Journal of Geographic Information System, 2022, 14, 503-515
https://www.scirp.org/journal/jgis
ISSN Online: 2151-1969
ISSN Print: 2151-1950

# Evaluation of the Physical and Chemical Fertility of Soils in the Sylvopastoral Zone: Case of the Pilot Site of the National Institute of Pedology in the Commune of Kelle Gueye (Louga/Senegal)

**Niang Aliou[1], Ndao Mohamed Lamine[2]**

[1]Silvopastoral Zone, National Institute of Pedology (INP/Louga), Louga, Sénégal
[2]Department of Land Planning, Environment and Urban Management, Graduate School of Applied Economics (ESEA), Cheikh Anta Diop University, Dakar, Senegal
Email: niangagro2015@gmail.com, mohamedlamine.ndao@ucad.edu.sn

**How to cite this paper:** Aliou, N. and Lamine, N.M. (2022) Evaluation of the Physical and Chemical Fertility of Soils in the Sylvopastoral Zone: Case of the Pilot Site of the National Institute of Pedology in the Commune of Kelle Gueye (Louga/Senegal). *Journal of Geographic Information System*, **14**, 503-515.
https://doi.org/10.4236/jgis.2022.145028

**Received:** July 19, 2022
**Accepted:** October 21, 2022
**Published:** October 24, 2022



## Abstract

The study of the reference state of the physico-chemical fertility of the soils of the pilot site of the National Institute of Pedology in the commune of Kelle Gueye to test the effect of phosphocomposte on cowpea and groundnut, allowed us to better understand the aptitudes of the above-mentioned crops. The methodology used consisted of taking soil samples on a regular 25 m grid, carrying out complete physico-chemical analyses at the INP laboratory and an analysis of climatic parameters. The results obtained were used to produce thematic maps to better interpret the various parameters. The physico-chemical analyses at the 0 - 20 cm horizon show a pH (6.1 - 7.9) close to neutral and a non-saline soil (EC < 250 µS/cm). The site is poor in organic matter; it is of the order of $0.1 \leq MO \leq 0.9$. The granulometric results determined from a laser granulometry which gives more precision, show that the soils have a texture dominated by fine sands with more than 50% in the site. This study reveals that the site is suitable for groundnut and cowpea cultivation. However, some chemical parameters need to be improved to make the soil more fertile.

## Keywords

Thematic Maps, Physico-Chemical Analysis, Phosphocomposting

## 1. Introduction

Land degradation, desertification and drought are a growing threat to the future of our environment. They lead to the loss of terrestrial ecosystem services, which are essential for economic and social development. Food production, water availability and energy security are compromised by the continued loss of land and soil. Failure to act on this threat could have major negative consequences for economies and prospects for sustainable development.

In view of these functions and challenges, soil management becomes necessary to promote sustainable agricultural activities. The control of soil characteristics is essential for a rational orientation of land occupation and use.

In the face of climate change risks, there is an urgent need to strengthen sustainable soil management strategies, especially in ecologically fragile agrosystems. In the field, soil properties are often characterised on a point or linear basis (augering or soil profile descriptions from pits). Exhaustive characterisation, which can be carried out by geostatistical methods, offers a synthetic view of the variability of the physico-chemical properties of the soil cover. It can thus guide judicious development choices and serve as a reference for developing soil quality management strategies. Geostatistics, in particular kriging, is the methodological approach used, with organic matter (CO) and hydrogen potential (pH) being the targeted properties.

Organic matter is a recognised indicator of the fertility of Sahelian soils [1]. For a given climate, organic carbon richness is often influenced by other intrinsic soil factors (texture, base richness, structure) [2]. Furthermore, it is established that organic carbon from inputs is essential for the development of soil quality and sustainable production systems in the Sahel [3].

The hydrogen potential (pH) provides information on the level of acidity of the soil. The degree of acidity or basicity of the soil plays a very important role in the assimilability of plant nutrients. Soil acidity is influenced by a complex set of chemical, physical and biological changes. Acidification considerably reduces soil fertility, affecting soil biology, decomposing organic matter and causing nutrient loss [4].

The Louga region is marked by the degradation of Arab lands despite the efforts of the government [5]. The impact of agricultural policies (peanut monocultures, deforestation) and the agro-pastoral system put in place since then favour situations of overgrazing, deforestation and overexploitation of the land precipitating the degradation processes [6].

SOS Faim and its local partner FAPAL (Federation of Peasant Associations of the Louga Region) are strategically associated with the aim of maintaining soil fertility in this region where more than 70% of households depend on family farming [6]. Conducting a soil fertility assessment seems to us to be a good option for choosing the most suitable species.

Thus, the main objective of this study is to evaluate the physico-chemical fertility of the different soils on the site before testing phosphocomposting on cowpeas and groundnuts.

## 2. Context and Presentation of the Study Area

### 2.1. Context

Land degradation, desertification and drought are a growing threat to the future of our environment. They lead to the loss of terrestrial ecosystem services, which are essential for economic and social development. Food production, water availability and energy security are compromised by the continued loss of land and soil.

The soil nutrient balance in the tropics is the most negative in the world due to aggressive rainfall, high temperatures and low pH levels [7]. Also, it must be recognised that the use of synthetic fertilisers in these regions is limited by the exorbitant and increasing price on the market and the acidification caused by their long-term application [8]. In the face of these socio-economic and environmental challenges, it becomes imperative to look for alternative sources of nutrients for sustainable agriculture at a time when agricultural imports are at an all-time high due to low crop yields. Moreover, the strategy of importing agricultural products is increasingly controversial as it absorbs a large share of countries' foreign exchange [9]. To mitigate the decline in crop yields, several approaches can be considered: organic fertilisation [10], the practice of crop associations, crop rotations and crop rotation [11].

The Ferlo forest-pastoral zone, which covers a vast area of 36,289 $km^2$, is undergoing a fairly advanced process of desertification with a marked disappearance of plant cover due to drought and the abusive pruning of woody plants by herders. It is home to weakly evolved tropical ferruginous soils with siliceous sands (transhumance rangelands) and slightly leached tropical ferruginous soils with a sandy-clay texture or ferruginous concretions (rangelands and groundnut cultivation); sub-arid brown soils and sub-arid red brown soils.

In tropical ecosystems such as the Ferlo, the extensive livestock system is the predominant type of land use. This system is based on the exploitation of pastures [12], which ensure various functions such as feeding livestock with fodder [13] [14] [15] and providing the soil with organic matter. However, this system, through overgrazing, causes environmental damage, namely soil degradation (encrustation, compaction) which favours water and wind erosion, thus accentuating the export of organic elements from the soil. With the demographic growth that this area has experienced in recent years, there has been a change in land use, which is increasingly turned towards agricultural and forestry activities that can have different consequences on the evolution of the physical and chemical fertility of the soil.

It is in this context that this study is being conducted at the pilot site of the National Institute of Pedology (INP) in the commune of Kelle Gueye. This study is a continuation of the numerous pedological studies carried out in the Ferlo area [16] [17] which have enabled the characterisation and determination of the different types of soil encountered in this region.

The non-existence of a study assessing soil fertility in the pilot site made it worthwhile to do so. Therefore, this study is carried out in order to analyse the physical and chemical parameters of the soil through the following question: What is the state of soil fertility in the pilot site?

### 2.2. Presentation of the Study Area

The area studied is the pilot site of the Institut National de Pédologie located in the commune of Kelle Gueye in the Louga region (Figure 1). It is located eight kilometres from the town of Louga. The pilot site covers an area of 3.37 ha. The climate is Sahelian. The rainy season lasts three months (July-September). The dry season lasts nine months (October to June). The vegetation is characterised by a typically Sahelian shrub steppe, composed of the species Acacia raddiana, Balanites aegyptiaca, Prosopis juliflora, Euphorbia balsamifera, etc.

## 3. Methodology

### 3.1. The Documentary Review

This documentary review focused on books and articles that deal with issues related to the characteristics and quality of the soil. This situation leads us to visit the library of the INP and that of the UCAD for the collection of data. This research has given us a lot of access to several documents and a better understanding of the region in several areas.

### 3.2. Field Work

Pre-field work was carried out using Landsat images, Google Earth and GPS

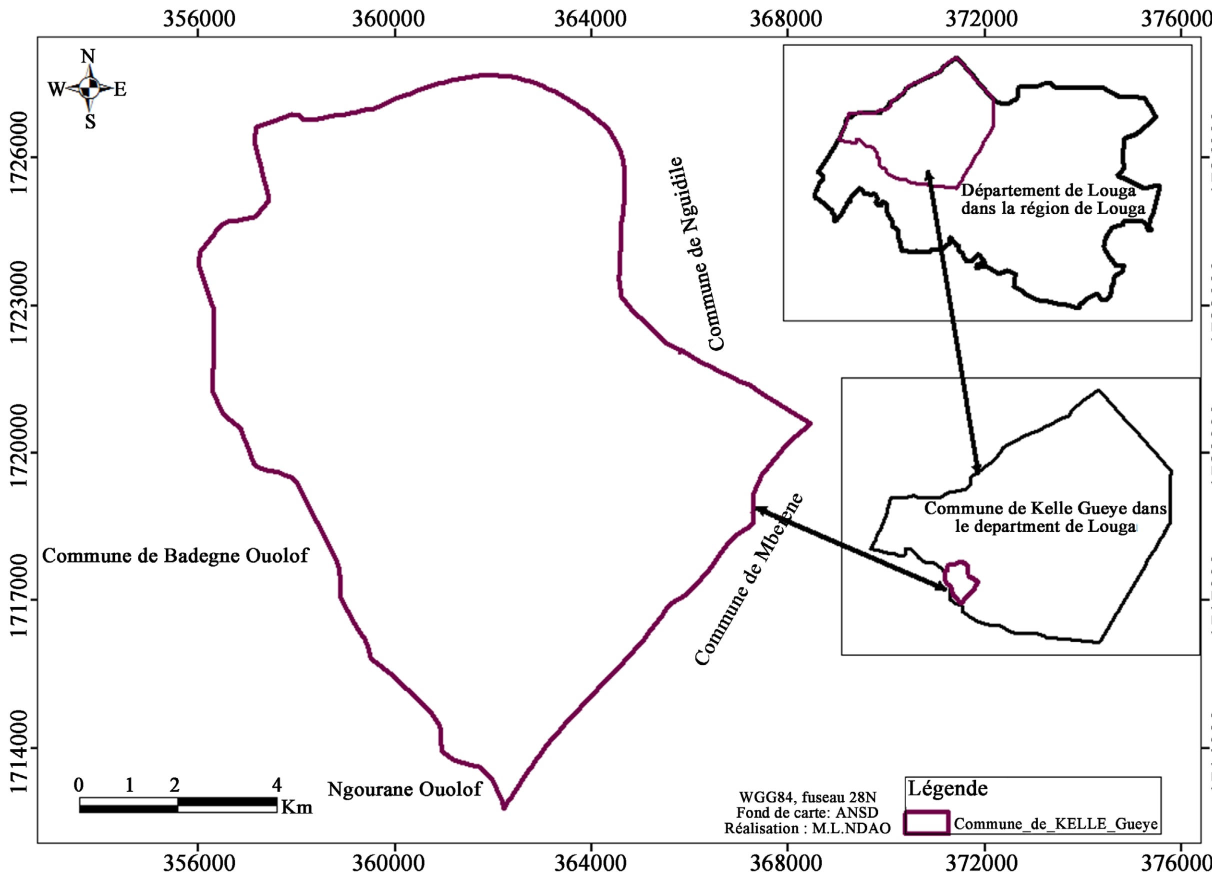


Figure 1. Location map.

readings, which allowed us to delimit the pilot site. To this end, we then drew up a plan for taking soil samples on a regular 25 m grid (**Figure 2**). Ensuite, nous avons organisé une mission sur le site de Kelle Gueye. Lors de cette mission, des prélèvements d'échantillon ont été effectués sur le site pilote.

All boreholes were augered, with a total of 58 samples in the 0 - 20 cm horizon. The geographical coordinates of each sampling point are located by GPS. These samples were brought to the laboratory dried and sieved before being analysed. The insertion of analytical soil parameters (pH and OM) into a geographic information system and the application of kriging with Arc Gis 10 software allowed a geostatistical characterisation of the variability of soil properties.

### 3.2.1. Measurement of Physico-Chemical Parameters at the INP Laboratory

The methods of soil analysis are documented in the laboratory. Among these analyses we measured pH (hydrogen potential) and OM (organic matter).

### 3.2.2. The Method for Measuring ph

The measurement of the pH-water of the soil is done from an aqueous solution with a ratio of soil/water 1/2.5, *i.e.* for 1g of soil 2.5 ml of distilled water are used. This means an equivalence of 20 g of soil for 50 ml of distilled water. The pH is

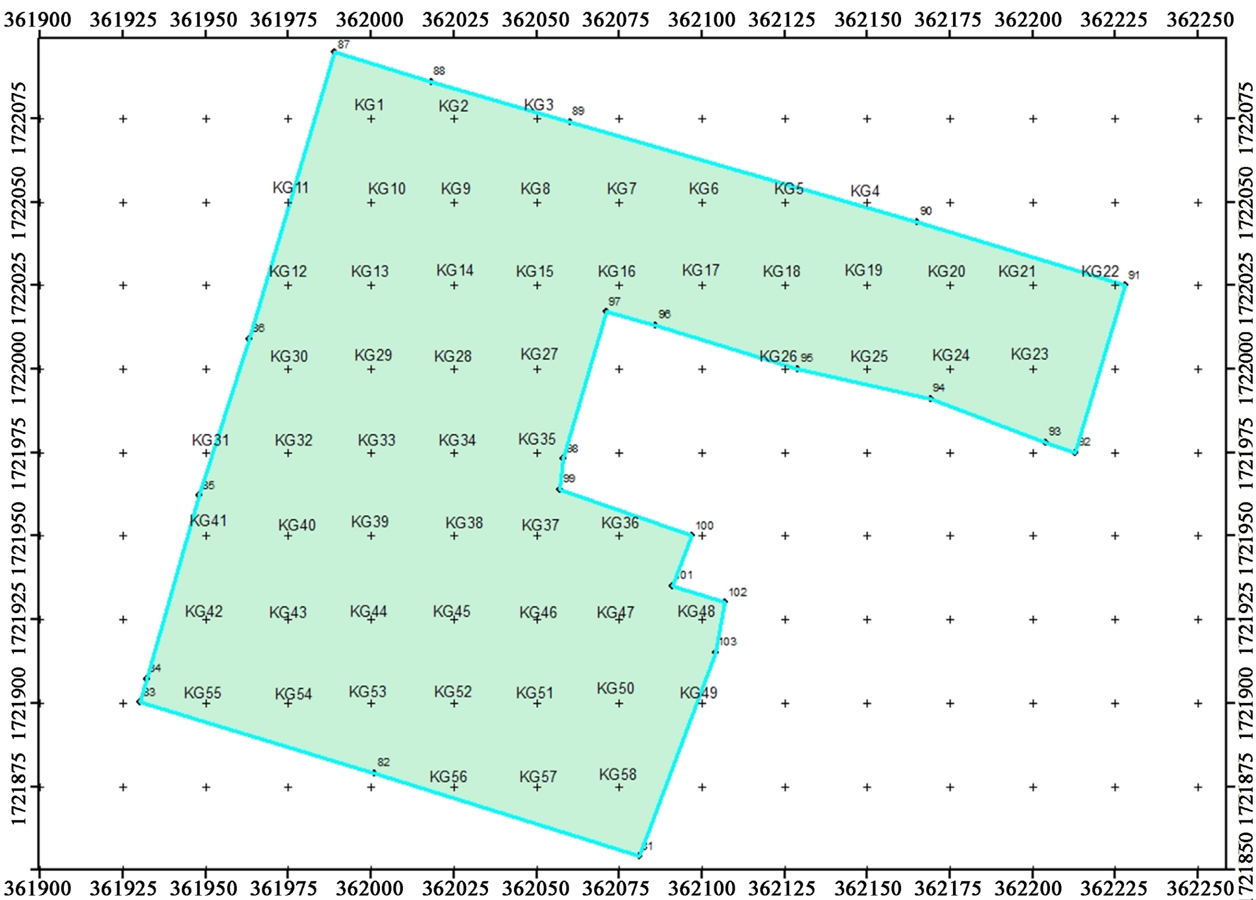


**Figure 2.** Location of survey points.

**Table 1.** Interpretation of soil pH proposed by ISRIC [18].

| <4.0 | 4.0 - 4.9 | 5.0 - 5.4 | 5.5 - 5.9 | 6.0 - 7.5 | 7.6 - 8.4 | 8.5 - 9.4 | >9.5 |
|---|---|---|---|---|---|---|---|
| Ext. acid | Very acid | acid | Light. acid | Neutral | Light. Alkaline | Alkaline | Very alkaline |

Ext.: Extremely; Light.: Lightly.

measured with a pH meter using the "glass electrode" 30 minutes after stirring. A range is defined for the pH-water values of the soil from <4.0 extremely acidic to >9.5 very alkaline (see Table 1).

#### 3.2.3. Method for the Determination of Organic Matter or Modified Walkley and Black Method

Since organic carbon (OC) is estimated to be 58% of the organic matter (OM), this method allows the determination of the total carbon contained in a sample. It is a redox reaction on 0.2 to 1 g of soil which consists of oxidising the carbon by an excess of 10 ml of potassium dichromate ($K_2Cr_2O_7$) solution in a 20 ml concentrated sulphuric acid ($H_2SO_4$) medium. The unreacted excess potassium dichromate is titrated back by dropwise ammonium iron (II) sulphate hexa hydrate [$(NH_4)\cdot 4Fe(SO_4^2)\cdot 6H_2O$] (Mohr's salt) in the presence of 10 ml ortho-phosphoric acid and 2 to 3 drops of diphenylamine (redox indicator). The percentage of organic matter is equal to 1.724 times that of organic carbon and the organic matter is determined by: (% MO = 1.724% CO).

Note: The test sample size varies from 0.2 to 2.5 g for surface soil horizons or depending on soil colour and 2 to 10 g for deep soil horizons.

#### 3.2.4. The Ammonium Acetate Method ($CH_3COONH_4$)

The determination of exchangeable bases or cations (K+, Na+, Ca++, Mg++) expressed in meq/100g or meq·100 $g^{-1}$ is carried out on the filtrate recovered during saturation of the soil with ammonium acetate. Sodium (Na) and potassium (K) are determined directly by flame photometer reading, while magnesium (Mg) and calcium (Ca) are determined by complexometry. In general, both magnesium and calcium (Ca + Mg) are determined and then calcium (Ca) alone. Magnesium is determined by the difference in the results of the determinations between (Ca + Mg) and (Ca). Ammonium acetate is used for soil with a pH < 7. Ethylene diamine tetra acetic acid (EDTA) of formula $C_{10}H_{14}N_2Na_2O_8\cdot 2H_2O$ is used to determine the amount of (Ca + Mg) in 20 ml of the extraction solution in the presence of 5 ml of the buffer solution pH 10.1 (consisting of a mixture of 67.5 g ammonium chloride and 570 ml ammonia in 1 litre) and an indicator The colour change is achieved when the colour changes from wine red to blue. The exchangeable bases are calculated by the formula of [19].

Sodium is calculated by the formula: Na me.100 $g^{-1}$ = 1.25 R where R is determined by the sodium calibration curve.

Potassium is calculated by the formula: Kme.100 $g^{-1}$ = 0.032 R.

Calcium and exchangeable magnesium: Ca + Mg me.100 $g^{-1}$ = 1.25 (M-B) where M = EDTA consumed to assay the sample in ml. Ca me.100 $g^{-1}$ = 1.25

(M-B) where B = EDTA consumed to assay the control in ml.

Mg me.100 $g^{-1}$ = (Ca + Mg) − Ca.

It should be noted that the total nitrogen content (%N) in the soil is determined by calculation in the laboratory.

#### 3.2.5. Measuring the Physical Parameters of the Soil

Granulometry consists of determining the size of the particles contained in a sample. At the INP, particle size measurement is carried out using the Mastersizer 3000 laser machine, a device consisting of an optical bench or instrument, a liquid dispersion module called hydro EV connected to a computer in which the Mastersizer 3000 software is installed. The computer is used to measure and display the results. The evaluation is done by volume distribution of the particle size with distilled water.

The principle of measurement is simple and is done manually with the computer on a dry sample sieved to 1 mm.

The analysis of a sample is done in four steps:

- Clean the instrument three (3) times with distilled water from the computer with a high speed shaker up to 3100 rpm;
- initialise the instrument with the water from the third cleaning by decreasing the speed of the shaker to between 1500 and 1700 rpm;
- measure the background noise while maintaining the same stirring speed;
- introduce the sample in the water contained in the hydro EV until the interval of 12% to 20% of the obscurance and finally analyse. The machine measures the sample 5 times within 50 seconds and gives the average of the measurement results.

The international scale classification (Atterberg, ISSA) (**Table 2**) can be used for the particles.

### 3.3. Data Processing

At the INP, the work of [19] and [18] is used as a reference for the analysis and interpretation of physico-chemical and chemical soil parameters. The texture triangle is used to analyse the texture of soils as a function of grain size to determine the main textural classes and fundamental soil textures (**Figure 3**).

## 4. Results

### 4.1. Physico-Chemical Parameters

#### 4.1.1. Physical Characterisation of the Pilot Site

The examination carried out on the Kelle Gueye samples in the laboratory made

**Table 2.** F.A.O. particle size classification according to [18].

| Clay | Fine silts | Coarse silt | Very fine sands | fine sands | medium sand | coarse sand | very coarse sand |
|---|---|---|---|---|---|---|---|
| <2 | 20 | 63 | 125 | 200 | 630 | 1200 | 2000 |

The unit in μm.

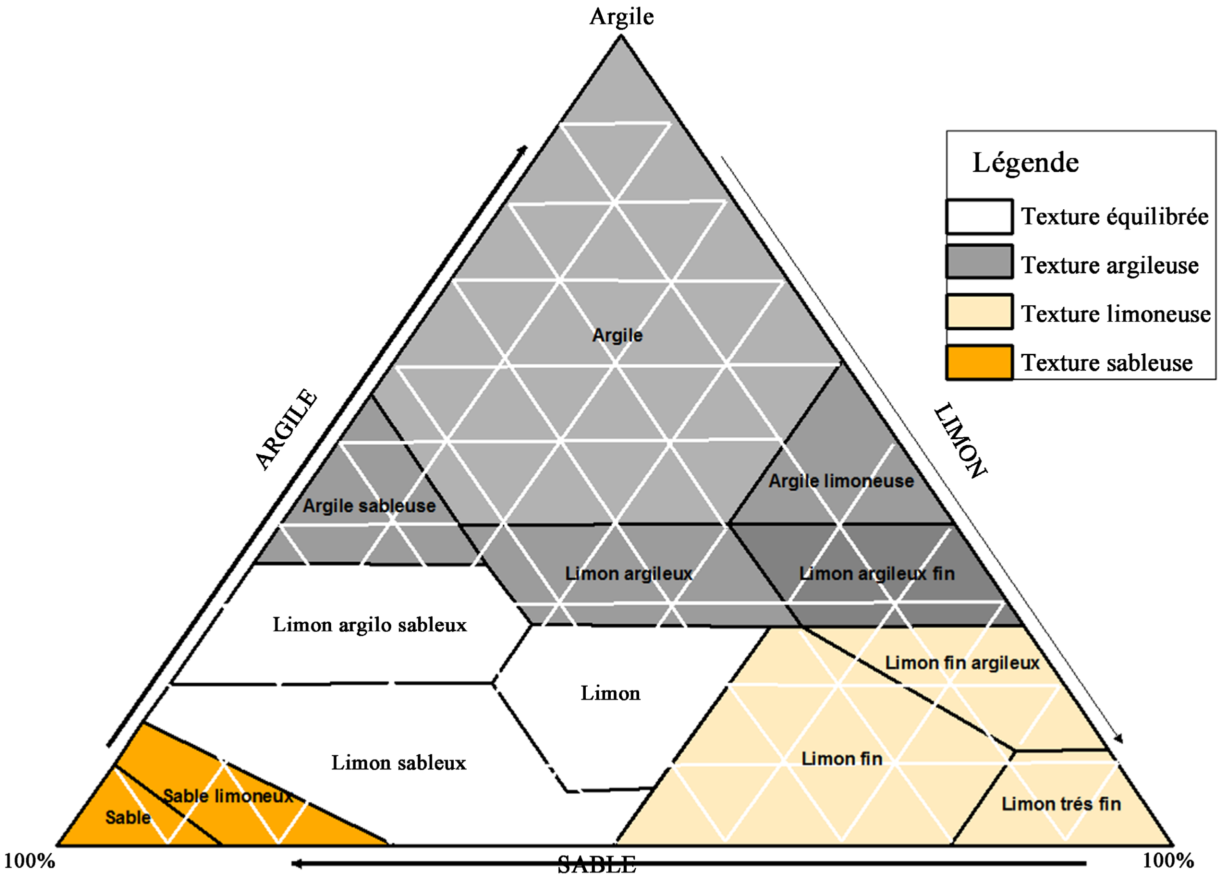


**Figure 3.** Triangle des textures [20].

it possible to establish the characteristics of the various physical properties. These different parameters made it possible to assess the texture and structure of the soil.

1) Texture

The analysis of the profile samples and boreholes of the KELLE GUEYE soils shows three granulometric fractions of medium coarse and fine sandy particles distributed in unequal proportions (**Figure 4**) with a dominance of fine sand over 50%.

2) Structure

Structure is a very important concept in practice because it conditions the circulation of air, water and rooting [21]. It is determined on the basis of observation of profiles in the field. The soil structure studied at Kelle Gueye is massive, with no aggregates. Consequently, the structure of the horizons is of considerable importance for plant growth. The massive structure offers a stability to the soils which are essential for the cultivation of groundnut and cowpea.

#### 4.1.2. Chemical Characterisation of the Site Soils

The examination carried out on the Kelle Gueye samples in the laboratory made it possible to establish the characteristics of the various chemical and organic properties of the soils. These different parameters made it possible to

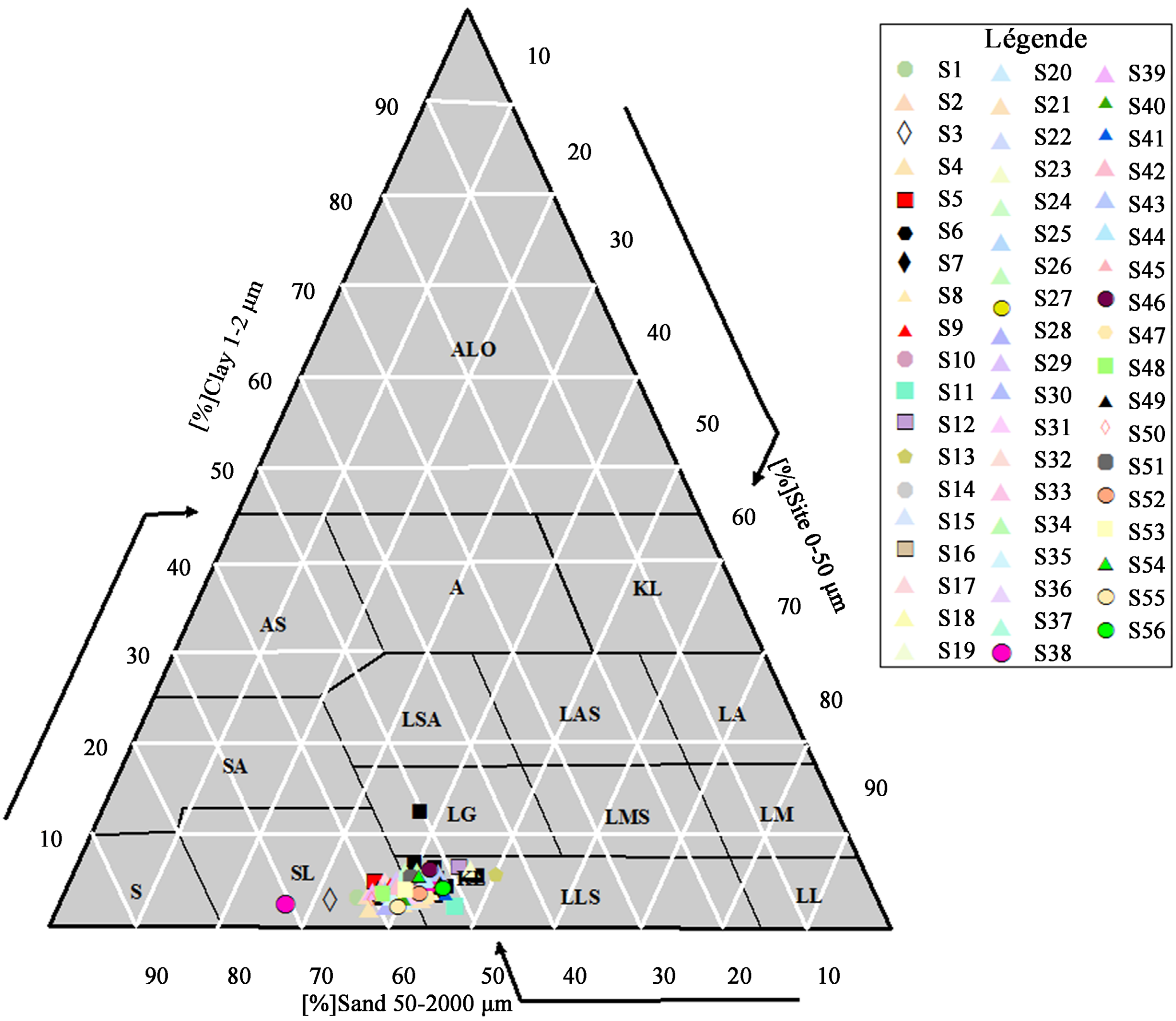


**Figure 4.** Textural triangle of the pilot site.

assess the chemical fertility of the soils, which are based on the one hand on the measurement of pH and organic matter MO (%).

1) pH variability

The pH variability map from the kriging shows generally neutral soils. In the 0-20cm horizons, pH values vary between 6 and 7.9 (**Figure 5**). Basic soils with a pH of 8.57 are poorly represented. They are located in the northern and southern parts of the site.

Eight types of pH vary from surface to depth and from block to block throughout the area. These near-neutral pH ranges (5.5 to 7.5) allow us to conclude that these soils are very favourable for groundnut and cowpea crops.

2) *Variabilité de la matière organique*

According to Calvet [22], organic matter represents on average 1% to 10% of the soil mass and nitrogen 0.006% to 0.3%, 90% of which is in organic form and 10% in inorganic form (ammonium). The results obtained on the organic evolution of the area show that the organic matter content is very poor to average in

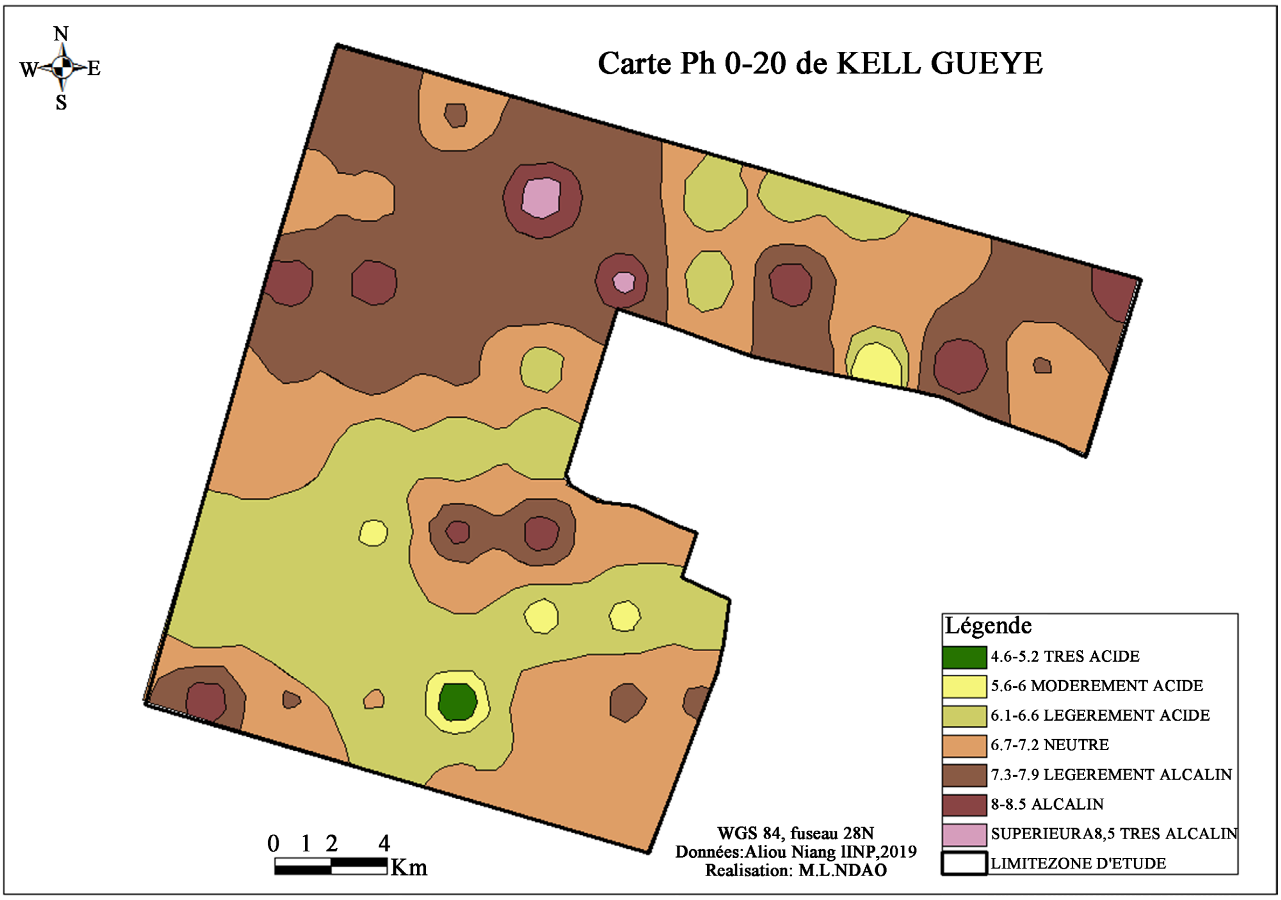


**Figure 5.** Ph variability of the 0-20 horizon

the boreholes overall. It is of the order (0.1 ≤ MO ≤ 0.9) in the boreholes of the site (**Figure 6**). The OM content is very low, less than 1% in the boreholes (S1 to S58) throughout the site. This low content may affect the yield if not corrected as OM plays an important role in the soil.

## 5. Discussion

Kriging gave more accurate results for the characterisation of organic carbon and pH variability. A fine characterisation of the variability of soil properties by kriging requires the prior development of a dense or spatially stratified sampling design. Our sampling strategy using a regular 25 m grid allowed us to obtain satisfactory results for the spatialization of organic carbon and hydrogen potential.

The evaluation of the physico-chemical fertility of the soils in the INP pilot site in the commune of Kelle Gueye, reveals that the soil is poor in organic matter at the 0 - 20 horizon.

This poverty could be explained by the biochemical nature of the organic matter inputs in the previous crops.

The acidity of point 53 could be explained by a deposit of organic matter. And the rise in pH level by phosphate amendments.

This decrease in carbon could also be explained by erosion or leaching of

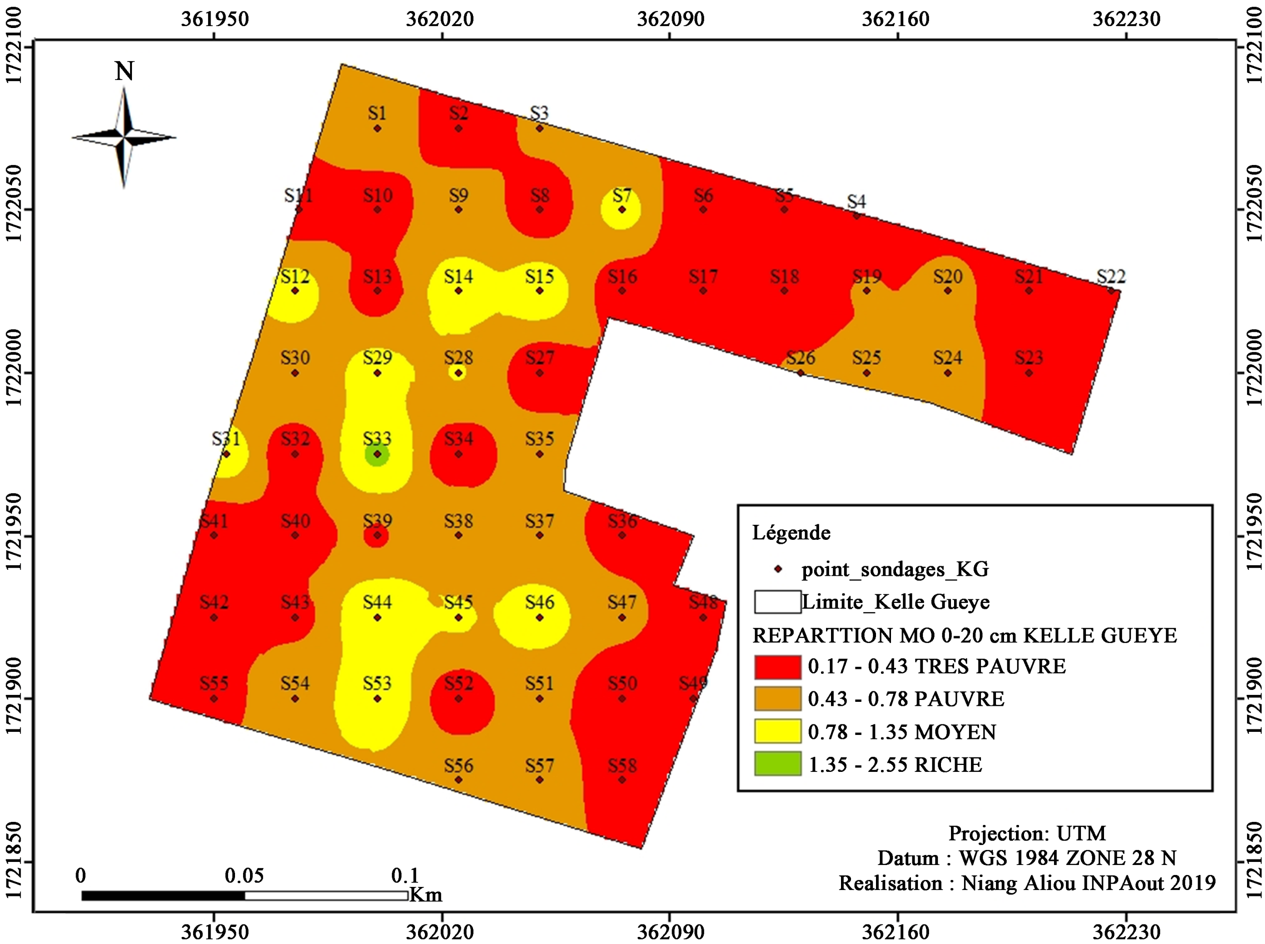


**Figure 6.** Variability of organic matter in the 0 - 20 cm horizon.

these elements due to substrate degradation (crusting, compaction) caused by overgrazing in parts enriched in fine elements.

In pastures, the low carbon could be explained by the contribution of easily degradable organic matter of animal origin which would stimulate the mineralisation of Som, moreover the C/N ratio found in this system generally between 8 and 10 indicates a good decomposition of the organic matter. This decrease in soil carbon and nitrogen in this system could also be explained by erosion or leaching of these elements due to substrate degradation (crusting, compaction) caused by overgrazing in the parts enriched in fine elements. There is also a physical protection of the organic matter ([23] [24]) due to an interaction with the mineral matrix, giving it a certain resistance to biodegradation; ([25] [26]).

Thus, for ferruginous kaolinite soils, the chemical and biological properties depend largely on the organic matter content, according to threshold and often linear functions.

The combination of kriging with remote sensing classification methods is another approach likely to improve the results of the spatialization of soil properties [27]. These different approaches will be tested in our previous work on the characterisation of the physico-chemical parameters of the soil cover.

## 6. Conclusions

Geostatistics has enabled us to know and better understand the soil characteristics of the Kelle Gueye pilot site. Soil pedological knowledge is of capital importance. It allows farmers to be guided towards precision agriculture.

The granulometry is dominated by the sandy fractions and the sum of the fine sand represents more than 50%. This high dominance of the fine fraction, combined with the permeability of the texture, provides good air circulation in the pores essential for groundnut and cowpea cultivation.

The physico-chemical analyses show non-saline soils and a weakly acidic to neutral pH. The soils are poor in organic matter. The results of the study also point to the need to explore other statistical methods that could provide a good characterisation of the dynamics of acidity in the soil.

It would be interesting to extend the study area to the whole commune and even create other pilot sites in the region in order to generalise the results.

It is also necessary to improve local practices of fertilisation, maintenance and regeneration of the land in order to improve production and the standard of living of the populations.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

[1] Feller, C. (1995) La matière organique du sol: Un indicateur de la fertilité. Application aux zones sahélienne et soudanienne. *Agriculture et développement*, **8**, 35-41.

[2] Dabin, B. and Maignien, R. (1979) Les principaux sols de l'Afrique de l'ouest et leurs potentialités agricoles. *cahier ORSTOM*, *série*. *Pédologique*, **18**, 235-257.

[3] Badiane, A.N., Khouma, M. and Sene, M. (2000) Région de Diourbel: Gestion des sols. Drylands Research Working Paper 15, Drylands Research, Somerset.

[4] Sensi, A. (2002) Agriculture et acidification, Eurostat (ed.).

[5] Corentin Debosschere. Etude des pratiques de gestion des sols et stratégies d'amélioration dans un contexte de diminution de fertilité au nord du bassin arachidier, Sénégal. Mémoire de fin d'études présenté par à la Haute Ecole Concordet (Ath) en vue de l'obtention du grade académique de Master en Sciences de l'ingénieur industriel en agronomie.

[6] Hugon, C. (2019) Maintenir la fertilité des sols grâce aux paysannes et aux paysans du Sénégal. SOS FAIM SÉNÉGAL Agriculture Familiale.

[7] Ngongo, M.L., Van Ranst, E., Baert, G., Kasongo, E.L., Verdoodt, A., Mujinya, B.B. and Mukalay, J.M. (2009) Guide des Sols en République Démocratique du Congo, Tome I: Étude et Gestion. Don Bosco, Lubumbashi.

[8] Victor, H. (1990) Pratiques cultures dans un sol ferralitique du Burkina Faso. Thèse de doctorat, INPL.

[9] Temple, L. and Paule, M. (2004) Les fonctions et contraintes de l'agriculture périurbaine de quelques villes africaines (Yaoundé, Cotonou, Dakar). *Cahiers Agricultures*, **13**, 15-22.

[10] Jama, B., Palm, C.A., Buresh, R.J., Niang, A.I., Gachengo, C. and Nziguheba, G. (2000) Tithonia as a Green Manure for Soil Fertility Improvement in Western Kenya. A Review. *Agroforestry Systems*, **49**, 201-221. https://doi.org/10.1023/A:1006339025728

[11] Nyembo, K.L., *et al.* (2013) Rentabilité économique du fractionnement des engrais azotés en culture de maïs (*Zea mays* L.): Cas de la ville de Lubumbashi, sud-est de la RD Congo. *Journal of Applied Biosciences*, **65**, 4945-4956.

[12] Akpo, L.E., André, G. and Michel, G. (1995) Structure spécifique d'une végétation sahélienne. Casde Wiidu Thiengoli (Ferlo, Sénégal). *Bulletin du Muséum National d'histoire Naturelle*, **17**, 39-52.

[13] Akpo, L.E. (1990) Dynamiques des systèmes écologiques sahéliens: Structure spécifique productivité et qualité des herbages: Le forage de Widdu Thiengoly. FST/UCAD, DEA.

[14] Akpo, L.E. (1992) Influence du couvert ligneux sur la structure et le fonctionnement de la strate herbacée en milieu sahélien. Les déterminants écologiques. Thèse de Doctorat de 3èmecycle, option Écologie, UCAD-FST, Département Biologie Végétale.

[15] Akpo, L.E., Banoin, M. and Grouzis, M. (2003) Effet de l'arbresur la production et la qualité fourragère de la végétation herbacée: Bilan pastoral en milieu sahélien. *Revue de Medecine Veterinaire*, **154**, 619-628.

[16] Audry, P. (1962) Etude pédologique du centre de recherches zootechniques de Dahra-Djoloff (République du Sénégal). Résultats analytiques complets. IEMVT/ORSTOM/CRP de Hann.

[17] CSE, ROSELT/OSS (2002) Synthèse des études diagnostiques des sites de l'observatoire du Ferlo. Dakar.

[18] Bocoum, M. (2004) Méthodes d'analyses des sols. Document de travail, Institut National de Pédologie (INP), Dakar-Sénégal.

[19] Mathieu, C. and Pieltain, F. (2009) Analyse chimique des sols: Méthode choisies, édition tec.

[20] Sarr, M.D. (2015) Contribution à l'étude de l'ensablement de la vallée de koussanar, un affluent de la vallée sandougou-*Mémoire* de Master Université Cheikh Anta Diop de Dakar (UCAD) Sénégal.

[21] Denis, B. and Bernard, J. (1995) Guide pour la description des sols. INRA, Paris, 132, 141.

[22] Calvet, R. (2003) Le sol, propriétés et fonctions. Edition France agricole 2ème édition, 446, 447.

[23] Piccolo, A. and Mbagwu, J.S.C. (1999) Role of Hydrophobic Components of Soil Organic Matter in Soil Aggregate Stability. *Soil Science Society of America Journal*, **63**, 1801-1810. https://doi.org/10.2136/sssaj1999.6361801x

[24] Chenu, C., Le Bissonnais, Y. and Arrouays, D. (2000) Organic Matter Influence on Clay Wettability and Soil Aggregate Stability. *Soil Science Society of America Journal*, **64**, 1479-1486. https://doi.org/10.2136/sssaj2000.6441479x

[25] Balesdent, J., Chenu, C. and Balabane, M. (2000) Relationship of Soil Organic Matter Dynamics to Physical Protection and Tillage. *Soil and Tillage Research*, **53**, 215-230. https://doi.org/10.1016/S0167-1987(99)00107-5

[26] Christensen, B., *et al.* (2001) Simple and Robust Method for Estimation of the Split between the Oxidative Pentose Phosphate Pathway and the Embden-Meyerhof-Parnas Pathway in Microorganisms. *Biotechnology and Bioengineering*, **74**, 517-523. https://doi.org/10.1002/bit.1143

[27] Douaoui, A.K., Nicolas, H. and Walter, C. (2006) Detecting Salinity Hazards within a Semiarid Context by Means of Combining Soil and Remote-Sensing Data. *Geoderma*, **134**, 217-230. https://doi.org/10.1016/j.geoderma.2005.10.009