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Soil suitability for the production of rice, groundnut, and cassava in the peri-urban Niayes zone, Senegal

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ABSTRACT

In Senegal, the peri-urban Niayes region has biophysical and socio-economic potential to contribute to national food security. Peri-urban agriculture highly contributes to the local food supply, but one potential constraint to expansion is soil suitability for new crops. We examined the suitability of soils for the cultivation of upland rice (*Oryza sativa* L.), cassava (*Manihot esculenta* Crantz), and groundnut (*Arachis hypogaea* L.) in a peri-urban wetland outside of Dakar. The selected crops are central to local diets. Study sites were located along a toposequence. We evaluated soil suitability metrics for these three crops based on physical and chemical characteristics. The results show that soil texture varied from sandy to sandy loam. The organic matter concentration varied between 0 g kg^{-1} and 2 g kg^{-1}. Total nitrogen and organic carbon had low values in all sites except in S4 while macronutrients (Ca, Mg, Na, and K) varied across sites. Calcium was the most abundant cation in the soils; followed by Mg, Na, and K. Based on these factors, we found that there is high suitability for groundnut production in peri-urban Dakar, slight potential for cassava, and marginal or poor suitability for rice production. It attempts to fill the knowledge gap with new data for soil suitability in research development (R&D) in Senegalese agriculture. The same approach could be applied in other areas when introducing new crops for diversification.

1. Introduction

Despite large global increases in crop productivity, yields in sub-Saharan Africa have remained stagnant over the last half-century (Ba and Aubry, 2011). These yield gaps have motivated recent trends in international agricultural development focused on increasing production among smallholder, rural farmers in Africa (Toenniessen et al., 2008). There is some evidence that these efforts are impacting on yields (Denning et al., 2009), with the potential to positively impact rural livelihoods.

However, demographic evidence and projections in sub-Saharan Africa show large-scale movement from rural, farming areas to urban areas (Seto et al., 2011; Linard et al., 2013). In 2010, for instance, 42% of Senegal's population was located in urban areas (Masse et al., 2013). This demographic clustering poses important challenges for feeding a largely urban population. This challenge was exemplified in 2008 food riots in developing countries, such as Senegal, over high prices of staple items (Cohen and Garrett, 2010). Thus, affordably meeting the food demand of a growing urban population in countries such as Senegal is a key priority.

The Food and Agricultural Organization (FAO) estimates that urban agriculture contributes to feeding up to 800 million urban dwellers (Zezza and Tasciotti, 2010). And 30–70 percent of urban families in poor countries engage in some form of urban food production (FAO, 2010; Cohen and Garrett, 2010). Urban and peri-urban food production can, thus, play an important role in providing food for growing and dense urban areas (Cohen and Garrett, 2010).

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In Senegal, peri-urban agriculture already contributes an important concentration of horticultural products to urban markets. The Niayes zone, a peri-urban wetland, gives 80% of all horticultural production in Senegal and represents 65% of all agricultural production in Senegal (Diallo et al., 2015a). Farm sizes vary but are rarely more than 1 ha. These small farms are partly due

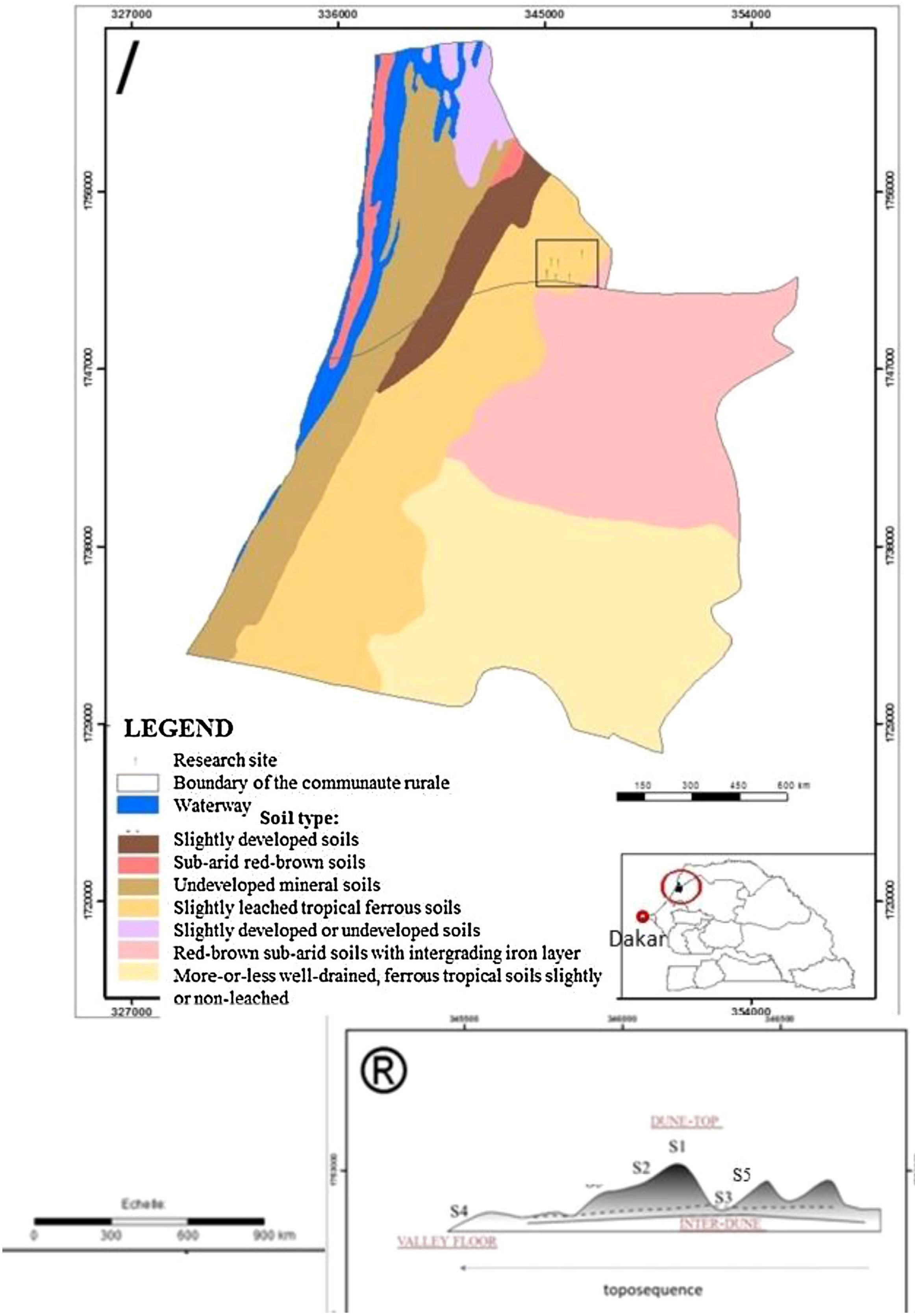

Fig. 1. Geographic sites location along toposequence in the Niayes zone.

Table 1
Climatic means in the Niayes area between 1994 and 2014.

Climate characteristics	Date																				
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total annual precipitation (mm)	182	180	59	239	284	282	111	220	273	362	329	256	262	350	140	282	295	311	257	295	335
Maximal mean temperature (°C)	32	31	32	31	31	31	33	33	33	31	32	33	33	32	32	33	33	33	34	31	32
Minimal mean temperature (°C)	21	20	21	21	21	21	21	21	21	21	19	21	21	21	21	21	20	20	21	20	22
Minimal mean relative humidity (%)	45	46	42	45	45	46	45	44	45	49	46	47	45	51	48	49	45	48	48	50	52
Minimal mean relative humidity (%)	85	88	85	86	85	86	87	86	86	87	86	88	87	88	91	89	88	89	89	92	93
Mean annual wind (m/s)	5	4	4	4	5	4	5	4	4	4	4	4	4	4	3	4	4	4	3	3	3
Insolation (times)	8	7	7	7	7	8	8	7	6	8	9	9	9	8	8	7	8	8	8	8	8
Evaporation (mm)	5	4	5	4	5	4	4	5	5	4	4	4	4	4	4	5	5	5	5	4	4

to two factors: low land availability in peri-urban zones because of strong development pressure and high costs of irrigation, which is especially needed in dune areas where the water table is steadily decreasing. The major feature of the Niayes climate is its influence by sea breeze. The coastal wind is relatively cool and moist and thus contributes to relatively moderate temperatures in the zone, along with high humidity, and frequent nocturnal dews (Touré and Seck, 2005). The high availability of water has driven a thriving market gardening sector; production is high and farming supply the nearby cities of Saint Louis and Dakar with various horticultural products. The main crops grown in the Niayes zone include potatoes, onions, cabbage, tomatoes, hot pepper, and eggplant. Though these crops are thoroughly incorporated into Senegalese cuisine, the staple crops on which the food system depends are rice, groundnut, and cassava. However, these crops, upland rice (*Oryza sativa* L.), cassava (*Manihot esculenta* Crantz), and groundnut (*Arachis hypogaea* L.), are mostly cultivated in rural regions of Senegal that have degraded soils and declining yields. The National Agency for Statistics and Demography, in its monthly report of economic statistics on March 2015, shows that the average cultivated areas during the last five years for groundnut is 933 ha with a yield of 902 kg ha^{-1}; 50 ha for cassava with a yield of 7 t ha^{-1}; and 128 ha for rice with a yield of 7 t ha^{-1}. The average price for the first three months of 2015 is 268 F CFA kg^{-1} for the locally-cultivated rice while the imported rice costs 365 F CFA kg^{-1}. Cassava price is estimated for 300 F CFA kg^{-1}, it is 242 F CFA kg^{-1} for groundnut with pods and 541 F CFA kg^{-1} for groundnut without pods. Seventy percent of this production is consumed. Thus, understanding whether key staple crops can be produced in the higher-fertility Niayes zone outside of Dakar could be important to meeting the food needs of a growing urban population.

The objective of this study was to quantify the suitability of soils in a key peri-urban ecosystem in Senegal for the production of three staple crops to the Senegalese diet: upland rice, cassava, and groundnut. We classify suitability according to Food and Agriculture Organization (FAO, 1976; Verheye et al., 2003; Ritung et al., 2007) to determine the appropriateness of these three crops to the peri-urban Niayes wetland. We expect to find high aptitude for cassava and groundnuts, but not for rice, because of local soil conditions, specifically a high concentration of sand in coastal areas.

2. Material and methods

2.1. Site description

The study was conducted in the Mboltime village (15°54′22.5″N and 016°24′41.2″W), in the region of Saint Louis, Senegal (Fig. 1). This site is part of the Niayes ecological zone, which spreads north and east of Dakar.

The climate is typical of the Sahel in that it is marked by a long dry season from November to June and a short rainy season from July to October. Mean annual rainfall is around 300 mm and mean annual temperature is 31 °C (Table 1). Unseasonable rains (called *heug*) may sometimes occur between December and February. These rains are the result of cold air coming into the zone from temperate regions (Seck, 1965). Although these rains are erratic and low in their contribution to total precipitation, they can play an important ecological role in the regeneration of vegetation and the fruiting of fruit trees (Trochain, 1940). The relative humidity of this zone is fairly high and can reach maximum up to 90% near the coast and a minimum of over 15% in the internal parts of the Niayes zone (Touré and Seck, 2005).

Morphologically, the area is characterized by dune formations separated by inter-dune corridors and interspersed with troughs and depressions. Shallow wetlands are found where the water table rises above the soil surface and soils are waterlogged clay soils that are very high in organic matter and with peat bogs containing standing water (Fall et al., 2001). Dunes with sandy soils

Table 2
Mean values of land characteristics of the study area.

Sites	Annual rainfall (mm)	Length of dry season (months)	Mean temperature (°C)	Slope	Relative humidity (%)	Drainage	Soil depth (cm)	Coarse fragments (g kg^{-1})	Texture class	pH (1:2.5 H_2O)	N (g kg^{-1})	K_2O (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})
S1	450	9	25	4	53	Good	0–20	56	SL	7	157	36	448	68
S2	450	9	25	1	53	Good	0–20	52	SL	6	157	51	728	102
S3	450	9	25	2	53	Good	0–20	66	SL	6	470	56	896	136
S4	450	9	25	1	53	Moderate	0–20	29	LS	5	3763	119	22344	2584
S5	450	9	25	2	53	Good	0–20	95	S	6	470	45	784	136

SL, sandy loam; LS, loamy sand; S, sandy.

surround these shallow wetlands. Dune soils are slightly leached, tropical ferruginous soil (Maignien, 1965) classified as a Lixisol by the FAO classification system (FAO, 1998). These soils are called *diors* in the local classification (Fall et al., 2001) and are often very low in macronutrients concentration (Table 2), which is likely due to long-term rainfed cultivation on the dune areas. The vegetation on dunes is a steppe vegetation dominated by thorny woody species of the genus *Acacia* with *Euphorbiaceae* bushes and herbaceous plants. The drainage system is mainly arms of the Senegal River and a large number of flooded pits (Thiam, 2005). The water in these depressions is generally from the water table or from floodwaters during the rainy season.

Five different land use types were investigated in this study. These sites were located along a toposequence running from dune-top to lowland inter-dune areas and each site was approximately 1 ha. Sites 1, 2, 3, and 5 (S1, S2, S3, and S5) were located in a dune-based geomorphological zone with a relatively weak slope. Morphological description of sites are in Table 3. Site S1 was located on the top of the zone, S2 at the next highest point in the topological gradient, S3 in the inter-dune depression, and S5 on the slope on the other side of the inter-dune depression (Fig. 1). Site S4 was located in a different geomorphological zone in the valley floor. To understand the geophysical constraints on the introduction of new crops, we sampled and measured the physical and chemical characteristics of surface soils (0–200 mm depth). Soils samples were obtained from agricultural fields. Fifteen composite samples were taken in each site, which makes a total of 75 samples. Each sample weighed approximately 200 g. Samples were placed in plastic bags, sealed, and transported to the laboratory for analysis. Sampling was conducted in July 2013.

2.2. Soil analyses

Physiochemical soil analyses were carried out in the National Pedology Institute in Senegal. Soils were air dried and sieved to 2 mm. The sieved sample was sub-divided into two fractions: one for physical analysis and the other for chemical analysis. The fraction for chemical analysis was ball milled for 10 min to a fine fraction.

Soil texture was determined using the Robinson pipette method. This approach allowed us to determine the fine fraction (clay and fine silt). Larger silt particles and sand were then removed by sieve (2 mm diameter) after removing the fine fraction (FAO, 2005). The soil sample (20 g) is put into a volumetric cylinder of 80 mm diameter and 300 mm height. 1 l of water is added along with sodium hexametaphosphate to keep the soil suspension disperse. Sampling is taking of 20 mm at a depth. This sampling corresponds to the <20 μm fraction (clay and silt). The second sampling is done at the same depth after 8 h. This consists now only of clay. These two fractions are dried at 105 °C and weighed. The sands are recuperated into two fractions using a 200 μm sieve. By this method, particles between 20 μm and 50 μm pass through and are calculated by difference. Soils were then classified according to Duchaufour (1991).

We measured pH in soil–water suspensions with a soil-to-water ratio of 1:2.5. Cation exchange capacity was determined by the ammonium acetate method used by Richards (U.S. Salinity Laboratory Staff, 1954) and recommended by the USDA (U.S. Soil Survey Staff, 1975). This method is carried out on 10 g of soil using five successive extractions with a solution of pH 7.0 in a soil to solution ratio (m/V) of 1:6, 1:5, and 1:4. We manually agitated the mixtures, let sit overnight, and centrifuged for 10 mn at 700 × *g*. The concentration of cations was measured by atomic absorption spectrometry. The abundance of ammonium ions (used to determine cation exchange capacity) was measured by titrimetry in the presence of formaldehyde (Loveday, 1974). This wet chemistry method can be divided into two phases: sample extraction (oxidation) and sample quantification.

Total soil organic carbon was determined by Walkley–Black method (Nelson and Sommers, 1996). In this method, organic matter is oxidized by a mix of potassium bichromate in excess in the presence of sulfuric acid by the dichromate oxidation method. The excess bichromate is measured by ferrous sulphate (Mohr salt). The sample result is measured from 0.3 g to 1.0 g of soil according to assumed carbon concentration. The measurement is carried out by calorimetry in a spectrometer with a wavelength of 600 μm (Duchaufour, 1984). The concentration of organic carbon is converted to organic matter by multiplying by 1.72. Total nitrogen was determined using the Kjeldahl method (Gallaher et al., 1976) followed by colorimetric determination with an autoanalyzer. A 30 ml portion of either sample was placed into 100 ml digestion

Table 3
Morphological description of sites.

Sites	Horizons	Thickness (cm)	Texture class	Structure	Soil consistency	Color	Transition	Soil condition
S1	H1	0–34	Sandy Loam	Particulate	Friable	7.5YR5/8	Progressive	Moist
	H2	34–60	Sandy	Particulate		7.5YR5/9		Dry
	H3	60–138	Sandy	Particulate		7.5YR6/6		Dry
	H4	138– 166	Sandy	Particulate		7.5YR5/8		Moist
S2	H1	0–34	Sandy Loam	Particulate	Friable	7.5YR5/8	Progressive	Moist
	H2	34–78	Sandy	Particulate		7.5YR5/9		Dry
	H3	78–163	Sandy	Particulate		7.5YR7/6		Moist
	H4	163– 177	Sandy	Particulate		7.5YR5/8		Moist
S3	H1	0–23	Sandy Loam	Particulate	Friable	7.5YR3/5	Net	Moist
	H2	23–47	Sandy	Massive		7.5YR3/6		Dry
	H3	47–100	Sandy	Massive	Compact	7.5YR2/6	Progressive	Dry
	H4	100–155	Sandy clay	Massive to polyedrique	Consisting	7.5YR2/4		Moist
S4	H1	0–24	Clay sand	Massive	Consisting	10YR3/4	Net	Dry
	H2	24–66/80	Clay	Granulare	Friable	10YR2/3		Dry
	H3	66/80–90/102	Sandy clay	Particulate		10YR3/4		Dry
	H4	90/102–151	Loamy clay	Polyedrique to angulaire		10YR1,7/1		Moist
	H5	151–174	Sandy clay	Particulate		10YR5/4		Moist
S5	H1	0–28	Sandy	Particulate	Friable	7.5YR5/6	Net	Moist
	H2	28–83	Sandy	Particulate		7.5YR5/7	Progressive	Dry
	H3	83–150	Sandy	Particulate		7.5YR5/8		Moist

tubes along with 3.2 g salt–catalyst (9:1 salt–catalyst ratio of anhydrous K_2SO_4:$CuSO_4$), and 10 ml of concentrated H_2SO_4. The water samples were evaporated slowly over several hours in an aluminum block digester at 150 °C then digested at 375 °C for a minimum of 2.5 h (Gallaher et al., 1976). Samples were cooled, vortexed while being diluted with deionized water and brought to 75 ml volume at room temperature (Duchaufour, 1984). Exchangeable cations (Ca, Mg, Na and K) were extracted with 1N NH_4OAC pH 7.0 (ammonium acetate). Sodium (Na^+), potassium (K^+), Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined with flame emission photometer with atomic absorption spectrophotometer (Ulery et al., 1995). This measure is expressed in milliequivalents per g of soil (cmol/kg) (Soltner, 1999).

2.3. Determination of soil suitability

Soil suitability evaluation involves characterizing the soils in a given area for specific land use type. The information collected in soil survey helps in the development of land use plans, which evaluate and predicts the influence of the land use on the environment (Rossiter, 1990). Selection of land qualities and land characteristic requirements were described by FAO (1983). A land quality is a complex attribute of land that has a direct influence on land use (Isitekhale et al., 2014). Most land qualities are determined by the interaction of several land characteristics (Table 3) and measurable attributes of the land (e.g., availability of water and nutrients, climate, erosion hazard, rates of tree growth, soil physical characteristics, etc.) (FAO, 1983; Sys, 1976).

We used two FAO-developed approaches (parametric and non-parametric) to evaluate the suitability of the soils of the different land use for rice, groundnut, and cassava cultivation in the peri-urban Niayes zone. In the conventional (non-parametric) method (FAO, 1976; Ogunkunle, 1993) soils were placed in suitability classes by matching these land characteristics (total annual precipitation, mean annual temperature and mean relative humidity) with the agronomic requirements of the particular crop (chemical characteristics: C, N, organic matter (OM), Ca, Mg, K, Na, etc.). In the non-parametric approach, if a soil property is optimal for a crop then there is said to be no limitation. But if the characteristic is unfavorable for the crop, there is said to be a limitation. These limitations vary in degree from 0 (no limitation) to 4 (very severe limitation). For the parametric method, when a characteristic of the soil is optimal for the use considered, the value of 100 is attributed. If the characteristic is not useful, then a lower value is given reflecting the degree of limitation. Average conditions are given values between 95 and 85, marginal conditions between 85 and 60, correctable unsuitability 60–40, and permanent unsuitability 40–0. This method is done for each of five parameters: climate (c), characterized by precipitation, temperature, and relative humidity; topography (t), particularly slope; soil hydric conditions (w) characterized by drainage and submersion; soil physical characteristics (s), including texture, porosity, and depth; soil chemical characteristics (f), including cation exchange capacity, saturation rate, concentration of organic C, and pH. The product of these parametric values gives the SI (soil suitability index or soil Iindex), which indicates the highest concentration of the classification according to FAO (1976) and Ogunkunle (1993).

Eqs. (1)–(3) show the index of climatic, pedologic and soil, respectively.

$$I_c = (R_{min}) \times \sqrt{\frac{A}{100}} \times \sqrt{\frac{B}{100}} \times \ldots \quad (1)$$

$$I_t = (R_{min}) \times \sqrt{\frac{A}{100}} \times \sqrt{\frac{B}{100}} \times \ldots \quad (2)$$

I_c: climatical index
I_t: pedological index
R_{min}: the minimum rated criterion$A$,B, . . . : criteria other than minimum rated criterion

$$SI = (A) \times \left(\frac{B}{100}\right) \times \left(\frac{C}{100}\right) \times \ldots \quad (3)$$

SI: soil index
A, B, C, . . . : ratings of criteria (c, t, w, s, f)

The rate for each criterion is obtained after field or laboratory measurements of the land characteristics, and the comparison of these measurements with the crop requirements in the reference tables. After matching measurements with threshold values, a rating of 0–100 is given to each criterion. The total score for a special land unit is also given a rate of 0–100 by calculation through the three methods discussed in this paper as ways of combining the criteria scores. The method of the maximum limitation is the selection of the most restricting criterion rate and considering it as the total score for a land unit.

2.4. Data analyses

We used principal components analysis (PCA) to determine the relationship between the requirements of specific crops (rice, groundnut, cassava) and the physicochemical characteristics of soils (sand, silt and clay, Na, Mg, K, organic C, total N, CEC and pH). Data were analyzed statistically following XLSTAT Pro Software, 2011 (version 13.2, AddinSoft®). PCA aims to summarize one table by searching orthogonal axes on which the projection of the

Table 4
Climate Index for each crop at the study area.

Climate characteristics	Crop	Crop needs	Mean annual yield	Limiting values (%)
Total annual precipitation (mm)	Cassava[a]	1400–1800	450	83
	Groundnut	500–900	425	94
	Rice	450–650	450	95
Mean annual temperature (°C)	Cassava	20–26	25	99
	Groundnut	22–26	25	98
	Rice	22–30	25	97
Mean relative humidity (%)	Cassava	35	53	100
	Groundnut	50–80	53	95
	Rice	Not indicated	Not indicated	100
Climatic index (I_c)	Cassava		82	
	Groundnut		88	
	Rice		92	

[a] Rice (*Oryza sativa* L.), cassava (*Manihot esculenta* Crantz), groundnut (*Arachis hypogaea* L.).

Table 5
Pedologic index for each crop at the study area.

Crops	Sites				
	S1	S2	S3	S4	S5
Cassava	25	39	39	74	30
Groundnut	83	97	97	92	96
Rice	49	48	48	47	48

Rice (*Oryza sativa* L.), cassava (*Manihot esculenta* Crantz), groundnut (*Arachis hypogaea* L.).

sampling points (rows of the table) has the highest possible variance. This characteristic ensures that the associated graphs (factor maps) will represent the initial data in the best way. To extract information common to both tables, canonical correlation analysis methods search successive pairs of axes (one for each table) with a maximum correlation.

3. Results

3.1. Suitability of soils for cultivation

3.1.1. Climatic index (I_c)

The suitability of soil for cultivation, based on several indices, differed significantly among the crops. Specifically, the climate index value was 82 for cassava, 88 for groundnut, and 92 for rice (Table 4).

3.1.2. Pedological index (I_p)

The pedological index (Table 5) was much higher for groundnut (83 for S1 to 97 for S2 and S3) and lower for cassava in certain sites (25 for S1 to 74 for S4). The pedological index for rice was nearly constant across sites and varied between 47 (S4) and 49 (S1).

3.1.3. Soil index (SI)

Results indicate 43–45% of SI for rice (Table 6), the soil suitability classes were only marginally apt due to a light climate limitation (91) and a severe pedological limitation (48, on average). For Cassava, SI varied between 20 and 61% (Table 6), and the suitability classes vary between apt in site S4, potentially apt in sites S1 and S5, and marginally apt in the other sites S2 and S3. For groundnut (Table 6), the suitability classes vary between apt in site S1 and very apt in the other sites. The climate limitation is only light (88) and there is no pedological limitation.

3.2. Principal components analysis

The PCA showed that the first two axes explained 98% of the data (Table 7). The essential part of this analysis was established on the factorial map created from these two axes (Fig. 2). The factorial space created by F1 and F3 was also studied to complete the analysis. The following variables had contributions that were greater than average for axis F1: soil C (17%), soil organic matter (17%), soil N (17%), pH (17%) and the soil indices ItM (slightly apt soil index) 16%) and ItR (inapt soil index) (14%). For axis F2, the only important variable was the soil index ItA (apt soil index) (91%).

The variables (physical and chemical parameters and soil indices) and observations (sites) having a greater-than-average contribution were used to define axes F1 and F2. Axis F1 opposes site S4 on the positive side of the *x*-axis and site S1 on the negative side of the *x*-axis. Site S4 is characterized by acid soils with a high concentration of organic carbon, organic matter, and nitrogen and a high aptitude for cassava cultivation. Site S1 contains alkaline soils with low concentrations of organic carbon, organic matter, and nitrogen and a poor suitability for the production of rice. Axis F1 is clearly related to chemical composition of soil and could correspond to an important chemical gradient observed in the sites. Regarding the vertical axis F2, it opposes sites S3, S2, and S5 in the positive quadrants and S1 in the negative quadrants. In the positive quadrants are soils that are characterized by a high suitability to produce groundnut. Site S1, by contrast, has soils that are poorly suited to the cultivation of groundnut. Thus, axis F2 can be seen to represent a gradient of suitability for groundnut cultivation.

3.3. Physical–chemical composition of soils

Results from texture analysis show that the texture of soils studied varies from sandy to sandy loam (Table 8). The soils are mainly made up of fine sands and silts. The percentage of sand varied between 29% (S4) and 95% (S5). The percentage of silt varied between 5% (S5) and 60% (S2). Clay percentage varied between 0% (S2 and S3) and 11% (S4). Thus, the concentration of clay in soils is extremely low, while the concentration of silt is somewhat high. The fertility scale established in terms of nitrogen and pH (Fig. 3) showed that the in supplying food for pH and nitrogen are low in site S4, but higher in all other sites. This higher concentration of nitrogen in the other sites suggests potential bioavailability of nutrients for crop growth and productivity. The borderline of nitrogen limitation is 1 $g\,kg^{-1}$ and its limit of deficiency is 2 $g\,kg^{-1}$. In Table 8, concentration of organic matter varied between 0 $g\,kg^{-1}$ and 2 $g\,kg^{-1}$. Concentration of nitrogen and carbon in soils, are considered to be especially low in all sites except S4 for C. Micronutrient cations (Ca, Mg, Na, and K) varied differently at the separate sites. The most abundant cation in the soils studied was Ca, followed by Mg, Na, and K. Site S4 had the highest concentration of these cations with values going up to 50 cmol/kg for Ca^{2+}, 10 cmol/kg for Mg^{2+}, 1 cmol/kg for Na^{+}, 60 cmol/kg for S. We found also that cation exchange capacity varied between

Table 6
Soil index (SI) and land suitability class for cassava, rice, and groundnut.

Sites	Cassava			Rice			Groundnut		
	Soil index (%)	Non-parametric Suitability class	Parametric Suitability class	Soil index (%)	Non-parametric Suitability class	Parametric Suitability class	Soil index (%)	Non-parametric Suitability class	Parametric Suitability class
S1	20	Moderate	Potential	45	Severe limitation	Marginal	74	Slight	Satisfactory
S2	32	Severe limitation	Marginal	44	Severe limitation	Marginal	85	Slight–none	Excellent
S3	32	Severe limitation	Marginal	44	Severe limitation	Marginal	86	Slight–none	Excellent
S4	61	Slight	Satisfactory	43	Severe limitation	Marginal	82	Slight–none	Excellent
S5	25	Moderate	Potential	44	Severe limitation	Marginal	85	Slight–none	Excellent

Satisfactory suitability; land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
Potential suitability; land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use.
Marginal suitability; land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

Table 7
Principal component Aanalysis (PCA) values and percentage explained for the first four axes of the PCA analysis.

	F1	F2	F3	F4
PCA value	5.8	1	0.1	0
Variability explained (%)	82.7	15.5	1.5	0.3
Cumulative concentration explained%	82.7	98.1	99.7	100

PCA, principal component analysis; F1, F2, F3, and F4, axes of the PCA analysis.

18 cmol/kg in site S1 and 90 cmol/kg in site S4. These results indicate a high potential for nutrient leaching in soils from all sites except for S4.

4. Discussion

4.1. Physical and chemical characteristics of soil

Our pH results show that the soils of this study zone are slightly acidic (between 4.6 and 6.6), which generally corresponds to productive soils according to the FAO (1987). The optimum pH for rice is between 5 and 8, for groundnut between 6.5 and 7.5 and for cassava between 5.5 and 7.0 (FAO (1987)). In addition, the soil fertility scale established by Dabin (1969) – which is based on nitrogen and pH – shows that the fertility of all of the sites studied is good, except for S4 which has a very acidic soil. Effectively, pH plays an important role in the biological activity of the soil and the availability of mineral nitrogen to plants, thus reflecting a synthetic indicator of the chemical fertility of the soil (Isitekhale, 2014; Diallo et al., 2015b Diallo et al., 2015b). The pH of the soil can influence the efficiency of plant growth in the soil as well as the bioavailability of crop nutrients, the activity of microorganisms, and is related to toxiurban risk (Tossou et al., 2006; Diallo et al., 2015b).

The low concentrations of soil organic matter in soil and cations indicates poor soils, except for site S4. These two indicators represent the actual or potential fertility of the soils (Azalfack, 2009; Diallo et al., 2015c). In cases where these elements are weakly represented, soils will quickly lose their fertility after cultivation (Meyim, 2000). Similar studies were carried out by Agboola (1981) and Lal (1996) and were able to show that there is a rapid decrease in soil organic matter concentration and nutrients after intensive cultivation. This loss of fertility could well be due to a decrease in pH caused by the assimilation of nutrients by plants, to the decomposition of organic matter, and to the leaching of soil water.

4.2. Suitability of soils for crop production

Suitability is largely a matter of producing yield with relatively low inputs, and there are two stages in finding the land suited to a specific crop. The first stage of this work focuses on being aware of the requirements of the crop, or alternatively what soil and site

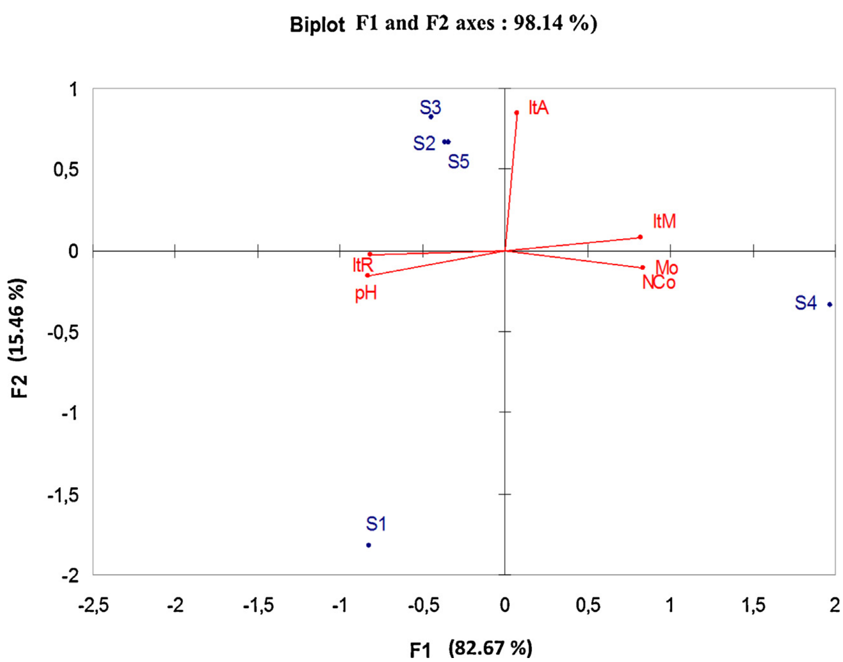

Fig. 2. Factorial plot of site physcio-chemical characteristics. The values in parentheses indicate the proportion of the data captured in the particular axis (S1, S2, S3, S, S5: Sites; ItA: apt soil index; ItR: inapte soil index; ItM: slightly apt soil index; Mo: soil organic matter, Co: soil organic carbon; N: nitrogen).

Table 8
Physical and chemical characteristics of soils.

Sites	Clay (g kg^{-1})	Silt	Sand	pHwater (1/2.5)	Corg (g kg^{-1})	OM	N	Ca2+ (cmol kg^{-1})	Mg2+	Na+	K+	S	CEC
S1	1	43	56	7	0	0	0	1	0	0	0	1	18
S2	0	48	52	6	0	0	0	2	0	0	0	2	25
S3	0	34	66	6	0	0	0	2	1	0	0	3	24
S4	11	60	29	5	1	2	0	50	10	1	0	60	90
S5	1	5	95	6	0	0	0	2	1	0	0	2	26

C_{org}, organic Carbone content; MO, organic Matter; S, base saturation; CEC, cation exchange capacities.

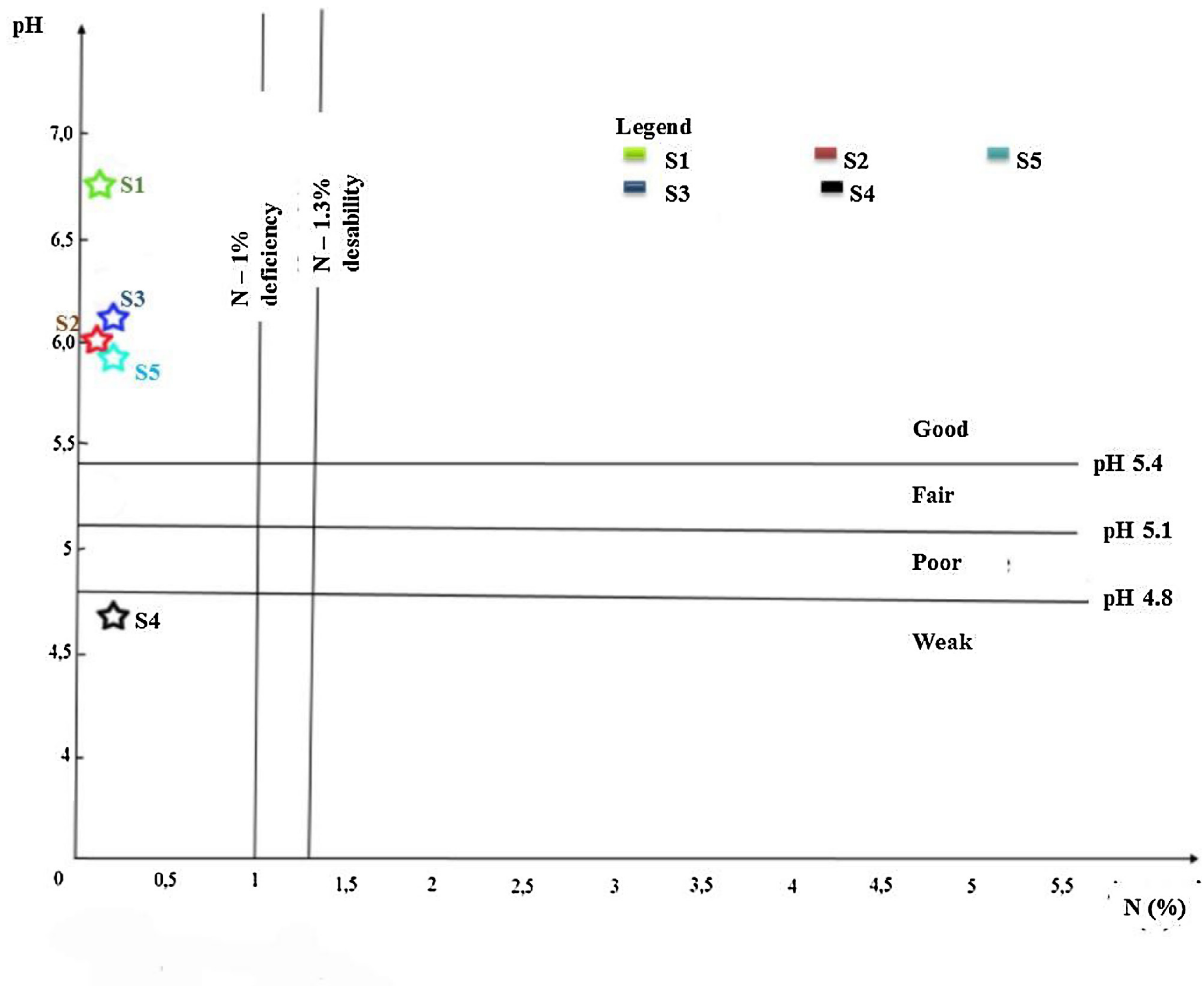

Fig. 3. Availability of N according to soil pH for the study sites applied to the fertility scale of Dabin (1969).

attributes adversely influence the crop. The second stage is to identify and delineate the land with the desirable attributes. Regarding the criteria evaluated to determine soil suitability, the soils of the study zone showed a high suitability for groundnut production, a marginal or weak suitability for rice production, and a potentially correctable suitability for the production of cassava. These results were partly verified our hypothesis which expected to find high suitability for cassava, and groundnut, but not upland rice. These findings can be explained by the fact that the groundnut fixes biological N but rice does not. Rice tolerates wet conditions while groundnut have less tolerance. The land suitability evaluation by different parametric methods indicated that most of the land units are classified into A3 (marginally suitable) to N1 (excellently suitable).

Different land characteristics are showed in our results like the concentration of soil organic matter in certain sites is quite low (S1–S3, S5), but high in another (S4). Based in parametric and non-parametric methods, soil physical and chemical characteristics are dominant limiting factors affecting the land suitability in the Niayes area. Here, the diagnostic role of soil organic matter is clear, facilitating the interpretation of initial stages of pedogenesis and the importance of the addition of organic inputs (Tossou et al., 2006; Wang et al., 2015). These soils do not store organic carbon well, except for in depression areas such as site S4. According to Yimer et al. (2007), inappropriate farming practices can seriously degrade soils. Farming practices that do not add nutrient inputs can have significantly lower concentrations organic matter in soil and total nitrogen. The addition of organic inputs, then, can contribute to maintaining this resource stock and to soil quality for soils with a very low C:N ratio. It is also likely that the limitations to crop production in this zone are due to climate because the water needs for these crops are greater than the edaphic conditions in the surrounding environment. The next important limiting factors are texture and finally characteristics of the soil, such as pH and nitrogen. Relatedly, similarly studies carried out in Nigeria showed a marginal suitability for rice production on sandy soils (Isitekhale et al., 2014) and alluvial soils (Udoh et al., 2011), with the major limitations being chemical, such as pH, N, P, K, Ca and Mg. In addition. The limitations observed in these studies were climatic, physical, and chemical. These soils are not suitable for production of tomatoes, due to severe chemical limitations and moderate physical and climate limitations.

5. Conclusions

This study surveyed land and climate characteristics based on FAO (1976) to produce a land suitability evaluation for specific crops as upland rice, cassava and groundnut in the peri-urband

Niayes area, Senegal. Our objective was to quantify the suitability of soils in a key peri-urban ecosystem in Senegal for the production of these three staple crops. The results were determined by qualitative and quantitative terms. We were expected to find high suitability for cassava, and groundnut, but not upland rice. Our hypothesis was partly verified, because, based on parametric and non-parametric approaches, we found that there is high suitability for the production of groundnut in peri-urban Dakar, slight potential for cassava, and marginal or poor suitability for rice production. We noted strong variability in the physical and chemical characteristics of these soils and, thus, variability in the suitability of these soils for specific crops. This work enhances comprehensive information on research and development (R&D) in Senegal by attempts to fill this knowledge gap with new data for soil suitability in R&D in Senegalese agriculture.

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