CHEMICAL FERTILITY OF GARDEN SOILS IN SOUTH TOGO: ANALYSIS, CORRELATIONS AND REASONED PROPOSAL OF FERTILIZERS RATE FOR EFFICIENT PRODUCTION OF *SPINACIA OLERACEA* L.

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Abstract. In this study, a sample of 12 garden soils were analyzed and compared to quality standards. A reasoned fertilization method was developed using online software "Fertilizer Rate Calculator". Results indicate that among macronutrients, those of potassium are very high and even tend to exceed standard. Moreover, 92% of soils studied are poor in nitrogen, 8% in phosphorus, 0% in potassium and 25% in organic matter. In a reasoned fertilization method developed for spinach production, 800 Kg/Ha and 567 Kg/Ha of NPK have been proposed for sustainable production of this vegetable on soils poor in nitrogen and phosphorus while a mixing of NPK 15-15-15 (340 Kg/ha) and compost 1.73-3.13-13.28 (4000 Kg/Ha) would be suitable for soils poor in nitrogen and organic matter. The study of correlations between the different parameters through PCA allows to conclude that contents of total and available nutrients in soils are independent of organic matter, pH and particle size. Contrary, those of total organic matter and the pH would be the most impacted by the particle size types. This aspect earns to be considered in any fertilization processes of soils to prevent elevation of C/N ratio and consequently hunger of nitrogen in these soils. These results may contribute to future soil's chemicals changes model and suitable fertilization methods development.

Keywords: land management, fertilizers formulation, sustainable development, vegetables production.

INTRODUCTION

Soil is essential for subsistence and mainly for plants which are the primary producers in the food chain. Unfortunately, for decades, it has been going through tremendous degradation (FAO, 2016). Soil degradation is caused by humans' activities which disrupt one, several or all essential functions of the soil (Brabant et al., 1996).

Moreover, these loss of essential functions lead to a reduction of the soil capacity to provide adequate resources in term of quantity and quality for human beings. Soil degradation is accentuated by farmer's practices, which very often do not follow the technical recommendations leading to soil depletion and creating a threat for agriculture sustainability (UNDP, 2008; Sogbedji, 2006; Jonas et al., 2012). Lands are practically exploited continuously without fallow, due to demographic pressure and unavailability of effective management policies (Lalle, 2008; UNDP, 2008). Erosion, leaching and poor farming techniques are the main factors for soil degradation. Soil degradation is characterized by a loss of structure, a decrease inorganic matter and nutrients and a progressively acidic character in sub-Saharan Africa's soil (Dabin, 1985; Roose, 1977)

Soil degradation has significant consequences on the biosphere such as a reduction in plants' food production which is the most recurrent consequence (UNEP, 2003; Sanchez et al., 1997). In the case of Togo as in most Sub-Saharan Africa countries, 80 to 90 percent of the population relies on soil for survival, as it remains the most efficient and economical natural resource (Brabant et al., 1996; OECD/FAO, 2016). Finding innovative and sustainable restoration methods is critical to solve the ongoing issue and allow for an economic development of SSA countries. However, any step towards fertilizer recommendations should first start with a diagnosis of the soil fertility. In Togo, few studies have examined the effect of soil degradation as a consequence of crop production. Existing studies focus on the management of nutrients in agrosystems and on the impact of various amendments and fertilizers on plant's production on experimental soils. Poss et al. (1997) study the return of crop residues to soil combined with potassium fertilizer in the coastal agricultural region of South Togo. Other studies examine the use of plant biomasses such as *Cajanus cajan* and *Vigna unguiculata* in enhancing the fertility level of some degraded soils (Sogbedji et al., 2006). Likewise, Ayeva (1993) shows that *Clotalaria sp*, when used as a cover crop improves both the structure and chemical fertility of lands in the savannah region of Togo. Other studies emphasize on the use of an invasive species, such as the *Cassia occidentalis* L, rich in nutrients like green manures and compost (Toundou et al., 2014, Bokobana et al., 2016). All the studies above call for an upgrade of soil fertility in Togo. However, the current practices focus mainly on experimental soil and therefore their findings are very specific. Moreover, these studies do not take into account the initial chemical characteristics of soils in their recommendations. For instance, in most agricultural areas of the country, dosage of N-P-K complex fertilizer (15-15-15) ranging from 150 to 200 Kg/Ha were recommend for maize production. Unfortunately, the recommended dosage not only causes environmental issues but also economical ones (Gnandi, 2009). Indeed, such dosage could contain high or low levels of nutrients compared to the needs of plants and could adversely negatively impact on the plant's production. For a sustainable development, it's advised to account for the soil's initial fertility before any supply fertilizers. This method is that of reasoned fertilization which consists in using the right source, the right dose, at the right time and in the right place.

After main crops such as sorghum, millet, corn, yams, cassava, peanuts and cotton, grown throughout the territory and widely consumed by majority of households, gardening vegetables are the second most cultivated type of crops in farms and gardens in Togo. There are about 27 gardening production sites spread across the country with the best producers found in the maritime region (Kanda et al., 2014). The poor quality of soils, pest invasion, scarcity of water and poor techniques for harvest conservation (Kirdja, 1991; ITRA, 2007; Kanda et al., 2014) are the main constraints to these vegetable's production. None of the measures taken by the population and which consist into the use of chemical inputs have been proven to be effective, and the persistency of soil degradation is causing food insecurity. The main goal of this study is to analyze the chemical fertility state of some selected vegetable gardening soils in South Togo, to identify correlations between soil's factors and provide a method for crops efficient fertilization contributing to a sustainable production of vegetables taking the case of *Spinacia oleracea*, a nutrient-demanding vegetable commonly produced in Togo.

MATERIAL AND METHODS

*The study area***.** The sites used in this study are located in eco-floristic zones V and III in south Togo. These areas are covered by a subequatorial climate with four seasons including two dry seasons and two raining seasons. A total of four districts were selected: two in the Maritime region (Yoto and Avé) and two others in the Plateau region (Moyen-Mono and Haho) (Figure 1). The sites in the maritime region are weakly ferralitic type soils on sandy-clay sediments while those in the plateau region are leached tropical ferruginous type soils with pseudo-gley (Lamouroux, 1969).

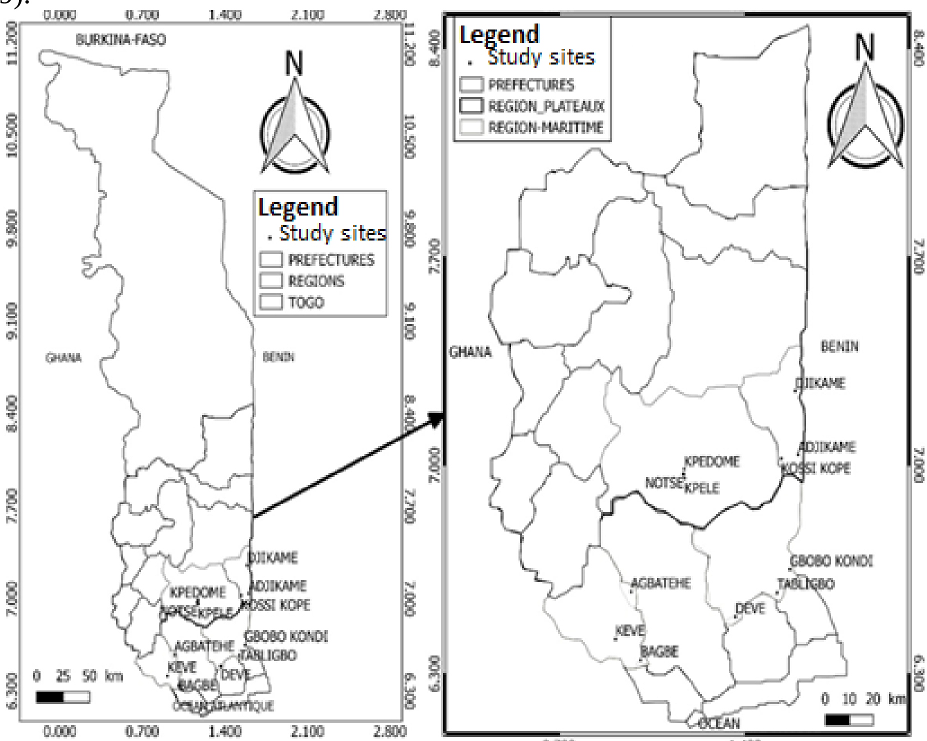

Fig. 1. Geographical location of the different sites

*Soil sampling technique and samples preparation for analysis***.** Soils selected for this study were chosen following a preliminary survey conducted to identify the main production sites of the vegetables sold in each regional market. A total of 15 to 25 soils samples were collected using an auger and then homogenized to have each sample weighing approximately 15 Kg. Each samples once brought back to the laboratory was divided into three parts. One part (F1) was dried for 48 hours in an oven, crushed and sieved to 2 mm. The representatively of the test portion was obtained by quartering before sieving. The second part (F2) was dried in ambient temperature of 25 ° C. The last part (F3) was stored without drying at a temperature of 4°C.

Physico-chemical analyzes. The pH and ionic conductivity were determined on aqueous suspensions of the F1 fractions (AFNOR NF ISO 10-390, 1994; Belyaeva et al., 2009; Yu et al., 2009). 20 g of the dry matter were dissolved in 100 ml of distilled water. The suspensions were homogenized for 15 minutes and pH is measured using a HANNA Instruments pH meter, model pH 210, equipped with a pH HI 1131B electrode combined with a reference electrode Ag/AgCl/KCl 35M and a probe HI 7669 temperature sensor for automatic temperature compensation The electrical conductivity is measured using a WTW brand conductivity meter (maximum error = 05%) fitted with a Tetracon 325 cell.

The organic component of soils was evaluated by measuring the contents of organic matter (MO) and Total Organic Carbon (TOC) on samples of fraction F1. The total organic matter is determined by calcination. Total organic carbon is determined according to French standard NF ISO 14-235. The principle of the method is based on a hot oxidation (135 °C for 1 hour) in an acid medium with presence of potassium dichromate. The mineral component was assessed by quantifying the nutrients (nitrogen, potassium, phosphorus, calcium and magnesium). The Kjeldahl nitrogen content (NTK) was determined using French standard AFNOR ISO 11-261. The contents of ionic species (calcium, potassium and magnesium) were determined by flame atomic absorption spectrophotometry (SAA Flame VARIAN SpectrAA). The mineral nitrogen was determined by extraction with potassium chloride and quantification by spectrocolorimetry while the assimilable phosphorus was evaluated using the method of Truog (1930).

Assessment of soil's chemical degradation states. In order to identify the deficiencies in mineral elements of the different soils, the contents of N, P, K and organic matter were compared with reference values proposed by Doucet (2006), CRAAQ (2003) and Duval and Well (2011). Soils were classified using triangle of Duchauffour (1997) and scale of Dabin (1970).

Proposition of fertilizer doses for sustainable vegetable production: the case of Spinacia oleracea. Two popular fertilizers available to farmers were selected for the fertilizers doses formulation. One is an organic fertilizer, a compost enriched with mineral elements developed by Bokobana et al. (2017) (173-313-328) for N-P_2O_5-K_2O and the other a mineral fertilizer commonly N-P-K (15-15-15). The calculation principle is based on this of reasoned fertilization which requires to consider the initial level of fertility of each soil and the mineral needs of crops. The online fertilizer dose calculation software ''Fertilizer Rate Calculator'' was used to determine the compost and NPK levels which could improve the initial soil levels and meet the N-P-K requirements of spinach. To optimize spinach production, the nutrient requirements of 120, 85 and 150 Kg/ha respectively for nitrogen, phosphorus and potassium were targeted according to Solangi et al. (2015).

*Statistical analyzes***.** A simple analysis of variance (ANOVA) was used to analyze data using SPSS 22.0 (SPSS, Chicago, Illinois, United States) and significant differences between means were compared using Fisher's Least Significant Difference Test (LSD) at a 95% probability level ($P \leq 0.05$). Duncan's test was used to classify treatments into homogeneous groups. Principal Component Analysis and the Pearson correlation test were used to study the correlations between parameters.

RESULTS AND DISCUSSIONS

Soil's chemicals parameters. Table 1 shows a strong heterogeneity of soils in relation to chemical parameters with a distribution of these soils in more than 8 groups A distinction is made between weakly acidic soils whose values are between 6.10 and 6.43 and moderately acidic soils (5.6-6.1). The electrical conductivity values range from 115 to 180 µS/cm in Gbobo Kondi and Notsé regions, respectively. The highest conductivities were found in soils samples from the Haho and Moyen-mono districts. According to the organic components, one find that poor soils have a concentration between 2 and 4.5% (Bagbe, Tchékpo-Dévé, Gbobo Kondi, kpédomé, Kossi-kopé and Adjikame), moderately rich soils (Kévé, Agbatépé, Tabligbo and Kpele) and rich soils ranges between 7 and 11% (Notse and Djikame) The C/N ratios are very high for the sites of Kpele and Djikame (122 and 186) while the site of Kpedome has the lowest ratio. The soils in this study have a moderately acidic pH and a conductivity between 112 and 181 µS/cm. They are acidic with a low electrical conductivities and are able to dissolve minerals. Indeed, pH is the most chemical parameter of soil which determines the availability of nutrients for plants and microorganisms (Doucet, 2006; Borah et al., 2010; Deshmukh, 2012). The acidic pH promotes the bioavailability of nutrients by making them more accessible to plants (Lucas and Davis, 1961). Macronutrients would be more available in soils with a pH below 6 such as those of Tabligbo, Gbobo kondi and Notsé. The major disadvantage with these soils is the probable leaching of the soluble nutrients towards the deep layers (Brady and Weil, 2004). This could be the case of Tabligbo's soil with a high acidity ensuing low electrical conductivity and low potassium contents. The organic matter contents of soils are between 2 and 12%. Four soils appear to be poor in organic matter (Dévé, Gbobo kondi, Bagbe and Kossi-Kopé). The low levels of organic matter in these soils could be explained by their exploitation without fallow land or the lack of organic amendments (Ballot et al., 2016). Although organic matter is not directly absorbed by plants, it participates enormously in chemical, physical and biological activities facilitating the absorption of nutrients by plants (Hubert and Schaub 2011). By participating in these phenomena, organic matter is permanently reduced if external contribution is not made over the seasons. The C/N ratios are very high for 2 soils (Kpele and Djikame) showing a disproportion between the contents in total organic carbon and total nitrogen. A high carbon content does not always indicate fertile soil but sometimes, soils where the conditions for organic matter transformation are hard (acid soils, too humid soils, too dry climate, lack of vegetation , too sandy soil) (Dabin 1970). Thus, the particle size analysis has shown that soils with high C/N ratios contain a high proportion of sand (more than 70%). This sandy state, combined with a high acidity could be factors which complicate the transformation of organic matter.

Table 1

Variation of soils pH, electrical conductivity, organic matter and cations contents (the letters a, b, c, d, e, f, g, h and i represent the different homogeneous classes)

Sites	pH	Electric Conductivity (µS/cm)	Organic matter (% m.s.)	Total organic carbon (% m.s.)	K mg/Kg	Ca mg/Kg	Mg mg/Kg	C/N
Kévé	6.43 a	124.3 g	4.9 c	2.88 f	395.70 ef	88.62 h	577.25 f	33.20 d
Bagbe	6.24 cd	122.4 h	3.2 de	01.88 h	327.20 f	190.56 e	755.4 e	19.20 g
Agbatehe	6.35 b	133.5 d	7.7 b	4.52 b	2613.20 b	386.55 d	2279.9 a	20.47 g
Dévé	6.44 a	129.6 e	2.6 e	01.52 i	325.45 fg	167.73 f	319.05 g	20.66 g
Tabligbo	5.62 h	112.2 e	8.8 b	5.17 c	277.10 g	704.70 b	1543.45 b	39.33 c
Gbobo Kondi	5.90 g	115.4 j	3.2 de	01.88 h	119.20 h	56.15 j	217.05 h	22.78 f
Kpele	6.22 d	102.8 i	7.0 b	04.11 e	430.70 e	37.59 l	304.65 g	122.54 b
Notse	5.90 g	180.9 a	11.1 a	06.53 b	3386.40 a	1703.90 a	2327.65 a	24.67 e
Kpedomé	6.26 c	116.5 i	4.3 cd	02.52 g	1358.10 c	64.11 i	895.7 d	03.47 i
Kossi-Kopé	6.07 e	159.0 b	2.2 e	02.41 g	1284.15 d	582.25 c	1295.25 c	10.74 h
Adjikame	6.23 d	147.1 c	4.1 cd	02.41 g	387.65 ef	117.92 g	558.9 f	25.71 e
Djikame	6.00 f	126.5 f	12.4 a	07.29 a	369.45 f	39.78 k	332.15 g	186.07 a

Main cations and macronutrients contents. The analysis of the main cation contents are shown in Table 2. We find a similar evolution as in the previous parameters. The potassium contents are fairly high in three soils from the plateau region (Notsé, Kpedomé and Kossi-Kopé) and one soil in the maritime region (Agbatehe). Soils of Agbatehe, Tabligbo and Notsé show the highest concentration in calcium and magnesium. Among the three cations analyzed, potassium contents are the highest and the optimal value was obtained in Notsé. Overall, soils from Notsé, Kpédomé and Kossi-kopé (plateau region) are rich in nutrients compared to others. In the maritime region, soil of Agbatehe presents an acceptable level of fertility. The total nitrogen content varies between 0.033% and 0.728% and this of total phosphorus is between 1180 and 968 mg/Kg. Analysis of the main cation contents shows that soils are rich in potassium contrary to other cations. Calcium and magnesium contents are higher in soils of Agbatehe, Tabligbo and Notse. The levels obtained for potassium are very interesting because producers no longer need an increase in potassium fertilization. The potassium contents of soils studied constitute a wealth to be exploited in order to optimize producer's resources. In fact, each chemical fertilization process must consider the initial potential soils in order to reduce risks associated with excess which could negatively impact on plants and other ecosystems. Phosphorus contents are slightly higher while those in nitrogen are low. Indeed, soils in Togo are very poor in nitrogen (Toundou et al., 2014) and confirmed with 90% of soils poor in nitrogen against 8% in phosphorus. Nitrogen fertilization is a real difficulty that face soils of Togo. However, nitrogen is the key mineral nutrient in all agricultural production systems (Havlin et al., 2010). It is absorbed by plants in nitric or ammoniac forms and is brought into soil in form of organic or mineral manures. The low contents recorded could be explained by unsuitable agricultural practices, which deplete soil over years.

Table 2

Soil's nitrogen and phosphorus content (the letters a, b, c, d, e, f, g, h and i represent the different homogeneous groups)

Regions	Prefectures	Sites	Total Nitrogen (% d.m.)	Mineral Nitrogen (% d.m.)	Total phosphorus (ppm)	Available phosphorus (ppm)
Maritime	Ave	Kévé	0.0868 ef	0.042 ef	163.07 e	17.182 g
		Bagbe	0.098 ef	0.0826 ab	104.4 h	14.904 h
		Agbatehe	0.2212 c	0.0708 bc	302.2 d	12.108 i
	Yoto	Dévé	0.074f g	0.056 bcd	1561 c	41.98 c
		Tabligbo	0.1316 d	0.056 cde	130.14 f	31.752 d
		Gbobo Kondi	0.0826 ef	0.035 def	97.62 j	9.102 j
Plateau	Haho	Kpele	0.0336 h	0.027 g	121.5 g	9.466 j
		Notse	0.2646 b	0.105 a	9368 a	169 a
		Kpedomé	0.728 a	0.077 abc	11.8 l	13.808 hi
	Moyen-Mono	Kossi-Kopé	0.1204 d	0.056 cde	3636 b	100.7 b
		Adjikame	0.0938 ef	0.063 cde	87.05 k	22.422 f
		Djikame	0.0392 gh	0.026 ef	100.9 i	25.922 e

Classification of soil's according to Dabin scale (1970) by associating the pH and the total nitrogen content. The classification of soils according to their fertility allows to distinguish three groups of soils. The first group qualified as "bad soils'' comprises soils from the Maritime's region and four from the plateau's region. The second group, containing only soil from Notsé qualified as "poor soil" and the third group containing soil of Kpédomé. Indeed, the latter has a high nitrogen content and a moderately acidic pH. It is qualified as ''medium soils''. Thus, we find that 83% of soils studied can be classified as bad soils, 8.5% as poor soils, and 8.5% medium soils (Table 3).

The analysis of soil's degradation was carried out by comparing the values of each parameter to standards (Tables 3). Overall, soils studied are mostly poor in nitrogen. The organic matter and phosphorus contents are moderately low compared to standards. Those of potassium are very high and even tend to exceed the required level. Soils of Togo have been always characterized as poor in nutrients and specifically in nitrogen (Toundou 2016; Sanou et al., 2018). A solution often proposed by technicians is a simple addition of the complex fertilizer N-P-K (15-15-15) with a dose of 200 Kg/Ha corresponding to 30 Kg/Ha of nitrogen. Furthermore, the high cost of a bag (50

Kg) of NPK fertilizer (13000 FCFA) discouraged producers from using this fertilizer. The quantities supplied by a few farmers who use it are also limited and do not effectively contribute to maintaining normal nitrogen levels of soils and crop production (Morris et al., 2007; Sanginger and Woomer 2009). Faced this diagnosis, use of reasoned fertilization will help to compensate the deficits in nutrients or organic matter. Taking into account soil initial analyzes before any fertilization is important to reduce the cost of fertilizer while maximizing crop’s harvests/ This process present a triple benefit: firstly, the deficient element is effectively available in soils with a normal dose; then, one can avoid excess of nutrients and eventually reduction of fertilizers costs.

Table 3

Levels of soils degradation in relation with essential nutrients and organic matter contents (* = CRAAQ (2003) standards for rich soil)

Parameters	Organic matter (%)	Level of degradation	Nitrogen (Kg/Ha)	Level of degradation	Total phosphorus (Kg/Ha)	Level of degradation	Potassium (Kg/Ha)	Level of degradation
Standards	4 % - 8%*		Scale of Dabin (1970)		400Kg/Ha*		800Kg/Ha*	
Kévé	4.9	Middle	2604	Bad	489.21	Excessively Rich	1187.1	Excessively Rich
Kpédomé	4.3	Middle	21840	Middle	35.4	VeryPoor	4074.3	Excessively Rich
Agbatehe	7.7	Rich	6636	Bad	906.6	Excessively Rich	7839.6	Excessively Rich
Adjikame	4.1	Middle	2814	Bad	261.15	Rich	1162.95	Excessively Rich
Tabligbo	8.8	Rich	3948	Bad	390.42	Very rich	831.3	Excessively Rich
Kossi-Kopé	2.2	Poor	3612	Bad	10908	Excessively Rich	3852.45	Excessively Rich
Devé	2.6	Poor	*2220*	Bad	4683	Excessively Rich	976.35	Excessively Rich
Bagbe	3.2	Poor	2940	Bad	313.2	Very rich	981.6	Excessively Rich
Gbobo Kondji	3.2	Poor	2478	Bad	292.86	Rich	357.6	Good
Djikame	12.4	Very rich	1176	Bad	302.7	Very rich	1108.35	Excessively Rich
Notse	11.1	Very rich	7938	Poor	28104	Excessively Rich	10159.2	Excessively Rich
Kpelé	7.0	Rich	1008	Bad	364.5	Very rich	1292.1	Excessively Rich

Proposals of fertilizers with their doses for sustainable spinach production on each soil. In order to offer adequate fertilizers to improve spinach production, soils were, firstly grouped into three categories according to their poverty in nitrogen, phosphorus and /or organic matter (Table 4). Thus, in order to improve the nitrogen and phosphorus content in soils poor in these elements, a mineral fertilizer N-P-K 15-15-15 is proposed. Compared to soils poor in nitrogen and organic matter, compost and N-P-K fertilizer have been proposed. For soils lacking in nitrogen, 800 kg/ha of N-P-K are needed to really compensate nitrogen deficits. For those poor in phosphorus, 567 kg/ha of N-P-K must be used. Soils poor in nitrogen and organic matter needed 340 Kg / ha of N-P-K and 4000 Kg/ha of compost.

Table 4
Grouping of different soils according to their degradation levels and reasoned proposal of adequate fertilizer doses by chemical type of soil for sustainable production of *Spinacia oleracea*

Soil's Group	Sites	Elements in deficits and recommendations	NPK dose (15-15-15) in Kg / Ha for the compensation of mineral elements	Compost dose in Kg / Ha (1.73-3.13-13.28) to compensate for mineral elements and organic matter
Soils poor in nitrogen	Kévé Agbatehe Adjikame Tabligbo Djikame Notse Kpele	N-P-K or nitrogen fertilizer	800	0
Soil's poor in phosphorus	Kpedome	N-P-K or phosphate fertilizer	567	0
Soils poor in Nitrogen and organic matter	Kossi-Kopé Dévé Bagbe Gbobo-Kondji	Compost + N-P-K	340	4000

Granulometric classification and typing of soils according to Duchauffour triangle (1997) and chemical classification. The combination of the results relating to chemical fertility and the granulometric state of the different soils allow to produce a classification of soils (Table 5). Thus, they are subdivided into 4 major groups: sandy silts representing 33%, silty (25%), sandy-silty (25%), clay-sandy silts (17%). These results show a predominance of silts in the soils of Togo. The analysis of the particle size parameters shows that most of soils contain silt and one distinguish medium and light rich soils in sands and silts.The texture of the soil plays an important role in it's density and porosity which are factors influencing roots functioning, the circulation of air and water. Thus, sandy soils are very permeable to air and water contrary to clay and silty soils. This could be the case of soils from Tabligbo, Djikame and Kpele reversely to Deve, Kossi-Kopé and Agbatehe soils. The texture of soils also affects nitrification. For soils with fine texture and compact structure, nitrification is very slow except at a pH above seven (Dabin 1970). In addition, sands could be poor in nutrients while clays would be rich although the balance between elements could not necessarily be analyzed. This is the case of soils from Djikame, Kpele and Tabligbo which are sandy soils with low nutrient contents and high C/N ratios. Mineralizing process would therefore be very slow in these soils, resulting in a storage of organic carbon. The texture of soils also gives an idea of useful water. It is lower if the texture is sandy, higher if the horizon is silty-clay (Duchaufour 1970). Therefore, plants cultivated on soils of Djikamé, Kpelé and Tabligbo are likely to suffer under impact of a water deficit compared to those cultivated on soils rich in silts and clays that are the soils of Notsé and Kpedomé. Indeed, these soils are the only ones containing in their granulometric composition silts, sand and clays. This exceptional texture (Ardouin 2012) has most qualities of the three textural types and would be the most favorable for agriculture (Ardouin, 2012; Koné et al., 2008).

Table 5

Granulometric classification of soils

Sites	Clay 2µ (%)	Fine Silt 2 to 20 µ (%)	Fine stringer 20 to 50 µ (%)	Fine Sand 50 to 200 µ (%)	Coarse sand 200 to 2000 µ (%)	Type of soil according to the textural triangle
Kévé	17.25	10.69	05.35	32.75	33.83	Low nitrogen sandy loam
Kpedomé	19.03	11.47	06.52	21.69	39.29	Low phosphorous clay loam
Agbatefé	25.17	18.88	10.42	23.05	20.30	Low nitrogen silt soil
Adjikamé	22.02	06.011	09.41	37.11	25.36	Low nitrogen sandy loam
Tabligbo	05.12	10.16	04.42	32.13	46.89	Low nitrogen sandy loam
Kossi-Kopé	25.17	18.88	10.42	23.04	20.30	Lime poor in nitrogen and organic matter
Devé	26.30	16.12	11.45	28.03	16.45	Lime poor in nitrogen and organic matter
Bagbe	17.25	10.69	05.35	32.75	33.83	Sandy loam poor in nitrogen and organic mattere
Gbobo Kondi	12.52	15.35	03.86	32.19	32.98	Sandy loam poor in nitrogen and organic mattere
Djikamé	05.81	08.68	04.78	24.42	55.42	Low nitrogen sandy loam
Notsé	19.03	11.47	06.52	21.69	39.29	Low phosphorous clay loam
Kpelé	08.10	11.33	05.84	31.91	41.49	Low nitrogen sandy loam

Correlations between soils characteristics using test of Pearson and PCA. The PCA let to classify soil parameters in 5 groups. The first group of variables containing available phosphorus, calcium, total phosphorus, magnesium, potassium and electrical conductivity were positively correlated. The second group of pH, fine sand and clay were also positively correlated, but negatively correlated with the third group (organic matter content, coarse sand and fine silt). The C/N ratio and the nitrogen content are independent and only in their group. PCA and correlations test show that the available phosphorus are negatively correlated with the fine sand. On the other hand, positive correlations were obtained between the available phosphorus and coarse sand.

pH and the organic matter content progress differently according to granulometry The organic matter is positively correlated with coarse sands and fine silts. Contrary, pH is positively correlated with fine sand and clay Coarse sands and fine silts retain organic matter better than fine sands and clay such as soils of Kpedome, Kévé, Agbatehe, Djikame, Tabligbo, Adjikame, Notse and Kpele. These soils have high contents of coarse sands with suitable organic matter contents In these soils, mineralization would be slow. The fertilization of these soils with organic

amendment deserves to be controlled in order to prevent a disproportion between the total nitrogen and total carbon (C/N ratio). The total nitrogen content is independent of other parameters and is found in the middle of the three main groups of parameters.
Relationships between the different parameters through regression tests and PCA allows to conclude that the contents of total or available mineral nutrients in the study soils are independent of the contents of organic matter, soil pH and particle size types. These results corroborate those of Hossain et al. (2014) who obtained non-significant correlations between available phosphorus, potassium and soil's chemical parameter such as pH and organic matter. Total organic matter content and pH would be the most impacted by the particle size types and change in the opposite direction depending on soil granulometry. Besides, under similar climatic conditions, soil's organic carbon (organic matter) dynamics were mainly affected by vegetation and soil characteristics, but not the soil clay content (Zhong et al., 2018). The soil organic matter would then depend on its content in fine silts and coarse sand.

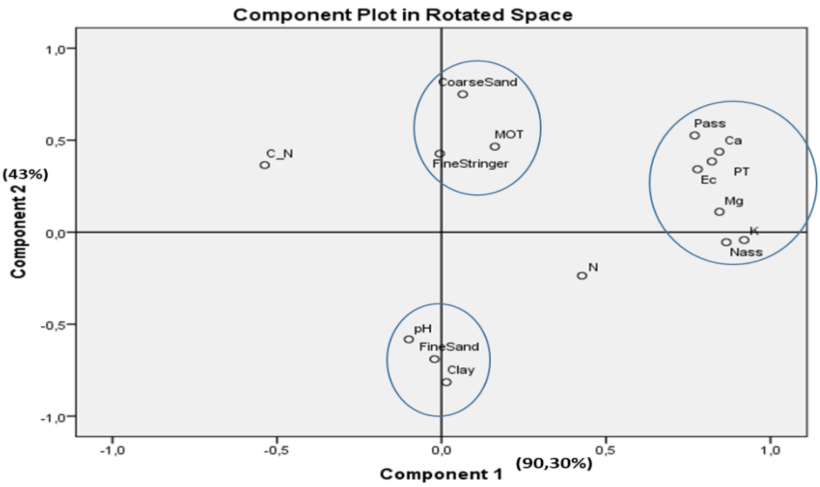

Fig. 2. PCA of soil's parameter's analyzed (C_N= Ratio C/N ; Ec= Electrical conductivity ; Pass= Available phosphorus; PT= Total phosphorus; Nass= mineral Nitrogen)

CONCLUSIONS

This study allows to draw up a mini-assessment of the gardening soils fertility in South Togo. The analysis reveals notable insufficiencies in mineral elements except potassium in the different soils. Their classification is an advantage of the vegetables production in South Togo. In fact, vegetables will be cultivated on their adapted soil in order to avoid harvest losses and to optimize their production, therefore the economic efficiency of producers. Results of this study allow to update the chemical data linked to soil's fertility in Togo for better decision-making in soil's fertilization process. However, agronomic tests on the different types of manure formula proposed will be done to obtain concrete results for sustainable vegetables production.

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