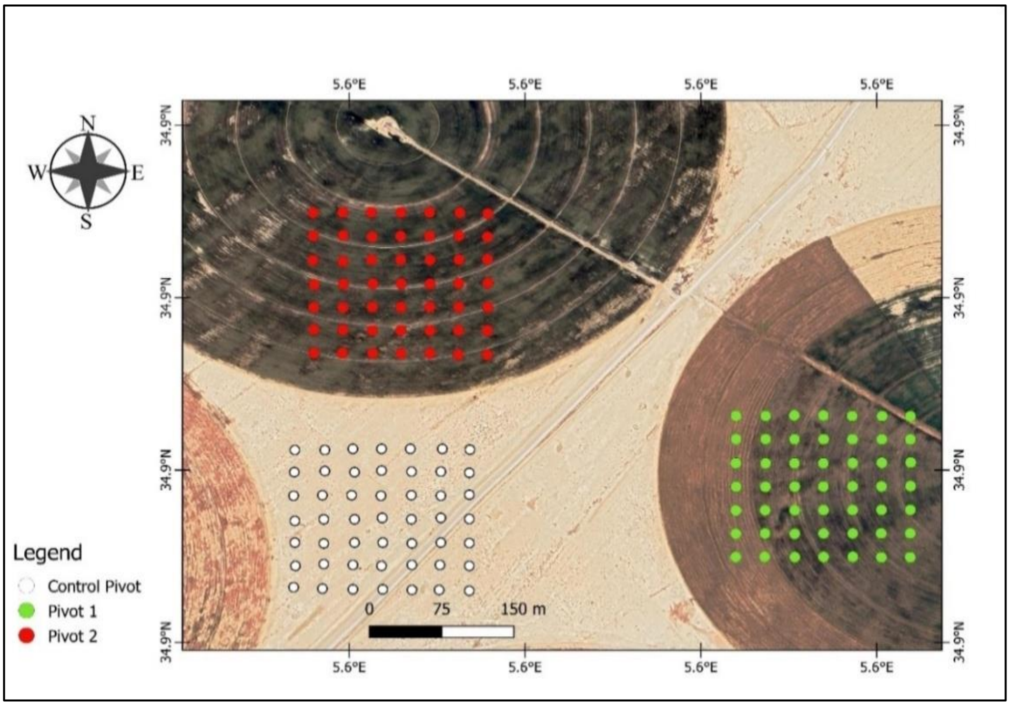


Figure 16 : Sampling method map.

3.3 Station 02 : Ourlal

The research was carried out in the southern region of Ourlal, a municipality located in the province of Biskra, northern border of Algerian Sahara (Figure 16). The specific coordinates of the study area were 34°26' North Latitude and -5°32' East Longitude. Within this region, a pivot cereal system was established, consisting of six distinct pivots with varying surface areas. Ourlal, located in an arid climate, experiences hot and dry summers, along with mild winters. According to (Boudibi, 2021), summer temperatures (June to August) can reach up to 35°C, while winter temperatures (December to February) average around 11°C . The region receives very low annual precipitation, with an average of approximately 150 mm. The months of November through January are relatively wetter compared to the rest of the year, with the majority of the year being predominantly dry (Abdennour *et al.,* 2020). Additionally, the area is prone to significant wind activity, particularly during the spring and summer seasons. These powerful winds are often accompanied by sandstorms and dust clouds caused by the influence of the hot and dry wind known as "sirocco."

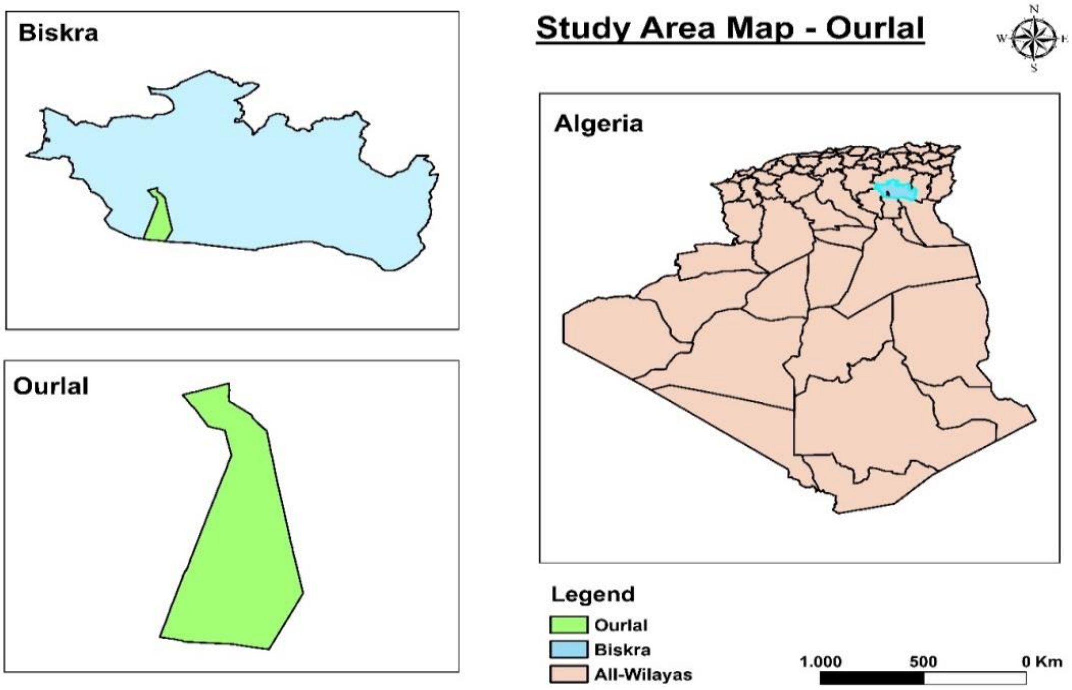


Figure 17: Location of the study region in Algeria.

Soil samples

The experimental pivots numbered P1 and P2, each covering an area of 20.5 hectares, were chosen for this study. These pivots had been dedicated to wheat cultivation since 2018. To conduct the study, three experimental plots were carefully selected within (P1 and P2). These plots had been consistently used for wheat cultivation for a period of four years. In contrast, the control plot (T) was had not undergone any soil exploitation (non-disturbed soil).

Table 7: coordinations of study site in Ourlal station .

Study site	Coordinations
Pivot 01	34°26'54.71"N 5°29'31.48"E
Pivot 02	34°26'52.74"N 5°29'56.52"E
Reference	34°26'59.33"N 5°32'41.40"E

The samples were also collected at a depth of 0-30 cm as a topsoil, because of the sandy texture of the soil that facilitates roots growth in depth, with a spatial interval of 30 m between each sample, stored using labelled plastic bags marked with the respective date. A total of 49 samples were collected for each pivot. This sampling arrangement follows a statistically optimal design.

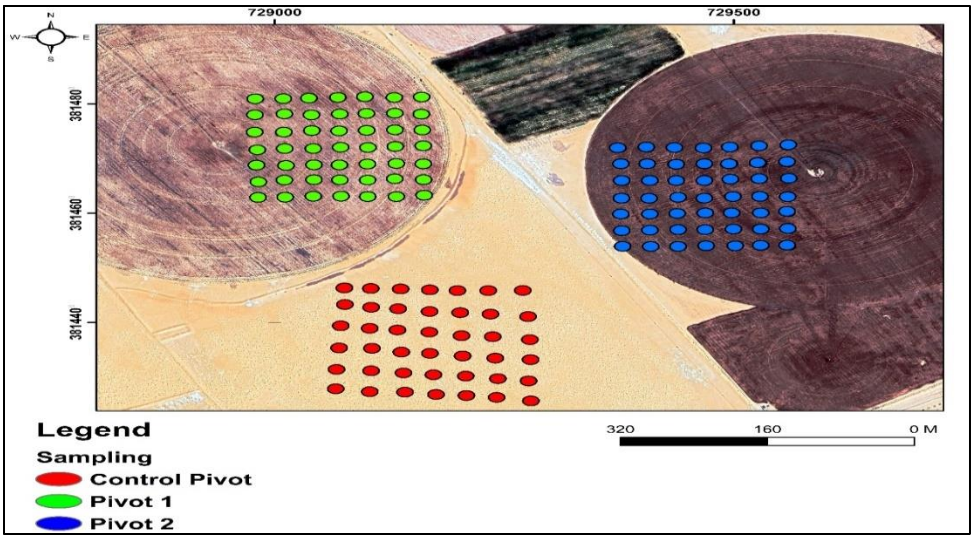


Figure 18: Soil sampling points in the study area.

3.4. Laboratory Analyses

3.4.1. Soil Analyses: Chemical Analyses of Soil

pH (Hydrogen Potential)

• pH in water (1/2.5)

Procedure

- Weigh 10 g of soil.
- Add 25 ml of distilled water to a 100 ml beaker.
- Stir for 15 minutes with a magnetic stirrer.
- Let it rest for 15 minutes.
- Measure the pH using a pH meter.

Interpretation Standard: According to the first version of the French soil reference framework in Baize 1988

pH less than 3.5 → Hyper-acidic

pH between 3.5 and 5 → Very acidic

pH between 5 and 6.5 → Acidic

pH between 6.5 and 7.5 → Neutral

pH between 7.5 and 8.7 → Basic

pH greater than 8.7 → Very basic

3.4.2. Electrical conductivity

Electrical conductivity (1/5):

Procedure:

- Weigh 10 g of soil.
- Add 50 ml of distilled water to a 100 ml beaker.
- Stir for 15 minutes using a magnetic stirrer.
- Let it rest for 15 minutes.
- Measure the EC (electrical conductivity) using a conductivity meter.
-

3.4.2.1.Organic Carbon Walkley and Black Method

Reagents:

- Potassium dichromate ($K_2Cr_2O_7$) 1N: weigh 49.04g of $K_2Cr_2O_7$, add distilled water into a 1L flask up to the mark.
- Concentrated sulfuric acid (H_2SO_4).
- Orthophosphoric acid or Phosphoric acid (H_3PO_4) concentrated.
- Ammonium iron sulfate [$(NH_4)_2SO_4.FeSO_4.6H_2O$] 0.5 M: dissolve 196g of ammonium iron sulfate in a quantity of distilled water, add 5ml of H_2SO_4, add distilled water up to one liter (mark the 1L flask).
- Diphenylamine (color indicator) $(C_6H_5)_2NH$: dissolve 1g of diphenylamine in 100ml of concentrated sulfuric acid.

Procedure:

- Weigh 1g of soil in a 500ml beaker.

- Add 10 ml of potassium dichromate 1N.
- Add 20 ml of concentrated sulfuric acid.
- Let it rest for 30 minutes.
- Add 200 ml of distilled water.
- Add 10 ml of concentrated orthophosphoric acid.
- Add 10-15 drops of the color indicator diphenylamine.
- Titrate with ammonium iron sulfate until a green color appears.
- Prepare a control using the same method but without soil.

Calculation:

$$C\% = \frac{(n'-n)}{p} * 1 * \frac{0.3}{0.77}$$

$$C\% = 1.334 \text{ x } \frac{(n'-n)x0.3\ x\ M}{p}$$

Here's the continuation and translation of the missing parts:

The organic matter content MO% = C% * 1.72

Interpretation standards: according to I.T.A 1977

< 1 ⟶ Very poor

1 to 2 ⟶ Poor

2 to 4 ⟶ Medium

4 ⟶ Rich

3.4.2.2.Total limestone

Reagents:

- 50% HCl (e.g., 50 ml concentrated HCl + 50 ml distilled water)
- Pure $CaCO_3$
- Procedure:
- Weigh 1 g of soil (0.5 g for highly calcareous soils).
- Place it in the calcimeter flask.
- Prepare a 50% HCl solution.
- Fill the tube with HCl and carefully introduce it into the calcimeter flask.
- Close the flask and pour the HCl tube, then lower the calcimeter bulb until the level of water in the latter is in the same horizontal plane as that of the water in the column.
- Read the volume V of released carbon dioxide.
- Repeat the same steps but with pure $CaCO_3$ (0.3 g) instead of soil and read the volume V' of released carbon dioxide (control trial)."

Calcul :

$$CaCO_{3\ total}\ (\%) = \frac{V*0.3}{V'*P} * 100$$

P: weight of the soil.

Interpretation standards: According to G.E.P.P.A in Baize 1988

1% $\longrightarrow$ non-calcareous

1 – 5% $\longrightarrow$ lowly calcareous

5 – 25% $\longrightarrow$ moderately calcareous

25 – 50% $\longrightarrow$ strongly calcareous

50 – 80% $\longrightarrow$ very strongly calcareous

80% excessively calcareous

Granulometry :

Reagents:

- Hydrogen peroxide
- Sodium hexametaphosphate (100g/l)
- Ethanol
- HCl (1N)

Procedure:

- Weigh 10g of soil (10g for clay soil, 20g for sandy soil) and place it in a 600ml beaker.
- Pour 50ml of hydrogen peroxide into the beaker, stir to homogenize while controlling foam formation. If foam threatens to overflow, add a dash of ethyl alcohol.
- Cover the beaker with a watch glass and let it react for at least 12 hours (overnight).
- Place the beaker on a sand bath with a temperature not exceeding 85°C.
- If there's prolonged effervescence, occasionally add small quantities of hydrogen peroxide.
- Let it cool.
- Pour sufficient HCl (1N) to eliminate carbonates, wait for effervescence to cease.
- Transfer the contents of the beaker into a 1000ml sedimentation flask using a wash bottle.
- Add 10ml of sodium hexametaphosphate to the flask.
- Fill with distilled water up to the mark (1000ml).

- Agitate the flask for at least 1 hour on a rotary shaker.
- Place the flask near the Robinson's pipette.
- Put the flask in a container with water at 20°C.
- Stir the liquid in the flask with a thermometer. If the temperature reaches 20°C, swiftly and vigorously agitate the flask by repeatedly turning it upside down to suspend all soil (around 10 turns).
- Quickly place the flask under the Robinson's pipette.

1- First sample: (clay + fine silt + coarse silt) < 50µ

Solution temperature: 20°C

Sedimentation time: 46 seconds

Depth: 10cm

2- Second sample: (clay + fine silt) < 20µ

Solution temperature: 20°C

Sedimentation time: 4 minutes and 48 seconds

Depth: 10cm

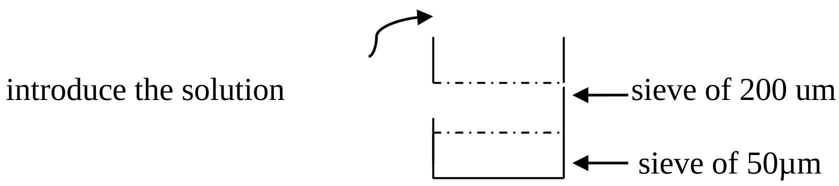
3- Third sample: clay < 2µ

Solution temperature: 30°C

Sedimentation time: 6 hours and 21 minutes

Depth: 10cm

4- Separation of coarse sands and fine sands using 200µm and 50µm sieves.



– Transfer the samples into capsules and weigh them before use.

- Place the capsules in an oven at 105°C for up to 24 hours.
- Weigh the capsules again..

2	20	50	200 micros	2mm

Clay | Fine | Coarse | Fine | Grossiers

$\underbrace{\text{Fine} \quad \text{Coarse}}_{\text{Silt}} \quad \underbrace{\text{Fine} \quad \text{Grossiers}}_{\text{sand}}$

Calculation:

$$\text{Clay (\%)} = (P2 - ph) - \frac{v2}{v1} \times \frac{100}{P - \left[\frac{p}{100}(MO\,\% + CaCO3\%)\right]}$$

$$\text{Fine Silt (\%)} = (P1 - P2) - \frac{v2}{v1} \times \frac{100}{P - \left[\frac{p}{100}(MO\,\% + CaCO3\%)\right]}$$

$$\text{Fine Sand (\%)} = \frac{\text{P3} \times 100}{P - \left[\frac{p}{100}(MO\,\% + CaCO3\%)\right]}$$

$$\text{Coarse Sand (\%)} = \frac{\text{P4} \times 100}{P - \left[\frac{p}{100}(MO\,\% + CaCO3\%)\right]}$$

Coarse silt% = 100 – (A% + LF% + SF% + SG%)

P: sample taken (10g)

P1: weight of clay + silt + sodium hexametaphosphate taken and dried

P2: weight of clay + sodium hexametaphosphate

Ph: weight of sodium hexametaphosphate in the suspension taken

P3: weight of fine sands

P4: weight of coarse sands

V2: total volume of suspension (1000ml)

V1: pipette volume (10ml)

MO: percentage of organic matter

Total CaCO3: percentage of total limestone

3.4.2.3.Interpretation of results:

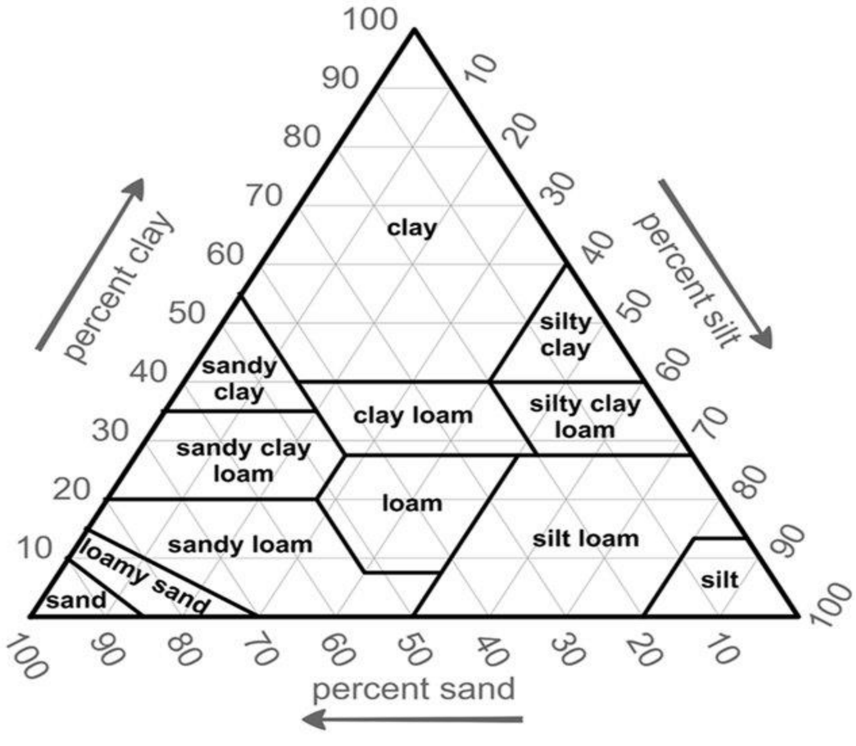


Figure 17: USDA-Soil-Texture Triangle

3.5. Statistical Analysis

This analysis tool generates a single-variable statistics report for the data within the input range, providing information about the central tendency and dispersion of the data. The data underwent standard analysis to acquire descriptive statistics, specifically the mean, minimum and maximum, median, variance, standard deviation (SD), coefficient of variation (CV). All data processing and analysis were conducted using STATISTICA version 5.1 and XLSTAT version 2014.5.03.

3.5.1. Two-Factor Analysis of Variance

We performed a two-factor analysis of variance to examine the interaction effects between the type of soil (reference plot vs. cultivated soil) and the specific locations (El Outaya and Ourlal) on various soil parameters across different horizons. This analysis aims to determine whether there are significant differences in the means due to the main effects of soil type and location, as well as their interaction.

The two-factor analysis of variance allows us to assess the individual and combined influence of these factors by comparing mean values based on sample variability. Significance levels are used to evaluate the effects, with a probability less than 0.001 indicating a highly significant effect, a probability of 0.01 indicating a highly significant effect, and a probability of 0.05 indicating a significant effect. When the probability is greater than 0.05, the effect is considered not significant. This method enables us to comprehensively understand the impact of both soil type and location on the physico-chemical properties of the soil.

3.5.2. Coefficient of Variation

The coefficient of variation represents the ratio of the standard deviation to the mean and is a useful statistic for comparing the degree of variation across different data series, even if the means differ significantly from one another.

CV (%) = 100.σ/m

Five (5) classes, based on the value of CV, are proposed by NOLIN et al., 1997, to describe the intensity of soil property variability (Table 04).

Table7: Classes of Variability Intensity (NOLIN et al., 1997)

Variability Intensity	Coefficient of Variation (%)
Low	<15
Moderate	15-35
High	35-50
Very High	50-100
Extremely High	>100

3.5.3. Geostatistical Modeling

Geostatistics is a tool for analyzing the structure of variation and spatial organization of geographic information, such as soil properties (fertility, texture, etc.). It encompasses a set of statistical techniques allowing soil scientists to better understand and replicate the model of soil spatial variability (TRANGMAR et al., 1986). These techniques rely on the numerical analysis of sample dependence in space. In other words, it means that "the closer the samples are in space, the more they resemble each other up to a certain distance beyond which they become independent" (NOLIN, 2000). A commonly used method to study the spatial dependence of observations is by analyzing the semivariogram, a graph that presents the variation of half-variance $\gamma(h)$ as a function of the distance (h) between samples.

Geostatistics has been widely applied to study the spatial distribution of soil properties (GOOVAERTS, 1998; SALDANA et al., 1998; SEPASKHAH et al., 2005; LIU et al., 2006; AL-OMRAN et al., 2013). Based on the theory of a regionalized variable (MATHERON, 1963, WEBSTER and OLIVER, 2007), geostatistics provides advanced tools to quantify the spatial characteristics of soil parameters and allows for spatial interpolation. The benefits of research on geographic information systems (GIS) have been demonstrated in numerous ecological and agricultural studies (BRADSHAW and MULLER, 1998; ADAMCHUK et al., 2004; MZUKU et al., 2005; ZANOLIN et al., 2007; JINFU et al., 2011; SEVERINO et al., 2016).

3.5.4. Variogram

- **Experimental Variogram**

The experimental variogram is a simplified form of more elaborate data exploration tools, such as the variographic cloud. While the latter is not new, computing now allows for nearly instantaneous graphing, whereas in the 1950s, it could have taken a year of manual calculations (GANDIN, 1963).

It is a statistical tool originating from the theory of regionalized variables. Initially used in mineralogy, it has been extended to other areas such as hydrology, soil mechanics, and forest resources (DELHOMME, 1976; MARBEAU, 1976; VAUCLIN, 1982; FAMIGLIETTI, 1995; GUEKIE et al., 2016). Variograms are used in geostatistics to solve spatial estimation problems, which in pedology can be applied to computer-assisted mapping (IRIS, 1986).

It is the commonly used tool to analyze the spatial dependence of a soil property, providing information about the nature of the spatial processes underlying an observed variable (WALTER, 2002; QUENUM, 2009). It is then fitted to a theoretical model that will be used during interpolation via Kriging (DAUPHINE et VOIRON-CANICIO, 1988; NOLIN et al., 1991). The experimental variogram is not applicable in Kriging estimation as it cannot be represented by an equation. It must be fitted to a theoretical model (spherical, Gaussian, etc.).

According to GODARD (1994), several fitting models (spherical, exponential, etc.) have already been tested by different authors on field data (BURGESS et al., 1981; MCBRATNEY et WEBSTER, 1986; WEBSTER et al., 1989).

- **The variogram is defined as follows:**

Var

Where:

Z: is the regionalized variable under study.

S: is the vector of coordinates.

H: is the distance vector.

D: is the considered geographical domain.

The variogram is characterized by three parameters: the range, the sill, and the nugget (Fig20).

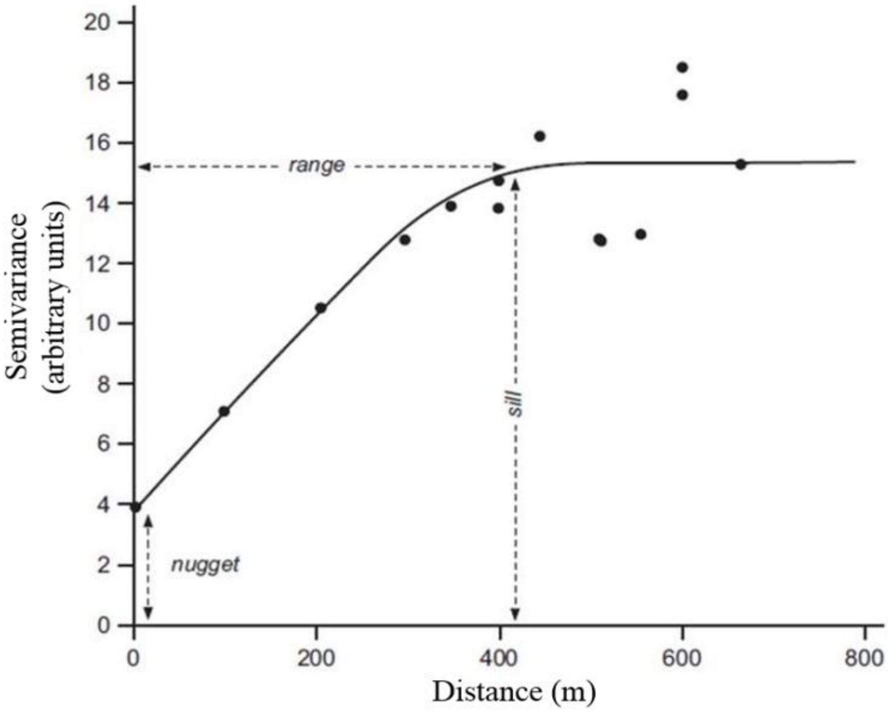


Figure18 : Variogramme (GAETAN et GUYON, 2008)

The sill corresponds to the maximum dissimilarity of the model (the maximum value of γ). The range is the distance at which the variogram reaches its sill. It is the distance from which two values are no longer correlated, and therefore, a sample beyond the range no longer contributes to the estimation. The nugget corresponds to the positive value of the model when it crosses the Y-axis. A nugget value greater than 0 means that even at sampling points separated by a very small distance, the values differ (small-scale variability). This can be explained by natural variability of the variable or by measurement error (instrument error, manipulation error, etc.) (SAHLIN, 2014).

In addition to the variogram parameters, the degree of spatial dependence (DDS) is commonly used in terms of the ratio between the nugget and the sill and expressed as a percentage (TRANGMAR et al., 1986; CAMBARDELLA et al., 1994; EMADI et al., 2008; ZUO et al., 2008). It helps define distinct classes of spatial dependence for soil variables, as shown in Table 05 (TRANGMAR et al., 1986; CAMBARDELLA et al., 1994).

Table 08 : Classes of spatial dependence (TRANGMAR et al., 1986; CAMBARDELLA et al., 1994)

Spatial Dependency Degree (DDS %)	Spatial Dependency
< 25%	Strong
25-75%	Moderate
>75%	Weak

The variographic study was conducted using ARCGIS 10.1 software, where four commonly used models in soil sciences were tested for variogram fitting: spherical, exponential, Gaussian, and circular (CAMBARDELLA et al., 1994; EMADI et al., 2008; ZUO et al., 2008; PARFITT et al., 2009; NAJAFIAN et al., 2012; AL-OMRAN et al., 2013; SAFARI et al., 2013).

The general shapes and equations of the mathematical variogram models used in this study are presented as follows (MCBRATNEY and WEBSTER, 1986; SRIVASTAVA and PARKER, 1988; OLIVER and WEBSTER, 1990; WEBSTER and OLIVER, 2007; GAETAN and GUYON, 2008):

- ❖ **Circular Model**

$$\gamma(h) = C_0 + C\left(1-\left(\frac{2}{\pi}\cos^{-1}\left(\frac{h}{a}\right)\right)+\frac{2h}{\pi a}\sqrt{1-\left(\frac{h}{a}\right)^2}\right) \qquad 0 < \mathrm{h} \le \mathrm{a}$$

$$\gamma(h) = C_0 + C \qquad h > \mathrm{a}$$

$$\gamma(0) = 0$$

- **Spherical Model**

$$\gamma(h) = C_0 + C\left(1{,}5\left(\frac{h}{a}\right)-0{,}5\left(\frac{h}{a}\right)^3\right) \qquad 0 < \mathrm{h} \le \mathrm{a}$$

$$\gamma(h) = C_0 + C \qquad h > \mathrm{a}$$

$$\gamma(0) = 0$$

- **Exponential Model**

$$\gamma(h) = C_0 + C\left(1-\exp\left(-\frac{h}{a}\right)\right) \qquad h > 0$$

$$\gamma(0) = 0$$

- **Gaussian Model**

$$\gamma(h) = C_0 + C\left(1-\exp\left(-\frac{h}{a}\right)^2\right) \qquad h > 0$$

$$\gamma(0) = 0$$

Where:

C0+C: represents the sill, with C0: Nugget effect and C: partial sill (variance of the random variable Z(s)).

a: represents the range.

3.5.5. Cross Validation

Cross validation allows for the proper choice of a variogram model that is likely to provide the best forecasts. The calculated statistics serve as diagnostics, indicating whether the model and the values of its associated parameters are reasonable (QUENUM, 2009). It is a crucial step before mapping a given surface or phenomenon through interpolation.

Cross-validation is performed by successively removing each observation and predicting it using the other observations through kriging (GAETAN et GUYON, 2008). This way, we can compare the predicted value to the observed value and gain useful insights into the quality of the kriging model.

The best variogram model is selected based on the following criteria (CRESSIE, 1993; SALLAM et al., 2011; BHADRA et al., 2012; YAN et al., 2015):

- Mean error (ME) close to zero.
- The smallest root-mean-square error (RMSE).
- Mean standardized error (MSE) close to zero.
- Root-mean-square standardized error (RMSSE) close to 1.
- Average standard error (ASE) close to root-mean-square error (RMSE).
- The calculation of cross-validation parameters is performed using ARCGIS 10.8. The analysis and determination of the best model are carried out through calculations in Excel.

3.5.6. Kriging

Kriging is named after its precursor, the South African mining engineer KRIGE. In the 1950s, KRIGE developed a series of empirical statistical methods to determine the spatial distribution of minerals from a set of boreholes. Ten years later, Georges MATHERON developed a tool to analyze the spatial continuity of concentrations called the "variogram," and an estimation method based on the variogram called "Kriging" (MATHERON, 1976). Today, geostatistics are used in various fields such as soil science, oceanography, hydrogeology, precision agriculture, ecology and the environment, and recently in health sciences... (FERNANDEZ-AVILES et al., 2012).

Kriging is the optimal statistical method for interpolation and extrapolation. It is the most precise estimation method (GRATTON, 2002) and considered the best linear predictor (OLIVER, 2010). Several studies have demonstrated the efficiency of kriging for interpolating soil parameters (MYERS, 1994; LOPEZ-GRANADOS et al., 2002; SULLIVAN et al., 2005; LIU et al., 2006; BENAZZOUZ, 2011).

The term kriging refers to a set of linear interpolation methods based on expressing spatial dependence through the semi-variogram (LAURENT and ROSSI, 1997). It uses the variogram to assign weights to the observation points during the interpolation process (BOIS, 2007).

The basic idea of kriging is to predict the value of the studied regionalized variable at an unsampled site by a linear combination of adjacent point data (BAILLARGEON, 2005).

There are several types of kriging (KRESSE and DANKO, 2012), the most well-known being: simple, ordinary, and universal (GRATTON, 2002; BAILLARGEON, 2005). In our work, we have adopted ordinary kriging, which is the most frequently used method (GRATTON, 2002; OSAMA et al., 2005; LI et al., 2012).

3.5.7. Production of Thematic Maps

Mapping variables showing spatial structures can be done through kriging (LAURENT and ROSSI, 1997). Thematic maps of different studied parameters are plotted using ARCGIS 10.8, based on the kriging of the most reliable variogram model.

RESULTS AND DISSCUSION

Chapter 04: Results and disscusion

4.1. El outaya region

Table 09: Granulometric analysis for soil texture of the 3 sites.

Sites	clay%	Fine silt%	Fine Sand %	Coarse Sand %	Coarse silt %	Granulometry
Pivot 01	29	34	15	13	10	Clay loam
Pivot 02	35	43	9	1	13	Siltyclay loam
Controlsoil	19	54	10	1	16	Clay loam

Soil texture in both working sites and testimony belongs to clay loam soil. according to soil texture Diagram courtesy of the USDA-NRCS.

The index was mathematically expressed by the following formula (Hossain et al., 2018):

Soil textural index (Txw)=ln (% Sand*5+% Silt) / (% Silt+% Clay*10).

Clay loam soils have good water-holding capacity due to the presence of clay particles, which makes them beneficial for plant growth in areas with limited rainfall. In addition, clay loam soils are able to retain nutrients such as nitrogen, phosphorus, and potassium (Tahir &Marschner, 2016),However, in arid regions, clay loam soils can be vulnerable to soil salinization due to the accumulation of salts in the soil(Munns &

Tester,2008).The soil may also be affected by wind erosion and lack of water (Lal,2017), which can lead to soil degradation and desertification.

It should be noted that the water used for irrigation in the station is characterized by a high salinity with an average of 8.65 ds/m at 25°C . According to laboratory analyses preceded.

Table 10: Descriptive statistics of pH, EC, TL, AL, OM dataset used for pivot 01, pivot 02 and Control soil .

Output	Date set	Number	Mean	Max	Min	CV%	Var	Sd .dev
pH	pivot 01	49	6.98	8.15	3.73	9.33	0.425	0.65
pH	pivot 02	49	7.06	8.15	6.17	6.75	0.22	0.47
pH	Control	49	7.71	7.95	7.09	2.13	0.02	0.16
	Total	147	7.25	8.15	3.73	2.74	0.03	0.19
EC	pivot 01	49	3.70	5.6	0.38	27.35	1.02	1.01
EC	pivot 02	49	3.89	7.3	2.17	34.80	1.84	1.35
EC	Control	49	2.05	3.1	1.4	17.08	0.12	0.35
	Total	147	3.14	5.8	0.38	15.59	0.24	0.49
TL	pivot 01	49	42.78	73.04	33	17.46	55.84	7.47
TL	pivot 02	49	41.76	51.42	30.06	12.82	28.68	5.35
TL	Control	49	33.69	47.82	25.77	12.12	16.67	4.08
OM	pivot 01	49	2.26	3.3	0.05	40.99	0.86	0.92

OM	pivot 02	49	2.17	3.5	0.04	36.44	0.63	0.79
OM	Control	49	1.18	2.66	0.06	52.33	0.38	0.61
	Total	147	1.87	3.5	0.04	12.79	0.05	0.23

Max: maximum,Min: minimum, St. dev: standard deviation, Cv: coefficient of variation,Var: variation.

The summary of descriptive statistics for soil salinity, based on 149 samples from two pivots (49 samples for each pivot) and an additional 49 samples from the control site, is presented in **(Table 10)**. In Pivot 01 and Pivot 02, the soil exhibits organic matter content ranging from 3.3 to 0.05 and 3.5 to 0.04, with average values of 2.264 ± 0.92 and 2.178 ± 0.79, respectively. This indicates a low organic matter (OM) content in the soil of these two pivots. In contrast, the control site shows organic matter content ranging from 2.66 to 0.06, with an average of 1.181 ± 0.61.

The pH values are relatively high, with a mean of 6.98 ± 0.65 for Pivot 01, 7.06 ± 0.47 for Pivot 02, and 7.71 ± 0.16 for the control site. These values suggest a slightly alkaline nature of the soil under study.

Regarding electrical conductivity (EC), Pivot 01 exhibits a maximum of 3.7 dS/m, Pivot 02 has 3.6 dS/m, and the control site records 2.05 dS/m. These EC values classify the studied soil as very saline (Aubert, 1978).

The average total limestone (TL) content for Pivot 01 and Pivot 02 is 42.78 ± 7.47 and 41.76 ± 5.35, respectively, while the control site has an average of 33.69 ± 4.08. These values indicate that the chosen sites have very high calcareous soil (Hopkins & Ellsworth, 2005;Keshavarzi et al., 2018).

The Coefficient of Variation (CV) serves as an indicator of the dispersion level of random variables. Typically, a CV of less than 10% signifies weak variability, while a CV falling between 10% and 100% indicates moderate variability. In contrast, a CV exceeding 100% suggests strong variability (Gardner et al., 2002 ; Madden & Hughes., 1995).

For the parameters under examination, the coefficient of variation reveals limited spatial variation in organic matter, with values of 40.99%, 36.44%, and 52.33% for both cultivation sites and the control site, respectively. This spatial variation in soil organic matter may be attributed to factors such as land use, irrigation systems, and schedules.

In terms of electrical conductivity, Pivot 1 exhibits a coefficient of variation of 27.35%, Pivot 02 has 25.80%, and the control site shows 17.08%. Meanwhile, the values for total limestone content are 17.46%, 12.82%, and 12.12%, respectively.

However, pH values appear relatively uniform, with measurements of 9.33%, 6.75%, and 2.13% for Pivot 01, Pivot 02, and the control site, respectively.

4.2. Distribution of Soil physic-chemical parameters Using OK Interpolation

Ordinary kriging is used in this study to map the spatial distribution of soil physicochemical parameters (EC,Ph,TL,OM) based solely on field measurements. A normality test (QQ Plot) was used to evaluate the distribution of the data, (the results do not follow a normal distribution). The logarithmic decimal method was used to normalize these data.

Table 11 : Descriptive statistics after logarithmic transformation for total limestone, pH, Electric conductivity, Organic matter.

Output	Date set	Number	Mean	Max	Min	St.dev	Cv	Var
pH	pivot 01	49	42.91	49.44	37.4	2.72	6.34	7.39
pH	pivot 02	49	41.79	48.92	36.53	2.62	6.28	6.86
pH	Control	49	33.79	38.28	28.74	2.57	7.62	6.6
EC	pivot 01	49	6.97	7.97	5.6	0.49	7.04	0.24
EC	pivot 02	49	7.06	7.56	6.63	0.21	3.05	0.04
EC	Control	49	7.71	7.84	7.52	0.08	1.08	0.006
TL	pivot 01	49	3.68	4.37	2.65	0.36	9.98	0.12
TL	pivot 02	49	3.65	4.53	2.67	0.38	10.65	0.14
TL	Control	49	2.06	2.78	1.57	0.23	11.48	0.05
OM	pivot 01	49	2.61	2.9	1.17	0.44	19.54	0.19
OM	pivot 02	49	2.17	2.776	1.12	0.37	17.39	0.13
OM	Control	49	1.17	1.767	0.41	0.26	22.53	0.06

Subsequently Variograms of the KRIGING method were calculated from the normalized data.

In Pivot 01, we delve into the geospatial attributes of four crucial soil parameters. Electrical conductivity (EC) is characterized by a low spatial dependency, demonstrated by an exponential best-fit model with a range of 56.2 meters. Total limestone (TL) exhibits moderate spatial dependence with an exponential model and a range of 108.4 meters. Organic matter (OM) similarly displays a moderate spatial dependency with an exponential model and a range of 135.7 meters. Conversely, the pH level is depicted with a Gaussian best-fit model, featuring a high nugget-to-sill ratio, suggesting reduced spatial dependency, and a range of 56.2 meters.

Table 12: Best-fit variogram models for OM, TL, pH, EC parameters for the three sites.

Parameters	Best-Fit Model	Nugget (C0)	Sill (C0+C)	Range (m)	Ratio %	Level of value
EC pivot 01	Exponential	0.48	0.49	56.2	98.4	>75 % (Low)
EC pivot 02	Gaussian	0.76	1.12	56.2	67.87	25-75 % (Moderate)
EC Control	Gaussian	0.01	0.13	58.94	7.46	< 25 % (High)
TL pivot 1	Exponential	22.65	33.94	56.2	66.74	25-75 % (Moderate)
TL pivot 02	Gaussian	10.48	24.74	58.94	42.37	25-75 % (Moderate)
TL Control	Gaussian	3.52	14.96	61.82	23.52	25-75 % (Moderate)
pH pivot 1	Gaussian	0.01	0.44	56.2	2.24	< 25 % (High)
pH pivot 2	Exponential	0.01	0.21	56.2	4.66	< 25 % (High)
pH Control	Spherical	0.002	0.02	58.94	7.68	< 25 % (High)
OM pivot 1	Exponential	0.25	0.88	124.99	28.78	25-75 % (Moderate)
OM pivot 02	Exponential	0.05	0.59	56.2	8.35	< 25 % (High)
OM Control	Spherical	0.01	0.43	207.37	0.02	< 25 % (High)

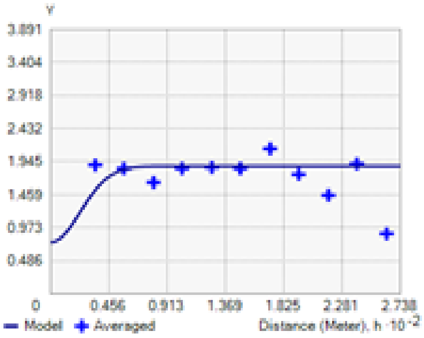
In Pivot 01, we delve into the geospatial attributes of four crucial soil parameters. Electrical conductivity (EC) is characterized by a low spatial dependency, demonstrated by an exponential best-fit model with a range of 56.2 meters. Total limestone (TL) exhibits moderate spatial dependence with an exponential model and a range of 108.4 meters. Organic matter (OM) similarly displays a moderate spatial dependency with an exponential model and a range of 135.7 meters. Conversely, the pH level is depicted with a Gaussian best-fit model, featuring a high nugget-to-sill ratio, suggesting reduced spatial dependency, and a range of 56.2 meters.

Pivot 02 also undergoes a comprehensive assessment of soil attributes. EC maintains a moderate spatial dependency, following an exponential best-fit model with a range of 56.2 meters. TL presents similar characteristics with a moderate spatial dependence, adhering to an exponential model and a range of 108.4 meters. OM follows a comparable pattern, displaying moderate spatial dependency with a range of 135.7 meters. However, in this pivot, the pH level is depicted using an exponential best-fit model with a high nugget-to-sill ratio, indicative of reduced spatial dependency, and a range of 56.2 meters.

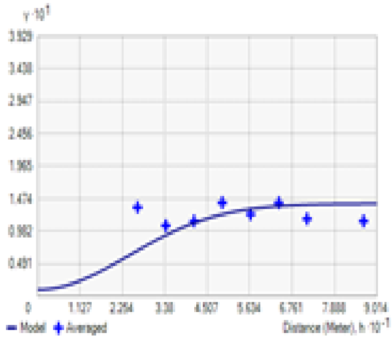
The control section reveals distinct findings. EC, TL, and OM all demonstrate high spatial dependence, evident from the low nugget-to-sill ratio. EC exhibits a range of 58.94 meters, TL extends to 117.87 meters, and OM spans 143.62 meters. The pH level is characterized by a spherical best-fit model and a high nugget-to-sill ratio

, aligning with the spatial dependence observed in the other parameters, with a range of 58.94 meters. These findings provide valuable insights into the spatial characteristics of these soil parameters, contributing to a better understanding of soil behavior and management.

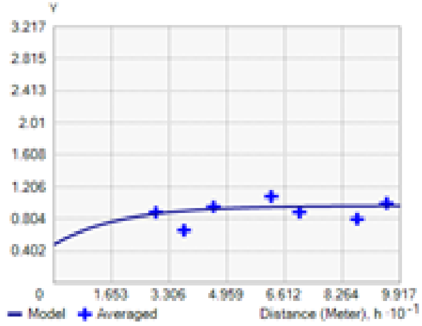
A) EC pivot



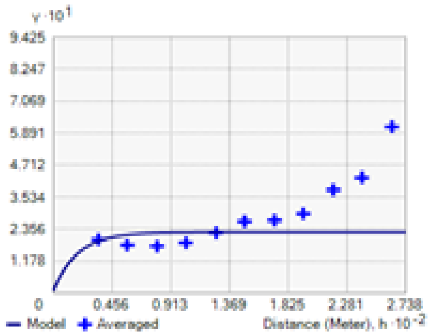
B) EC pivot



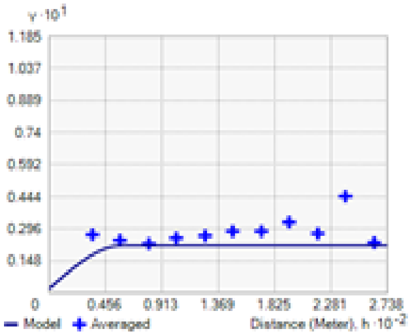
C) EC T



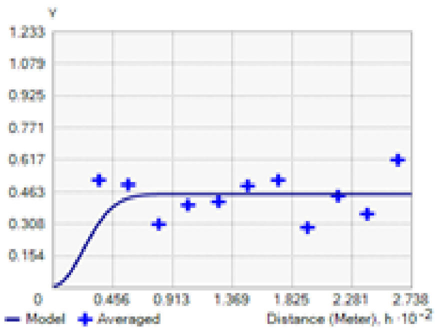
C) pH



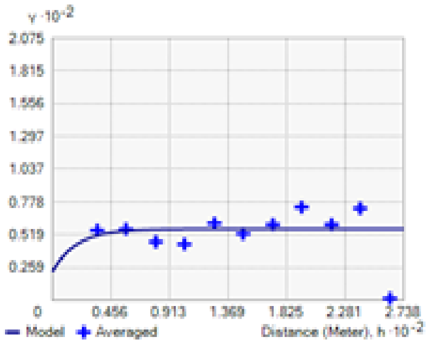
B) pH



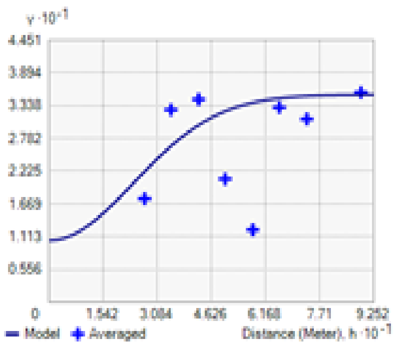
A) pH T



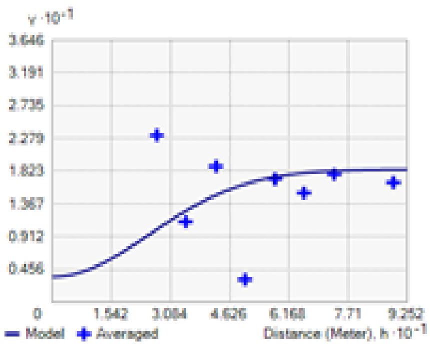
A) TL pivot 01



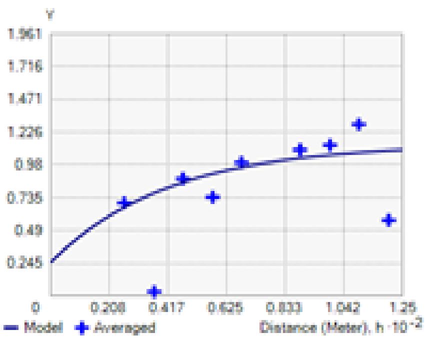
B) TL pivot 02



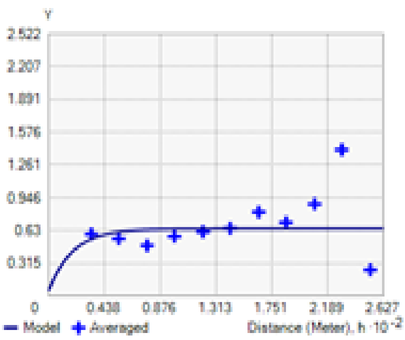
C) TL T



A) OM pivot



B) OM pivot



C) OM T

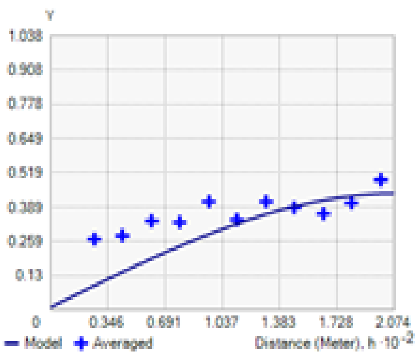
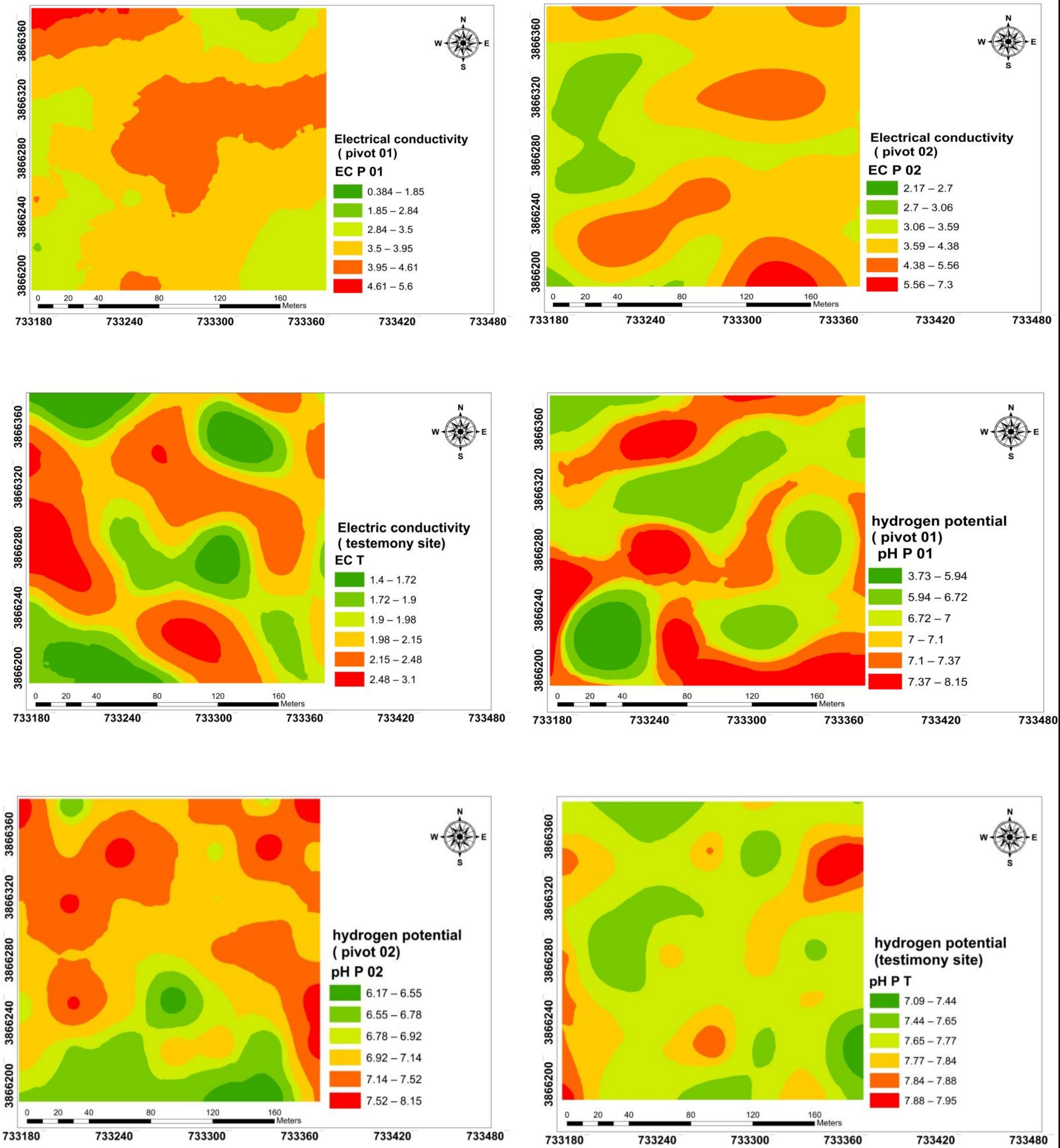
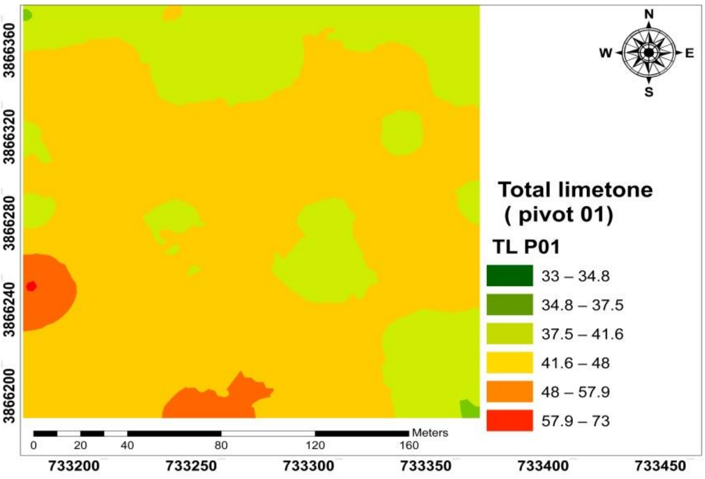
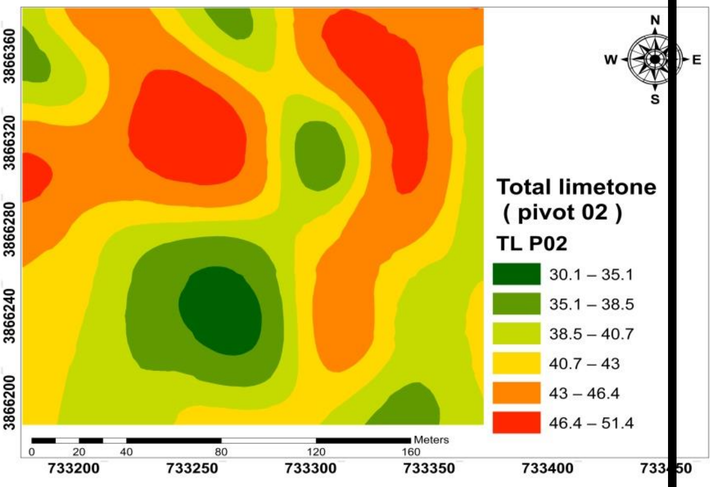


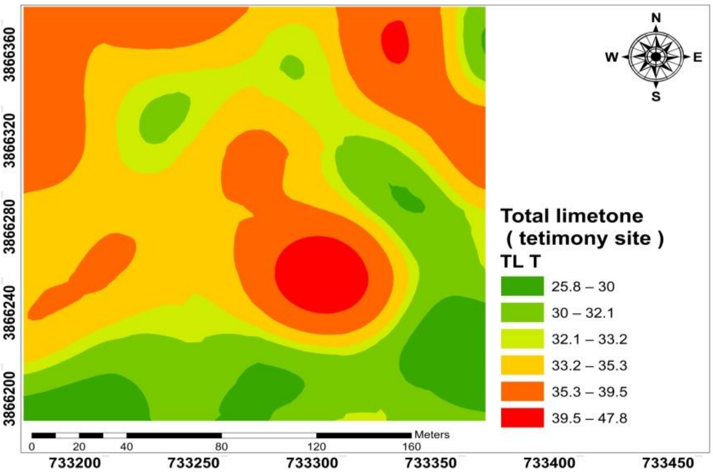
Figure 19: Directional semivariograms model calculated for soil total limestone, organic matter,Ph and Electric conductivity with log transformed data.

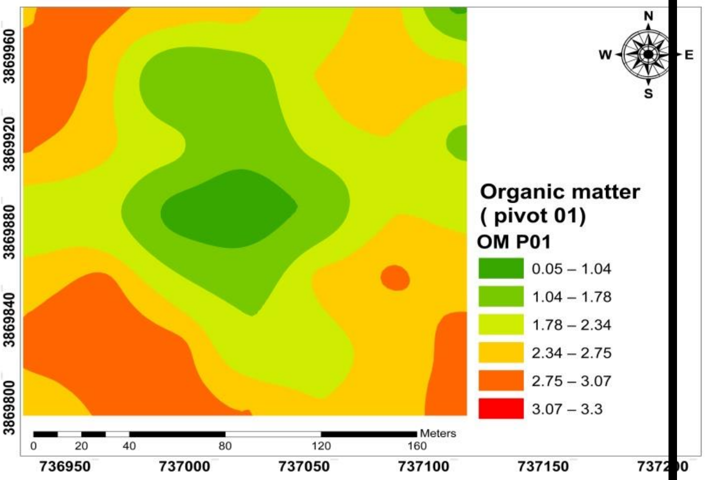


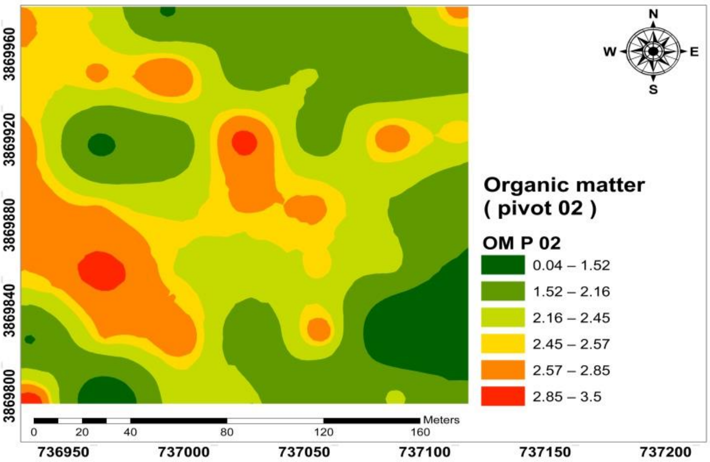
This information, derived from the semivariograms, highlighted the reality of different spatial dependence for the soil properties collected in the field **(Table 13).** The proportion of nuggets to the threshold mimics spatial autocorrelation


Total limetone
(pivot 01)
TL P01
33 – 34.8
34.8 – 37.5
37.5 – 41.6
41.6 – 48
48 – 57.9
57.9 – 73
Meters
0 20 40 80 120 160
733200 733250 733300 733350 733400 733450
3866200 3866240 3866280 3866320 3866360


Total limetone
(pivot 02)
TL P02
30.1 – 35.1
35.1 – 38.5
38.5 – 40.7
40.7 – 43
43 – 46.4
46.4 – 51.4
Meters
0 20 40 80 120 160
733200 733250 733300 733350 733400
3866200 3866240 3866280 3866320 3866360


Total limetone
(tetimony site)
TL T
25.8 – 30
30 – 32.1
32.1 – 33.2
33.2 – 35.3
35.3 – 39.5
39.5 – 47.8
Meters
0 20 40 80 120 160
733200 733250 733300 733350 733400 733450
3866200 3866240 3866280 3866320 3866360


Organic matter
(pivot 01)
OM P01
0.05 – 1.04
1.04 – 1.78
1.78 – 2.34
2.34 – 2.75
2.75 – 3.07
3.07 – 3.3
Meters
0 20 40 80 120 160
736950 737000 737050 737100 737150
3869800 3869840 3869880 3869920 3869960


Organic matter
(pivot 02)
OM P 02
0.04 – 1.52
1.52 – 2.16
2.16 – 2.45
2.45 – 2.57
2.57 – 2.85
2.85 – 3.5
Meters
0 20 40 80 120 160
736950 737000 737050 737100 737150 737200
3869800 3869840 3869880 3869920 3869960

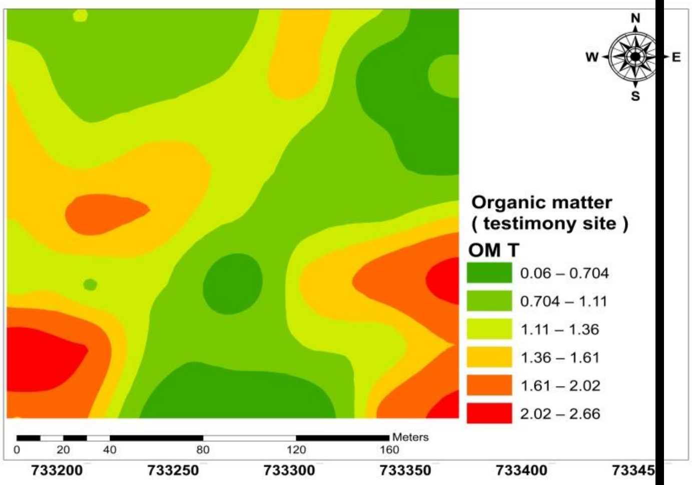

Organic matter
(testimony site)
OM T
0.06 – 0.704
0.704 – 1.11
1.11 – 1.36
1.36 – 1.61
1.61 – 2.02
2.02 – 2.66
Meters
0 20 40 80 120 160
733200 733250 733300 733350 733400
3866200 3866240 3866280 3866320 3866360

Figure 20: SpatialDistribution maps of soil total limestone(TL), organic matter(OM) , electric conductivity (EC) andpH for the three sites using Ordinary Kriging Interpolation method.

Based on the spatial distribution maps of pH levels, we observe fluctuations in pH classes within these pivot areas, ranging from slightly alkaline to slightly acidic. Notably, elevated pH values are primarily concentrated in the southern sectors of Pivot 02 and along the periphery of Pivot 01. It's important to note that the spatial analysis indicates relatively low pH variation across the study area, with coefficient values of variation amounting to 9.33% for Pivot 01, 6.75% for Pivot 02, and 2.13% for the Control soil.

Similarly, when examining the spatial distribution maps of total limestone content in the soil, the values classify total limestone content into categories ranging from highly calcareous to very strongly calcareous, based on the Scale of Salinity (Triki Fouratiet al., 2017). The preponderance of high values is chiefly evident in the northern regions of Pivot 02 and the central region of Pivot 01. Furthermore, the analysis reveals a relatively low variation in total limestone content across the study area, characterized by a moderate coefficient of variation.

When examining the spatial distribution maps of organic matter content, the data classify organic matter content in the soil as very low and deficient in organic matter (Koull&Halilat, 2016). The most notable accumulations of organic matter are identified in the southern regions of Pivot 01 and the western sector of Pivot 02. In contrast to pH and total limestone, organic matter demonstrates a significant degree of spatial variability, with coefficient values of variation reaching 40.99% for Pivot 01, 36.44% for Pivot 02, and 52.33% for the reference soil.

Furthermore, when examining the spatial distribution maps of electric conductivity (EC), these values categorize EC into classes ranging from very saline soil to extremely saline soil. Predominantly elevated EC values are concentrated in the central regions of both working pivots. The spatial analysis reveals a moderate degree of EC variation across the study area.The distribution of soil properties is elucidated through an analytical examination of the pivot irrigation system, which is intricately regulated by climatic factors, particularly during the summer season marked by elevated temperatures and evaporation rates, in conjunction with the velocity and orientation of prevailing winds.This phenomenon is further compounded by the agricultural practice known as "intensification agriculture". Furthermore, anthropogenic activities have engendered suboptimal natural resource management and perturbations to the soil structure. The employment of groundwater-based irrigation can exert a substantial influence on soil salinity, especially within regions characterized by elevated concentrations of dissolved salts in the groundwater(Triki et al., 2016). Upon irrigation, water undergoes a partitioning process, with a fraction undergoing evaporation, while the remainder percolates through the soil profile, transporting dissolved salts along (Jones, 2016). The deleterious consequences of heightened soil salinity encompass water stress, perturbations in nutrient equilibrium, and toxicity, thereby negatively affecting plant growth and crop yields.

Elevated levels of soil salinity can detrimentally affect the capacity of cereal crops to assimilate water and vital nutrients, culminating in stunted growth, diminished harvests, and potentially plant mortality (Akbarimoghaddam et al.,2011). Moreover, excessive salt concentrations can induce ion imbalances within plants, subsequently precipitating nutrient deficiencies and a reduction in photosynthetic efficiency (Yadav et al., 2011.).

The relationships among these variables are in line with the recognized significance of electrical conductivity (EC) and total limestone in affecting soil salinity. The increase in electrical conductivity, due to the introduction of organic matter, is attributed to the mineralization of organic compounds, subsequently raising soil salinity. Additionally, a correlation exists between pH and total limestone, as limestone has the ability to neutralize acidity by reacting with hydrogen ions (H+) in acidic solutions. The specific amount of limestone required to achieve a particular pH level depends on the initial pH and the amount of acid present. This reaction is commonly referred to as acid neutralization or the acid-base reaction (Haby& Leonard, 2002 ;Brady & Weil, 1990). Furthermore, negative correlations are observed between pH and electrical conductivity, indicating that as the calcium concentration in the solution decreases, pH tends to increase (Brady & Weil, 1990). This decline in pH is associated with the presence of limestone in the soil, as noted in Benbrahim's 2018 study, consistently demonstrating a negative correlation between pH and electrical conductivity.

Table 13: Prediction performance measures of Ordinary Kriging .

Parameters	RMSE	MAE
TL pivot 01	2.433	1.902
TL pivot 02	2.178	1.711
TL testimony	1.998	1.638
pH pivot 01	0.233	0.345
pH pivot 02	0.159	0.131
pHtestimony	0.687	0.655
EC pivot 01	0.345	0.25
EC pivot 02	0.367	0.279
EC testimony	0.233	0.171
OM pivot 01	0.42	0.333
OM pivot 02	0.344	0.282

OMtestimony	0.252	0.192

In order to evaluate the accuracy of the determined model, two statistical indices, the Root Mean Square Error (RMSE)and Mean Absolute Error (MAE) were used .

Based on a comparison between the results of the Table 13 , both of the ME and RMSE was satisfactory (values were close to zero) for the three parameters except the Total limeston which is superior than 1.we marked that the RMSE and MAE for the two working sites are higher than the testimony for the three parameters (Total limestone , Electric conductivity and Organic matter) .for the pH we noticed that the testimony soil is higher than the two working sites .Comparing the RMSE value for the two working sites with the RMSE value for the testimony site. when the RMSE value for the the testimony site is lower than the RMSE value for the two working sites, it suggests that the testimony site is performing better than the two working sites.

Principal component analysis (PCA) is applied to check for possible correlations between the studied soil parameters. The resultsobtained are summarized in Figure 21 .

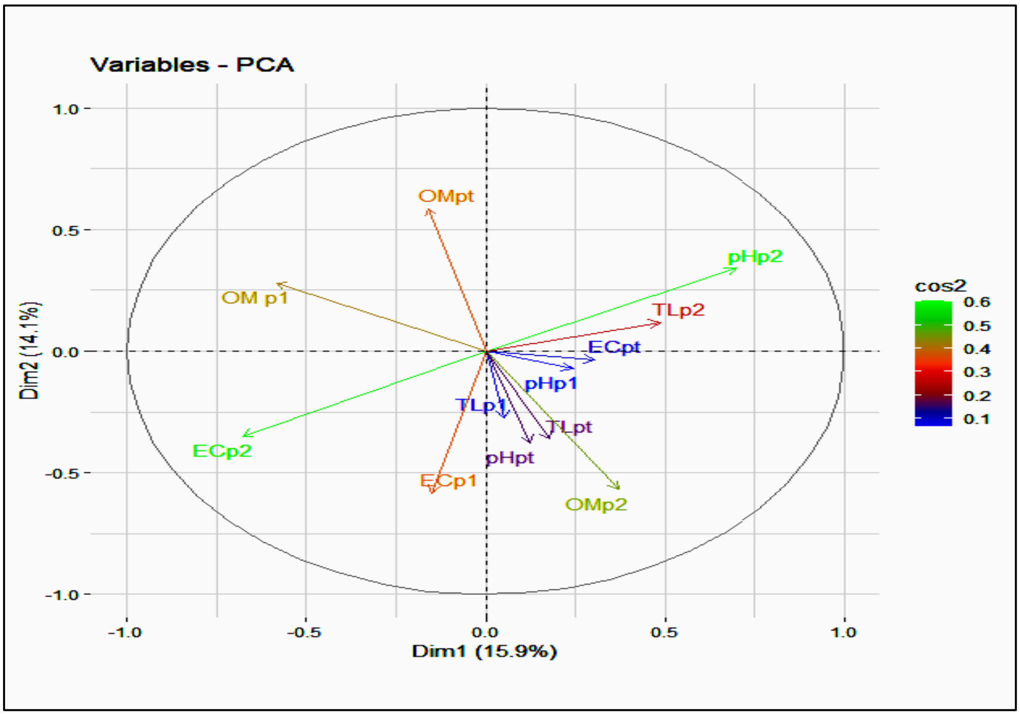


Figure 21: Principal component analysis (PCA) between the soil parameters studied for the three sites in El outaya region .

The data presented in figure 21 reveals that Axis 1 contributes 15.9%, while Axis 2 contributes 14.1% to the overall variance, reflecting a moderate representation of the studied variables on the factorial plan, which collectively explains 30% of the total inertia . These significant contributions by the first two dimensions suggest a noteworthy degree of variability in the soil properties among the samples. This variability can be attributed to various factors, such as distinct soil types, diverse management practices, or varying environmental conditions .Axis 1 is characterized by a positive correlation among the parameters pH and the total limestone across all three pivots, as well as organic matter (OM) for pivot 02 and electrical conductivity (EC) for the testing soil. Conversely, Axis 2 demonstrates a negative correlation involving the OM factor for pivot 01, the testing soil, and the EC factor for both operational pivots. In a general context, it is observed that for pivot number 01, the two parameters MO and EC exhibit negative correlations with the other two parameters, namely pH and active Tl . Regarding pivot 02, pH displays a negative correlation with Ph and the other two parameters, while in the case of the testing soils, OM exhibits a negative correlation with the remaining parameters.The results of the multiple correlation study reveal no significant correlations among the different parameters studied ($P > 0.05$). However, a noteworthy positive correlation is observed between organic matter (OMp1) and electrical conductivity (ECp1) . Furthermore, the strong correlation observed among the variables OMpt, OM PT, and pHp2 with dim1 suggests a close relationship among these three variables, which aligns with the established significance of organic matter (OM) and pH as critical factors influencing soil fertility.Similarly, the strong correlation between pHp1, ECp1, and Lpt with dim2 suggests a close connection among these variables, consistent with the recognized importance of electrical conductivity (EC) and total limestone in soil salinity. The increase in electrical conductivity with the contribution of organic matter can be attributed to the mineralization of organic compounds, subsequently raising soil salinity . Additionally, there is a relationship between pH and total limestone, as limestone has the capacity to neutralize acidity by reacting with hydrogen ions (H^+) in acidic solutions. The precise amount of limestone needed to reach a specific pH level depends on the initial pH and the amount of acid present. This reaction is commonly referred to as acid neutralization or the acid-base reaction (Haby and Leonard, 2002 ; Brady and Weil, 1990).Furthermore, negative correlations are evident between pH and electrical conductivity, where pH tends to increase as the calcium concentration in the solution decreases (Brady and Weil, 1990). This decrease in pH is related to the presence of limestone in the soil (Benbrahim, 2018), and the study consistently demonstrates a negative correlation between pH and electrical conductivity.

4.3. Ourlal region

4.3.1. Characteristics of Irrigation Water

The sustainability of agricultural yield in arid zones depends significantly on the quality and quantity of irrigation water (Rathore *et al.*, 2019). In August 2021, we conducted measurements to assess the physico-chemical characteristics of irrigation water. The mean values obtained from the characteristics of the irrigation water are presented in Table 1. It is worth noting that each pivot was irrigated using a distinct water source. Specifically, water source one (S1) was utilized for P1, while water source 2 (S2) was employed for the second pivot (P2).

Table 8: Water analysis of the water sources used for irrigation.

N° samples	EC	pH	Cations (meq/l)				Anions (meq/l)				Mineralization
	ds/m		Na^+	Ca^{2+}	Mg^{2+}	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	(g/l)
S 01	4.16	7.82	24.96	33	36.6	0.46	0.8	2.4	5.58	30.9	2.66
S 02	4.73	8.04	36.71	30	31.6	0.46	0.8	2.4	9.9	42.06	3.02

The water analysis results reveal that both water sources used for irrigation in the study exhibit high salinity levels, as indicated by the EC values (Rhoades FAO). This high salinity can have negative implications for soil health and crop growth. The alkaline nature of the water, as indicated by the pH values, can also affect soil pH, potentially influencing nutrient availability and microbial activity. Looking at the cation concentrations, both water sources have relatively high levels of Na^+ and Ca^{2+} (Tam, 1998; Irshad *et al.*, 2005). Haigh sodium levels can contribute to soil sodicity, negatively impacting soil structure and permeability (Raouf CITA). The high calcium concentrations can have a positive influence on soil structure and provide essential nutrients for plant growth (Leifeld*et al.,* 2013). Analyzing the anion concentrations, both water sources show moderate levels of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-). These can contribute to alkalinity and influence soil pH. The chloride (Cl^-) concentrations are also significant, which can have adverse effects on plants if accumulated in the soil. The high sulfate (SO_4^{2-}) concentrations in S2 suggest potential risks of soil salinization and sodicity, as sulfates can contribute to the formation of gypsum.

4.3.2. Soil Characteristics

The results related to the study of soil granulometry were summarized in the figure 25

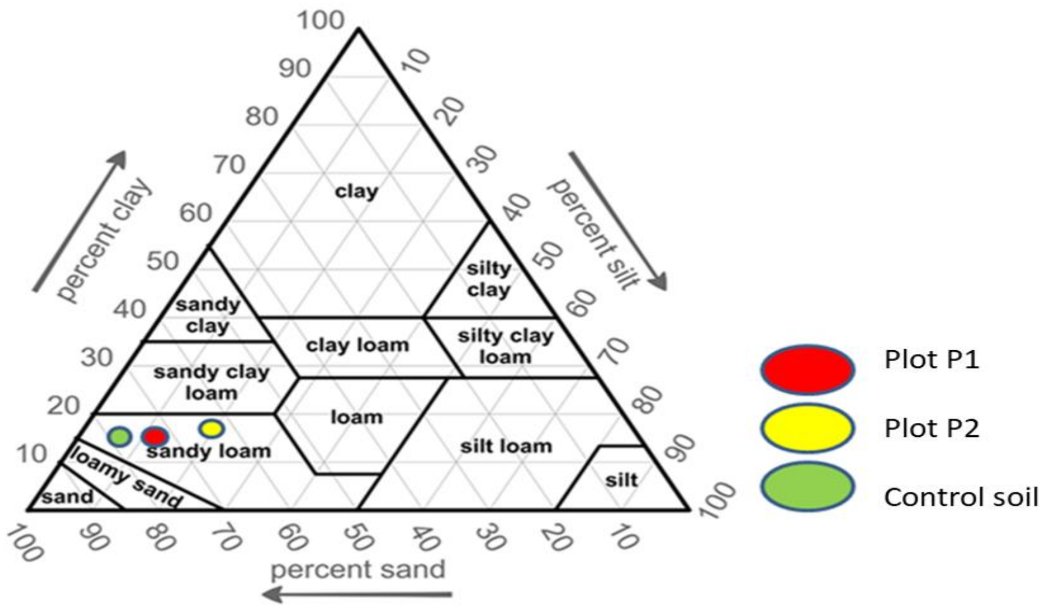


Figure 19: Soil texture represented in the triangle based on USDA-NRCS.

As shown in Figure 24, sandy loam soil dominates at both cropping sites and in the control soil. Because of its coarse texture, sandy loam soil has high drainage capacity, which is influenced by the unique mix of sandy texture and arid climatic conditions in arid zones (Arshad *et al.*, 1992). Water moves swiftly through the soil profile, reducing the risk of water logging and excessive soil moisture. Despite efficient drainage, sandy loam soil has a limited water-holding capacity because does not retain water and dries up quickly

(Lal and Shukla, 2004; Retzer*et al.*, 1952). Sandy soil, on the other hand, is prone to nutrient leakage due to its high permeability.

Table 9: Descriptive statistics of pH, TL, EC and OM dataset used for three sites.

Parameters	Area	Number	Mean	Max	Min	Var	St.dev	CV**%**
pH	P1	49	8.1	8.5	7.9	0.029	0.17	2.1
	P2	49	8.2	8.7	7.7	0.036	0.19	2.32
	T	49	7.8	8.5	6.9	0.06	0.24	3.17
EC	P1	49	2.18	2.81	1.05	0.12	0.34	15.93
	P2	49	2.38	3.35	1.03	0.19	0.43	18.31
	T	49	1.09	2.78	0.4	0.256	0.5	46.2
OM	P1	49	0.26	0.61	0.04	0.02	0.14	52.97
	P2	49	0.24	0.55	0.04	0.02	0.14	58.89
	T	49	0.21	0.45	0.04	0.01	0.1	49.59
TL	P1	49	9.74	14.59	7.66	2.12	1.45	14.96
	P2	49	12.35	16.67	7.9	3.01	1.73	14.06
	T	49	8.72	28.69	3.27	10.46	3.23	37.08

Table 15 presents the summary of descriptive statistics for soil proprieties. The pH values of pivot 1 (P1), pivot 2 (P2), and the control soil (T) were measured and found to be 8.1±0.17, 8.2±0.19, and 7.8±0.24, respectively.). These results indicate a moderately alkaline reaction for the two cultivated soils and a slightly alkaline reaction for the control soil soil (Retzer*et al.*, 1952).(POR QUÉ SUBE pH The TL values indicate that the soil in P1 had a mean of 9.74 with a standard deviation of 1.45, Pivot (P2) had an average TL of 12.35 with a standard deviation of 1.73, and the control soil site (T) had an average TL of

8.72 with a standard deviation of 3.23. The Electrical Conductivity (EC) values ranged from a maximum of 2.81 (dS/m) in Pivot (P1), 3.35 (dS/m) in Pivot (P2), to 2.78 in the control soil soils (T). The average EC values were 2.18±0.34 for Pivot (P1), 2.38±0.43 for Pivot (P2), and 1.09±0.5 for the control soil site (T). These findings classify the studied soil as very saline for both working sites and moderately saline for the reference soil (Kiani and Salehnia, 2014). Regarding the Organic Matter (OM) values, they ranged from a maximum of 0.61% in Pivot (P1), 0.55% in Pivot (P2), to 0.45% in the control soil soils (T). The average OM values were 0.26±0.14 for Pivot (P1), 0.24±0.14 for Pivot (P2), and 0.21±0.10 for the control soil site (T). These results indicate that the studied soil can be classified as poor in Organic Matter (Baize, 1988; I.T.A, 1977).

The Coefficient of Variation (CV) is used to measure the dispersion of random variables. A CV value ≤10% indicates weak variability, while a CV between 10% and 100% denotes moderate variability, and a CV ≥100% represents strong variability (Gardner *et al.*, 2002; Madden and Hughes, 1995). In our study, the CV for both TL and OM values in all three sites fell within the range of 10% to 100%, indicating a moderate variation in these parameters across all three sites. While for the pH values in all three sites was ≤10%, indicating weak variation. However, for Electric Conductivity, we observed a moderate variation with a CV between 10% and 100%.

Table 16: Descriptive statistics after logarithmic transformation for OM, TL, pH, EC.

Parameters	Area	Mean	Max	Min	St.dev	CV	Var
	P1	7	8	5.6	0.49	7.04	0.012
pH	P2	8.2	8.4	8	0.07	0.94	0.005
	T	7.7	8	7.4	0.12	1.55	0.014

	P1	42.91	49.44	37.4	2.72	6.34	7.4
TL	P2	12.35	13.74	10.85	0.69	5.6	0.47
	T	8.71	12.56	6.87	1.1	12.7	1.22
	P1	3.68	4.37	2.65	0.36	9.98	0.018
EC	P2	2.37	2.74	1.97	0.18	2.14	0.034
	T	1.11	1.67	0.71	1.1	12.7	0.045
	P1	2.26	2.9	1.17	0.44	19.54	0.19
OM	P2	0.28	0.35	0.15	0.04	19.33	0.002
	T	0.21	0.32	0.09	0.06	30.07	0.004

These findings, obtained from the semivariograms, provided evidence of diverse spatial dependencies among the measured soil properties in the field.

Table 17: Best-fit variogram models for pH, TL, EC and OM parameters for the three sites.

Parameters	Area	Best-Fit Model	Nugget (C0)	Sill (C0+C)	Range (m)	Ratio %
pH	P1	Gaussian	0.01	0.02	74.41	46.15
	P2	Exponential	0.01	0.02	56.2	35.03
	T	Exponential	0.001	0.07	75.45	1.38
TL	P1	Gaussian	0.99	1.17	63.75	84.99
	P2	Exponential	1.23	1.86	58.94	66.1
	T	Exponential	4.33	6.81	94.46	63.57
EC	P1	Exponential	0.01	0.125	56.204	7.99
	P2	Exponential	0.019	0.171	58.948	11.56
	T	Exponential	0.031	0.269	75.295	11.56
OM	P1	Gaussian	0.01	0.012	63.18	83.01
	P2	Exponential	0.009	0.013	56.2	65.01
	T	Exponential	0.001	0.009	73.58	10.53

The Table 17 shows the best-fit variogram models for TL (total limestone) and OM (organic matter) parameters for the three sites. The nugget is the variance of a single point, the sill is the total variance contribution, and the range is the distance after which the variogram levels off. The ratio is the percentage of the sill that is accounted for by the nugget.

The Gaussian model is a good fit for the TL and OM in P1 data as the nugget is small and the sill is close to the total variance. The exponential model is a good fit for the TL in pivot P2 and TL in control soil (T) data, as the nugget is larger and the sill is further from the total variance. The range is relatively short for all of the data sets, indicating that the spatial correlation between points is limited.

Also for the total limestone, the nugget-to-sill ratios for both pivots P2 and control soil T ranged from 25% to 75%, indicating a moderate level of spatial dependence. Conversely, P1 value was more than or equal to 75%, indicating a low level of spatial dependence.

For the Organic matter parameter, all three sites exhibited a different spatial dependence with control soil values less than or equal to 25% ,for the working sites it is high and moderate for pivot 01 and 02 respectively for the spatial dependence characteristics of the pH parameter. The nugget-to-sill ratios for both working pivots (P1) and (P2) ranged from 25% to 75%, indicating a moderate level of spatial dependence. Conversely, the Control soil (T) value was less than or equal to 25%, indicating a high level of spatial dependence. The chosen models had ranges of 74.71, 56.20, and 75.25, respectively.

For the Electric Conductivity parameter, all three sites exhibited high spatial dependence with control soil values less than or equal to 25%. The ranges of the chosenmodelswere 56.20, 58.94, and 75.29, respectively.

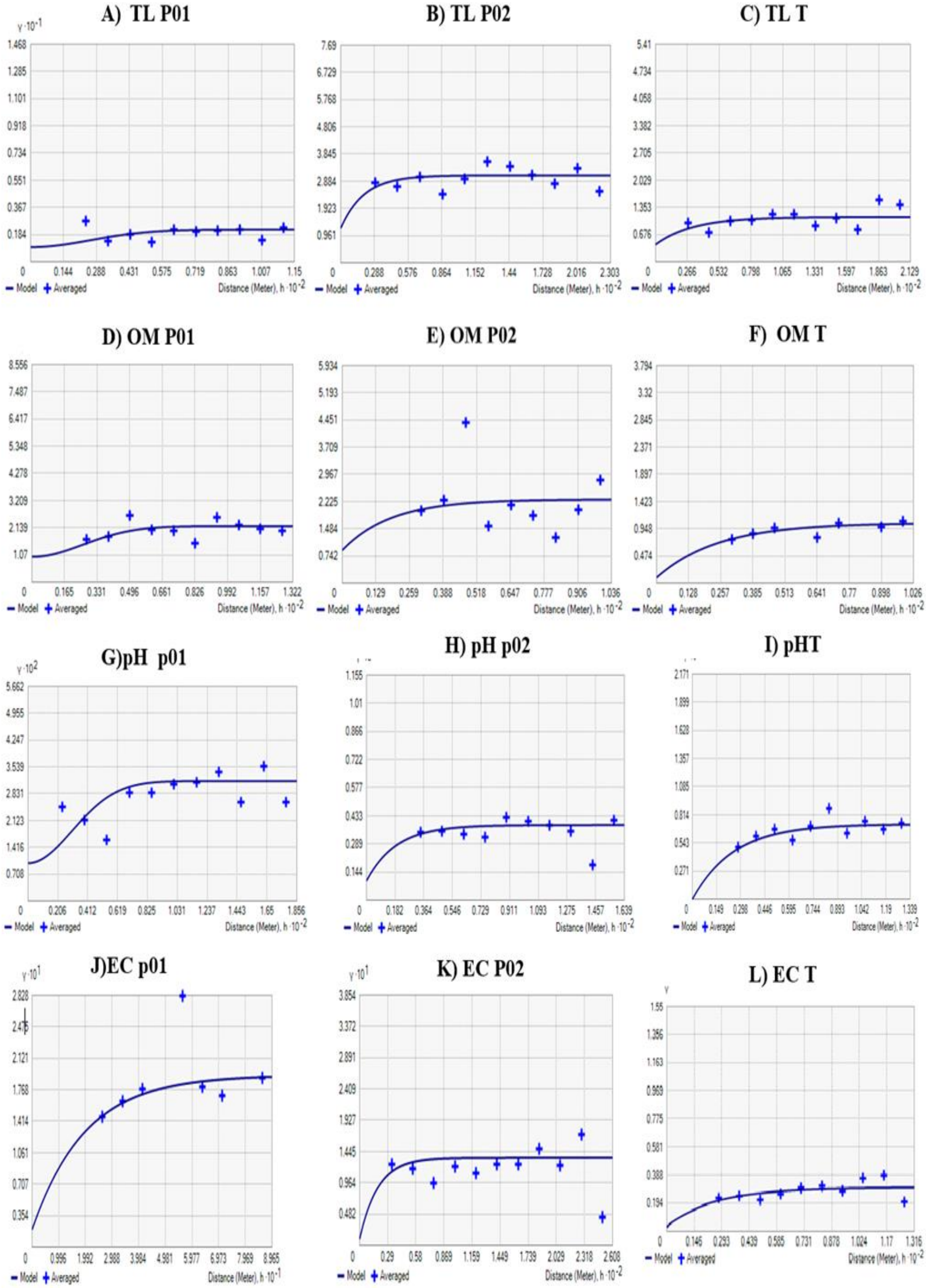
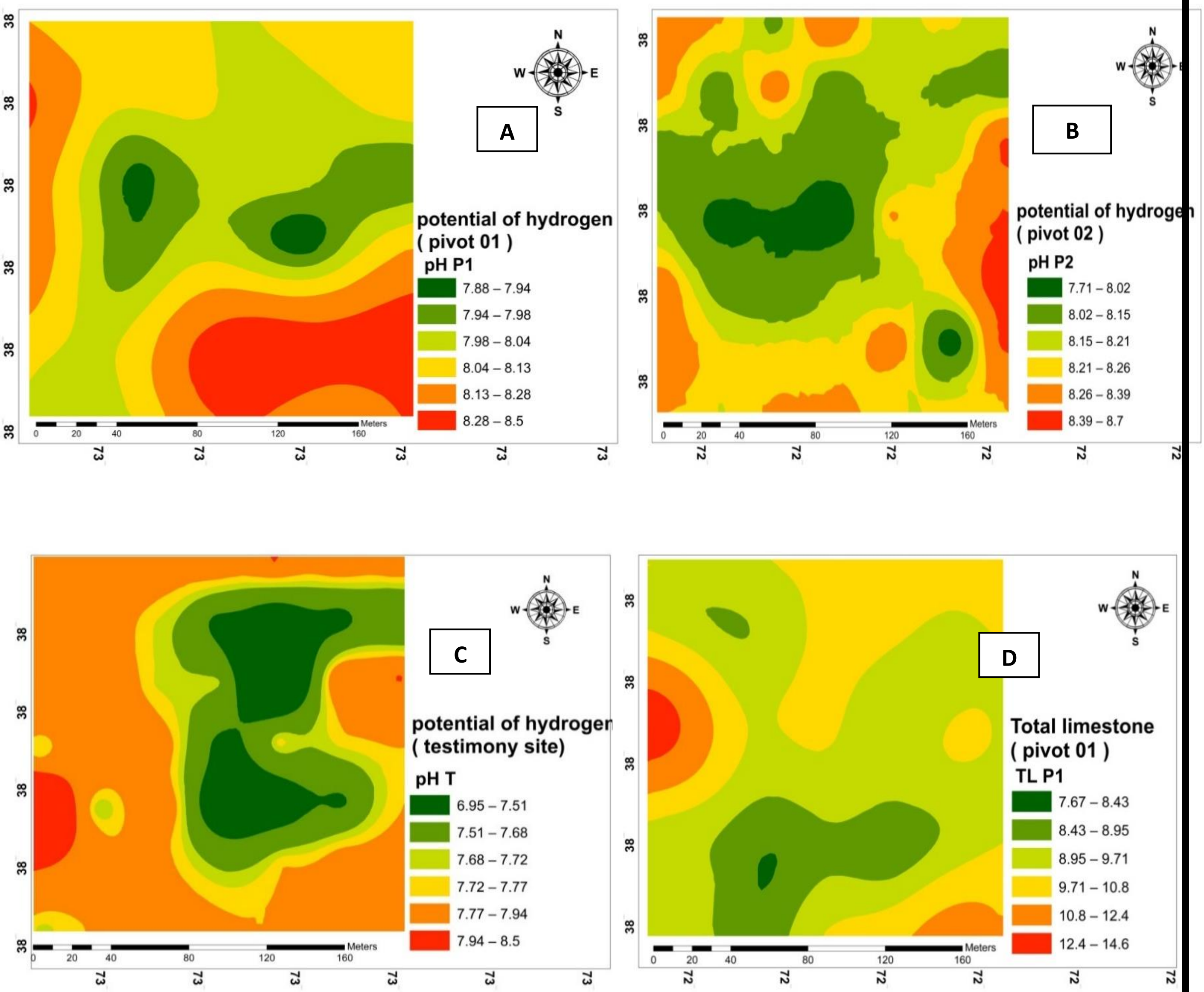
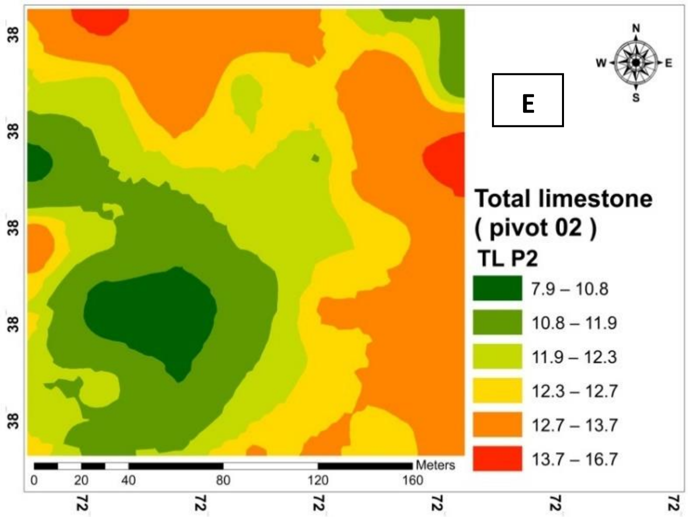

A) TL P01
B) TL P02
C) TL T
D) OM P01
E) OM P02
F) OM T
G)pH p01
H) pH p02
I) pHT
J)EC p01
K) EC P02
L) EC T
Model
Averaged
Distance (Meter), h ·10^-2

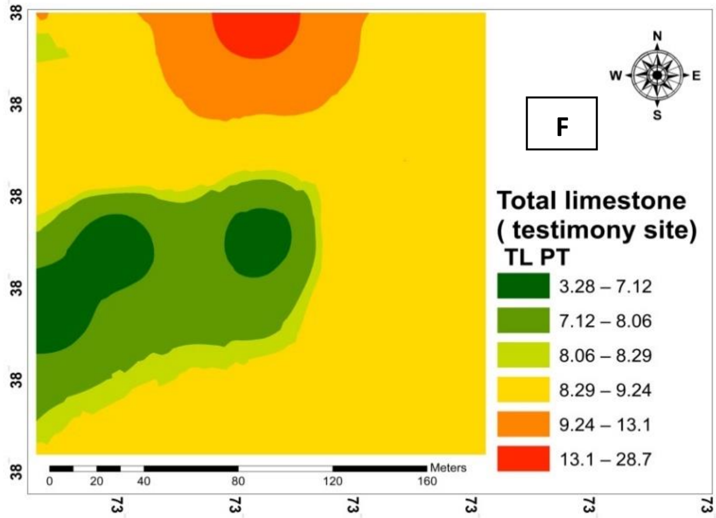
Figure 23: Directional semivariogram model calculated for soil pH, total limestone, EC and organic matter with log transformed data.

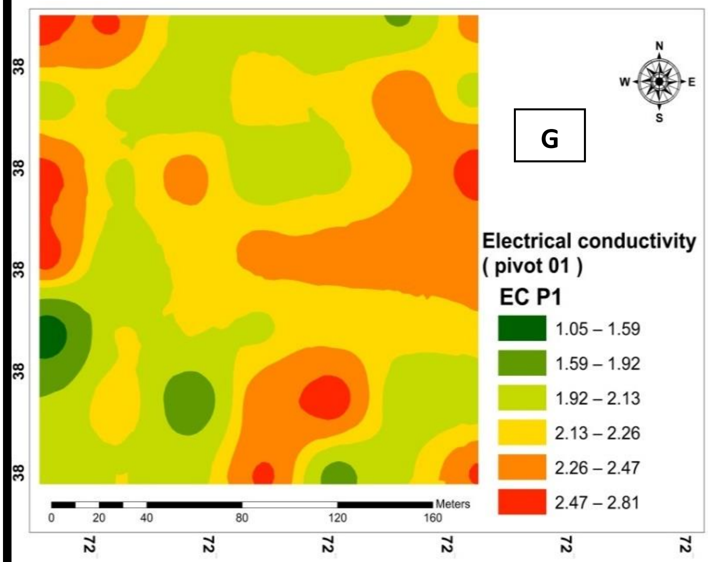
The data obtainned from the semivariograms highlighted that the pH, TL, EC and OM parameters are spatially correlated, but the correlation is limited to short distances. The nugget is a significant contributor to the total variance, indicating that there is a lot of variability that is not explained by the spatial correlation.

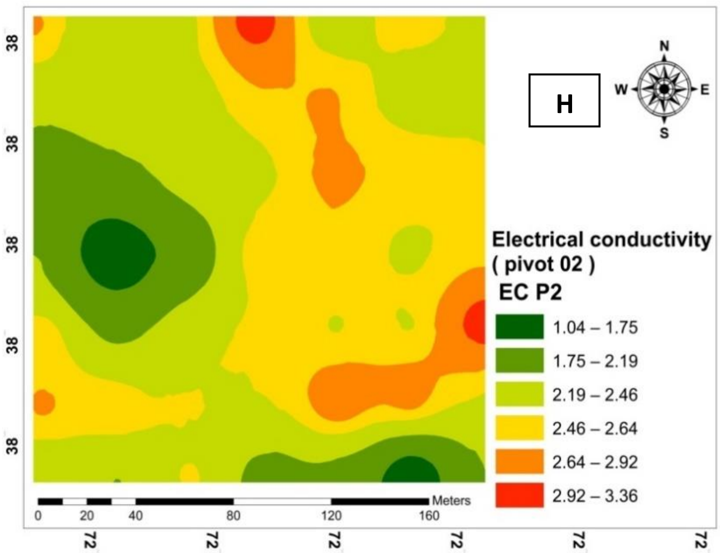
variance, indicating that there is a lot of variability that is not explained by the spatial correlation.




E
Total limestone
(pivot 02)
TL P2
7.9 – 10.8
10.8 – 11.9
11.9 – 12.3
12.3 – 12.7
12.7 – 13.7
13.7 – 16.7
Meters
0 20 40 80 120 160
N W E S
38
72


F
Total limestone
(testimony site)
TL PT
3.28 – 7.12
7.12 – 8.06
8.06 – 8.29
8.29 – 9.24
9.24 – 13.1
13.1 – 28.7
Meters
0 20 40 80 120 160
N W E S
38
73


G
Electrical conductivity
(pivot 01)
EC P1
1.05 – 1.59
1.59 – 1.92
1.92 – 2.13
2.13 – 2.26
2.26 – 2.47
2.47 – 2.81
Meters
0 20 40 80 120 160
N W E S
38
72


H
Electrical conductivity
(pivot 02)
EC P2
1.04 – 1.75
1.75 – 2.19
2.19 – 2.46
2.46 – 2.64
2.64 – 2.92
2.92 – 3.36
Meters
0 20 40 80 120 160
N W E S
38
72

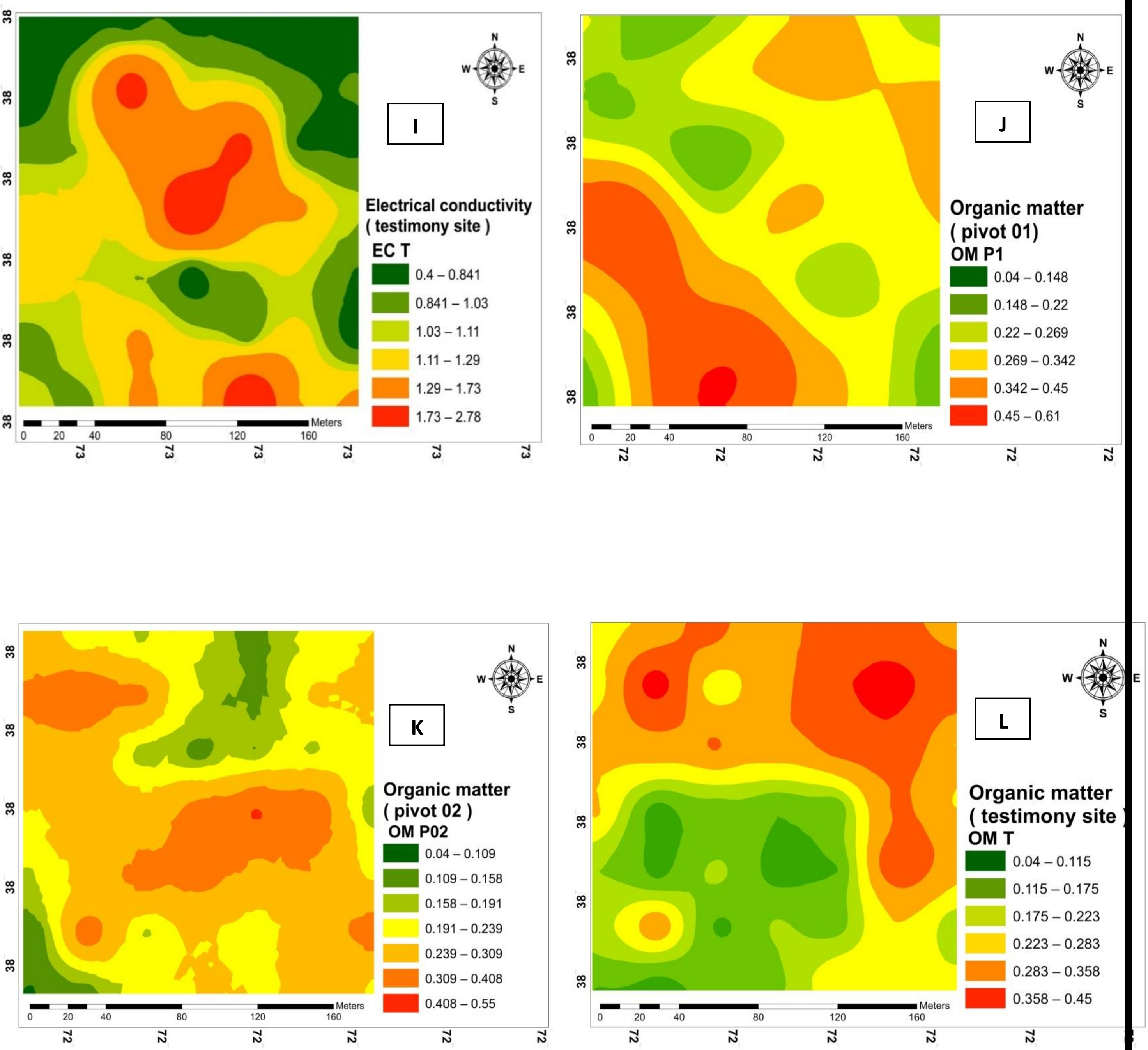


Figure 24: Spatial distribution maps of soil total limestone, organic matter, pH, TL, EC, OM for the three sites (P1, P2 and T) using Ordinary Kriging Interpolation method

Based on the spatial distribution maps shown in Figure 24, the pH (Figure 6A,B and C), testing soil values varied from 6.95 to 8.5, the map showed that slightly Alkaline soil is the dominated class (Retzer*et al.*, 1952). The lowest values were found in the middle. For the pivot (P1) value varied from 7.88 to 8.5, the moderately alkaline class was the dominant class, the lowest values were in the middle while the highest values situated in the eastern south. For the pivot (P2) the lowest values were also situated in the middle with a moderate alkaline soil. While for the Total Limestone (TL) values (Figure 6 D,E and F) in the testing soil varied from 3.28 to 28.7. The lowest values were found in the western region, while the highest values were observed in the northern part of the parcel, indicating a predominance of moderately calcareous soil class. For pivot (P2), the highest TL values were located in the eastern region, while the lowest values were found in the western region, ranging from 7.9 to 16.7. In pivot (P1), the TL distribution indicated a moderately calcareous class (Rachid *et al.*, 2018).The presence of limestone in the soil poses challenges for soil development and utilization, as only species tolerant to limestone can be effectively utilized. Non-resistant species may encounter growth difficulties and physiological disorders in the presence of limestone (Wang *et al.*, 2018). According to the maps of the spatial distribution of Electric conductivity in Figure 6 (G, H and I), the testing soil values varied from 0.4 to 2.78, the lowest values were found in the north while the highest values were found in the middle of the parcel with a dominant of moderately saline soils class. For pivot (P2) the highest values were situated in the west and the lowest in the east with the values that varied from 1.04 to 3.36, that made it belong to the class of very saline soil ,while in pivot (P1) the distribution of the EC is heterogeneous that has 3 different classes. The spatial patterns of soil properties can be attributed to the influence of the pivot irrigation system, which is intricately regulated by climatic factors, particularly during the summer season characterized by high temperatures, intense evaporation, and prevailing wind speed and direction. Regarding the Organic Matter (OM) values shown in Figure 6, the testing soil values ranged from 0.04 to 0.45. The map displayed that the highest values were found in the southern region. For pivot (P1), the values ranged from 0.04 to 0.61, with the lowest values in the central area and the highest values situated in the southeastern region. In pivot (P2), the highest values were also observed in the central area, indicating very low Organic Matter content in all three sites. Several studies have reported that soils in the Algerian Sahara region are generally poor in organic matter, often measuring less than 0.1% (Durant, 1954 ; Dutil, 1971 ; Daoud and Halitim, 1994 ; Halilat, 1998). This low OM content can be attributed, on one hand, to the extreme climatic conditions in Saharan regions, particularly high temperatures and low rainfall (Citeau*et al.,* 2008; Soco, 2009). On the other hand, agricultural intensification, including irrigation, can create optimal conditions (humidity and temperature) for the degradation of soil organic matter in Mediterranean regions (Laurence, 1998 ; Badraoui*et al.*, 2000). The relatively low amount of soil OM in agricultural soils may also result from the removal of crop residues (Awasthi *et al.*, 2005). A recent study by (Kharal*et al.,* 2018) found that intensive tillage for crops can decrease nutrient concentration and soil OM, leading to a decline in soil fertility. The conditions are further exacerbated by the implementation of intensified agricultural practices. Additionally, inadequate natural resource management and human-induced alterations to soil structure contribute to the observed distribution of soil properties.

By depicting the spatial variability of pH, total limestone, electric conductivity and organic matter, they enhance our understanding of these parameters, allowing for targeted interventions and the implementation of sustainable resource management practices (Stoorvogel and Bouma, 2005).

To evaluate the accuracy of the model, two statistical indices, namely Root Mean Square Error (RMSE) and Mean Average Error (MAE), were used. These indices provide quantitative measures of the model's performance and help assess the level of error in the predictions. Table 5 Prediction performance measures of ordinary Kriging for pH, TL, EC and OM for the three sites (P1, P2 and T).

Table 18: Prediction performance measures of ordinary Kriging

Parameters	Area	RMSE	MAE
	P1	0.482	0.345
pH	P2	0.274	0.259
	T	0.119	0.09
	P1	0.86	0.65
TL	P2	0.67	0.54
	T	0.97	0.69
	P1	0.345	0.25
EC	P2	0.183	0.153
	T	0.151	0.149
	P1	0.042	0.033
OM	P2	0.04	0.04
	T	0.06	0.05

Upon reviewing the findings presented in Table 18, it is evident that the ME (Mean Average Error) and RMSE (Root Mean Square Error) values for both parameters were close to zero. This comparison suggests that the model employed is valid and demonstrates satisfactory performance in accurately predicting the parameters (Hyndman et al., 2018).

Upon further analysis of the data presented in Table 20, it becomes apparent that the RMSE and MAE values for all parameters were higher for the two working sites compared to the reference site. Notably, the RMSE values for the reference site were lower than those for the two working sites, indicating superior performance of the reference site compared to the working sites.

4.3.3. Relationship between the two methods

Principal component analysis (PCA) is applied to check for possible correlations between the studied soil parameters. The resultsobtained are summarized in Figure 27 .

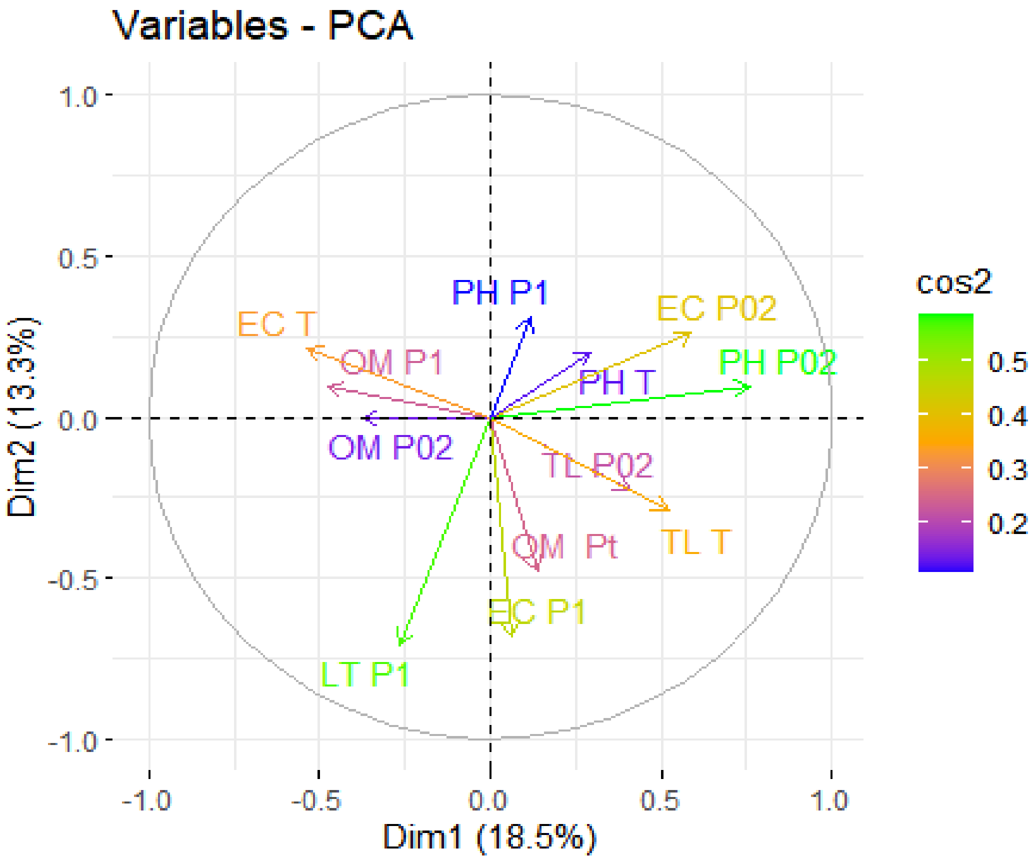


Figure 25: Principal component analysis (PCA) between the soil parameters studied for the three sites in Ourlal region .

Based on the image, it appears that the first principal component (Dim1) is positively correlated with EC and OM, and negatively correlated with PH and TL. This suggests that Dim1 represents a gradient of salinity and organic matter content, with higher values on the right side of the plot indicating higher salinity and organic matter content.

The second principal component (Dim2) is positively correlated with PH and TLT, and negatively correlated with AC P1 and LT P1 (which are not labeled in the image). This suggests that Dim2 represents a gradient of hydraulic potential and total limestone content, with higher values on the top of the plot indicating higher hydraulic potential and total limestone content.

Interpretation in the context of arid soil

The fact that the first principal component is positively correlated with EC suggests that the soils in the study area may be saline. This is consistent with the fact that the study was conducted in arid soil, where evaporation can lead to the accumulation of salts.

The negative correlation between Dim1 and PH suggests that the soils with higher salinity may also have lower hydraulic potential. This is also consistent with the fact that arid soils are typically dry and have low hydraulic potential.

The positive correlation between Dim2 and PH suggests that the soils with higher hydraulic potential may also have higher total limestone content. This is possible if the limestone is helping to hold water in the soil.

Overall, the results of the PCA analyses suggest that there is a gradient of salinity and organic matter content in the arid soils that were studied. The soils with higher salinity also tend to have lower hydraulic potential. There is also a gradient of hydraulic potential and total limestone content, with the soils that have higher hydraulic potential also tending to have higher total limestone content.

The intricate interaction between organic matter and total limestone in arid agricultural soils eludes unequivocal patterns. Scholarly inquiries have uncovered divergent outcomes, wherein heightened limestone content has been linked to both organic matter reduction due to organic-limestone bonding impeding microbial decomposition (Dekhinat*et al.*, 2010), and organic matter elevation facilitated by limestone provision of calcium and stimulating microbial activity (Leifeldet al., 2018; Edmeades*et al.*, 1981; Haynes, 1984; Haynes and Swift, 1988; Badalucco*et al.*, 1992). In summation, the nuanced correlation between organic matter and total limestone hinges upon multifarious determinants.

The intricate spatial distribution of soil properties is attributable to the impact of the pivot irrigation system, modulated by climatic factors, particularly during hot summers characterized by elevated temperatures, intensive evaporation, and prevailing wind dynamics (Paustian*et al.*, 1998; West and Post, 2002; Conant *et al.*, 2007), further influenced by intensified agricultural practices. Concurrently, inadequate natural resource management and anthropogenic alterations of soil structure contribute to the observed soil property distribution. Depiction of spatial variations in Total limestone and Organic matter augments comprehension of these parameters, affording targeted interventions and sustainable resource management (Stoorvogel and Bouma, 2005).

The intricate interaction between EC and pH across the three sites manifests as a negative correlation. This signifies that as soil pH ascends, EC descends, attributed to diminished mobility of electrically conducting ions in acidic soils. The potency of this negative correlation fluctuates across sites, being most pronounced in Site 1 and most attenuated in Site 3, implying that the EC-pH relationship evinces greater linearity in Site 1.

In acidic soils, reduced ion mobility stems from hydrogen ion (H^+) binding to negatively charged soil particle surfaces, hindering free ion movement and electrical conductivity (Smith and Doran, 1997). As pH rises, hydrogen ion concentration wanes, facilitating unhindered ion mobility and heightened EC.

In a general context, the inverse correlation between EC and pH serves as an insightful indicator of soil quality. Soils exhibiting high EC and low pH typically inhibit plant growth due to impeded water and nutrient absorption resulting from heightened EC, and soil toxicity stemming from low pH (Patriquin*et al.*, 1993).

The inverse correlation between EC and TL augments the soil quality insight. Soils characterized by elevated TL and diminished EC offer a conducive milieu for plant growth. This is attributed to heightened TL enhancing soil drainage, thereby easing water absorption (Mueller *et al.*, 2003), while low EC signifies soil non-salinity, conducive to plant vitality. Generally, soils characterized by high TL and low EC are apt for agricultural pursuits, juxtaposed against low TL and high EC scenarios. The EC-TL correlation is explicable by limestone's electrical conductivity (Lamare and Singh, 2017); higher TL corresponds to augmented limestone ions, facilitating enhanced electrical conductivity. Conversely, TL diminution reduces ion mobility, curtailing EC. The variance in correlation strength among sites suggests site-specific relational dynamics arising from disparate soil types, climates, and vegetation

Conclusion

The investigation into the spatial variability of soil quality within agrosystems of the Algerian Sahara, focusing on pivot cereal farming as a model for intensive agriculture in these regions, was carried out across two stations: the Dris Omor Farm Station in El Outaya, Biskra, and the station in Ourlal, Biskra. Employing a systematic regular grid sampling method of 30 x 30 meters for both stations, the study scrutinized key soil properties including soil salinity (expressed by electrical conductivity), pH, total soil limestone, and organic matter.

Statistical analyses, including descriptive statistics reports, analysis of variance, and assessment of annual variation rates, provided insights into the dynamics of soil properties over time. Additionally, a geostatistical approach was adopted to characterize the spatial variability of the study parameters, utilizing variographic analysis, cross-validation, and the creation of thematic maps through ordinary kriging with the most reliable model provided by cross-validation.

The meticulous examination of soil quality in the irrigated regions of Ourlal and El Outaya revealed significant variations in key parameters such as pH, electrical conductivity, organic matter, and total limestone content. Granulometry analysis unveiled sandy loam soil dominance, with pH values ranging from moderately alkaline to slightly alkaline in cultivated soils compared to the reference soil. Notable salinity levels were observed in irrigation water, further indicating the impact of agricultural practices on soil salinity levels.

Variogram modeling revealed complex spatial variability patterns for pH and electrical conductivity, underscoring the importance of understanding these dynamics for effective soil management. Root Mean Square Error (RMSE) values provided insights into the accuracy of the models, highlighting the need for precision in assessing soil characteristics.

The coefficient of variation highlighted minimal spatial variation in organic matter content but significant fluctuations in electrical conductivity and total limestone values across the study sites. For example, in Ourlal, pivot 1 exhibited a coefficient of variation of 27.35% for electrical conductivity, while pivot 02 had 25.80%, and the reference soil displayed 17.08%. In El Outaya, similar variations were observed, with different coefficients of variation for the same parameters.

These findings underscore the profound impact of agricultural practices on soil characteristics, emphasizing the necessity for improved management strategies to ensure the long-term sustainability of farming systems in irrigated regions.

To address these challenges and pave the way for more sustainable agricultural practices, future research should consider extending the study to other parameters and stations, studying the vertical variability of soil properties, and utilizing geostatistics to diagnose the spatial variability of irrigation water distribution. By integrating interdisciplinary insights and advanced analytical techniques, such as geostatistics, we can enhance our understanding of soil dynamics and develop more informed decision-making frameworks for sustainable agriculture in challenging environments like the Algerian Sahara .

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