Abstract

Food security is an increasing issue within Sub-Saharan African (SSA), particularly in urban regions with increasing population and less access to agricultural produce. A farmer socio-economic survey (n=40) and soil survey was conducted in two valley bed suburbs of Yaoundé, Cameroon in 2014 to identify soil constraints and farming practices that may limit food production. The objective of the study was to identify potential soil constraints that may limit crop growth in these valley beds. More specifically, the study aimed to identify soil physical and chemical properties affecting crop yield in two sites Nkolodom and Nkolbisson. Farmer survey on fertility management and soil sampling in these areas were conducted to characterize the sites. The depth to water-table at both sites was 60-70 cm, being dependent on the topography. The soil texture at both sites was clay loam (0-20 cm depth), though the colour of the soils ranged from red brown to yellowish brown to dark reddish brown. The soils had medium to high levels of organic carbon (C), high total nitrogen (N) and a low C/N ratio. The pH at Nkolodom was mostly neutral, though slightly acidic at Nkolbisson. The cation exchange capacity (CEC) was high at Nkolodom (21.30 cmol (+)/kg) and medium (15.85 cmol (+)/kg) at Nkolbisson, although characterised by low levels of exchangeable Ca²⁺, Mg²⁺ and K⁺. Available phosphorus (P) (Bray 2) at Nkolbisson was 400 mg/kg and 1,715 mg/kg at Nkolodom. Soil salinity levels at Nkolodom measured brackish to moderate (810 mS/m) where as low at Nkolbisson (135 mS/m). Chicken manure was the fertiliser applied by farmers spread at rates of 200 kg/ha/pa. Overall, the results show that the levels of the nutrients N and P from soil tests were considered adequate for plant growth. Salinity may pose a constraint to crop growth at Nkolodom and warrants further investigation. Soil fertility is affected by the distance from each farmers house with the most fertile soils (60%) being close to the farmer's house and poorer soils (5%) being furtheest from the house where less house waste is applied.

Keywords

Food production; Soil fertility; Urban agriculture; Valley beds

Abbreviations

CEC: Cation Exchange Capacity
SSA: Sub-Saharan Africa

Introduction

Within Sub-Saharan Africa (SSA), such as Cameroon, urbanization is becoming more rapid with urban agglomerations accounting for about 52% of the population living in towns, which are characterized by a high density of about 30 inhabitants per km² and low incomes [1]. The imminent challenge is to feed the growing population to avoid potential famine [2]. Within SSA, the maize-legume rotation is the traditional cropping system used including a range of garden market products such as capsicum (*Capsicum annuum*), tomato (*Solanum lycopersicum* sp), basil (*Ocimum basilicum*), celery (*Apium graveolens*), lettuce and Jute mallow. Food is usually produced in rural areas and brought to the city; however, a lack of adequate local transport mechanisms for food distribution has not yet been achieved [3,4]. Consequently, urban agriculture has the potential to improve food supplies and income in urban regions to address the food shortage [5]. In 2007, urban agriculture was practiced by 13.6% of households in Yaoundé, the capital of Cameroon [6]. Overall, African agriculture is highly diverse [7,8]. Large differences between regions, soil, farming systems and crops are matched to each of the main agro-ecological zones [9,10]. Studies have
shown that a large proportion of soils in SSA are derived from old land surfaces with low levels of remaining nutrients [11]. Research to date has predominantly focused on the types of crops cultivated [12-14]; however, there is a scarcity of information related to the suitability of these soils for agriculture, particularly in terms of their soil properties and constraints to crop production. The history of the land and the soil parent materials affect soil fertility which influences the types of farming systems [15,11].

According to the International Soil Classification System, the majority of soils in Cameroon are Ferralic: yellow, ochre or red in color depending on the mother rock and the landscape [16] and arise from migmatitic gneiss soil parent material [17,18]. Soils of this type are categorized as clay and acidic with a pH in the range from 4 to 5.5 in CaCl2 [19]. The replenishment of nutrients for food production is an important component of good farm management and will ensure that potential yields are achieved that will help to provide adequate food supply in urban regions. Where the fallow system or shifting cultivation is practiced by smallholder farmers, the length of time since cultivation from the last fallow period influences soil fertility [20]. This study aimed to identify constraints to soil fertility and crop production in two valley bed regions in Yaoundé by investigating soil physio-chemical properties and current soil fertilizer management used by smallholder farmers that may limit potential yield and improve food supply to urban regions.

Materials and Methods

The study was conducted at Yaoundé, Cameroon (located between 3°45’ and 4°00’ N latitude and 11°00’ and 16°12’ E longitude) in the tropical forest zone. The climate is characterised by a bimodal rainfall comprising two rainy seasons (March-June and September-November) and two dry seasons. The annual rainfall ranges from 1,000 to 1,500 mm with an average temperature from 17°C to 30°C [21,22]. Information for the study was collected from two sites within Yaoundé during December 2014, at Nkolodom and Nkolbisson where urban agriculture is practiced.

A total of 20 respondents were interviewed at Nkolodom and Nkolbisson, respectively, comprising a total of 40 households. The participants selected had valley bed farms that ranged between 0.5 and 1 ha in size and common in these regions. Generic questions covered personal details (age, level of education, position in the household) soil fertility management, crop production and other socio-economic activities. Primary data collected included: farmer demographics such as gender of the household head, marital status, farming experience, types of crops produced, type and amount of fertilizer applied, farmers’ income, yield data and soil constraints. In addition to the questionnaire, group discussions and direct observations in the field were conducted to complete the information obtained during interviews.

A total of ten soil samples were collected at random from each of two sites using a 75 mm diameter auger at 0-20 cm depth. Soil texture, consistency, pH and EC were assessed in the field for each sample. All samples at each site were then bulked into a composite sample and three sub-samples analysed at the IRAD Yaoundé soil laboratory for pH, organic matter (OM), available phosphorus (P), exchangeable bases and exchangeable cations using the methods described by [23], total nitrogen (N) using Kjeldahl method, organic carbon (OC) using chromic acid digestion analysis and saturated electrical conductivity (ECe) estimated using the [24] method.

Data collected was entered into Excel spreadsheets for analysis using Statistical Package for Social Sciences (SPSS version 17) to generate simple statistical information. The data obtained was subjected to descriptive statistical analysis at 95 % confident limit and Pearson correlation coefficient. One-way ANOVA was used to compare soil pH between sites. Previous studies used statistical analysis to describe soil constraints for urban horticulture in Yaoundé for compost adoption in sub-Saharan Africa [5,25]. In this study, we used SPSS for characterization of soil quality of valley beds for better soil fertility management by farmers.

Results and Discussions

Demographic characteristics and household activities

Of the 40 households interviewed, the demographics were similar for both Nkolodom and Nkolbisson and indicated that the majority (87.5%) of smallholder farm households were headed by males, with a minority of farms headed by females (12.5%) (Table 1). The smallholder farmers inherited land from their parents. There were relatively few single farmers: 85% percent of the households were married and 15% were either single or widowed. In these villages, females were involved in many activities within the farming production system being responsible for sowing, weeding, fertilizer application and harvesting. Farming represented the main activity for 92.5% of households in the study areas, with business the main activity for only 7.5% of the households. The greater part of the household income was derived from farming (87.5%), with products from peri-urban agriculture sold to markets in the cities to generate income for families. On the other hand, almost 13% of farmers considered trading as their main source of income.

Crops grown in the study areas

The average farm size across the study site ranged from 0.5 ha to 1.0 ha, with an average of 0.8 ha. The main crops grown at the two study sites included a mixed system of maize (Zea mays) and a range of vegetable crops including Amaranth (Amaranthus sp.), lettuce (Lactuca sp.), Jute mallow (Corchorus olitorius) and Okra (Malvaceae family) (Table 2). Very few legumes were reported. Maize production was measured in this study and will be discussed in further detail later in this paper.

Soil fertility, fertilizer source, type and application

From the farmer’s perspective, three classes of soil in their system are used to assess the level of soil fertility based on visual indi-
The majority of the farmers indicated that the benefits derived from using chicken manure included yield increases and the lower cost compared to inorganic fertilizers. The farmers surveyed indicated that input costs are the major constraint limiting inorganic fertilizer use. Several studies have shown that within regions of SSA, prices of inorganic fertilizer are not affordable by smallholder farmers [29,30]. Thus, these farmers focus on chicken manure to replenish soil fertility rather than purchase inorganic fertilizers. In 2017, a bag (50 kg) of chicken manure cost $2, while a bag (50 kg) of inorganic NPK fertilizer (20-10-10) cost $30. Therefore, a 50 kg bag of NPK (20% N) would supply 10 kg N costing $3 kg/N, whereas a 50 kg bag of dried chicken manure (3.9% N) would supply 1.95 kg N costing $1.03/kg. Hence, the poultry manure is the cheaper source of N to purchase, although a larger volume is required. The typical application rate of 200 kg chicken manure applied by farmers in the survey would supply a total of 7.8 kg N/ha/pa, which is low considering the amount of N removed by harvested crop produce. Recommended fertilizer rates in SSA regions are much higher according to several researchers [31-33], for example, NPK at 150 kg/ha and urea (46% N) at 50 kg/ha to provide a total N loading of 53 kg/ha/pa. However, these loading rates and prices do not consider other nutrients supplied by chicken manure. There are few studies that have determined the nutrient value of the chicken manure being used in order to determine overall nutrient budgets for the crops grown. In comparison with other animal manures, studies have reported that chicken manure has higher amounts of N, P and K per unit volume [26,34]. Disadvantages with the use of manure can include reduction in nutrients, such as P, following long stockpiling periods [35]. The legumes grown in rotation with maize provide an important source of N [36], though were largely absent at the two sites surveyed in this study. Given the close proximity to the river systems, the overuse of inorganic fertilizers could result in nutrient loss into water bodies, which needs to be avoided and hence a better rotation with legumes should be promoted as a more environmentally friendly option.

### Soil physical properties

The two study areas covered large swampy valleys adjacent to...
river systems. The texture for both sites was a clay loam, although the colour was different (Table 4). At Nkolbisson the topsoil (0-20 cm) was red (5YR 5/6), brown red (10YR 3/4) to yellowish brown (10YR 5/6). At Nkolodom the topsoil was dark reddish brown (2.5YR 2.5/3). The depth to water-table in these valley beds was between 60 cm and 70 cm depending on the relief, the topography position and the depth of the A horizon. In a study by [37] the Yaoundé gneiss is comprised of sandy clays in the narrow and large valleys and organic clays in the lower parts of the large valleys. From a morphological point of view, these clays are very heterogeneous with several clay loam or sandy textures as cited by diverse studies [18,38]. The large swampy valleys are at risk of waterlogging, which could inhibit plant growth by reducing the availability of oxygen and nutrients to the roots. There is also the potential leaching of nutrients into waterways through run-off from rainfall and leaching if not taken up by plant roots.

| Soil property | NKOLODOM | NKOLBISSON |
|---------------|----------|------------|
| Colour (Munsell) | 2.5YR 2.5/3 | 10YR 5/6 |
| Texture | Clay loam | Clay loam |
| Depth to water table (cm) | 60 | 70 |

**Table 4: Soil physical description at the two study sites**

**Soil pH and electrical conductivity**

The mean soil pH of topsoil (0-20 cm) was slightly acidic at Nkolbisson at 5.2 (SD=0.174) though was more neutral at Nkolodom at 6.0 (SD=0.172) (Table 5). One-way ANOVA indicated a significant difference between the sites in terms of soil pH (P<0.05). The low pH at Nkolbisson could potentially start to inhibit plant growth through aluminium (Al) toxicity, nodulation failure in legumes and reduce the availability of Ca, Mg, N and P in soil [39]. Soil acidity at Nkolbisson should be monitored and a solution would be for farmers to apply lime to increase soil pH and/or better manage fertiliser N inputs. In general, lime is available in the market but is not easily affordable by farmers.

The electrical conductivity (EC) value in the 0-20 cm soil depth varied between the two sites, with Nkolodom samples measuring 90 mS/m and Nkolbisson measuring 15 mS/m (Table 5). Salinity values based on a saturated extract (ECe) were calculated to be 810mS/m at Nkolodom (medium salinity) and 135mS/m at Nkolbisson (low salinity) (Table 6). The ECe gives a more definitive measurement of the salt content than EC and was estimated using the [24] technique:

\[ ECe \text{ (mS/m)} = \text{EC (mS/m) } \times 9 \] (nominated factor determined by soil texture).

The difference in salinity levels between the two sites may be due to their position in the landscape. Nkolbisson has good soil drainage and low salinity whereas at Nkolodom the drainage tends to be reduced by a flat landscape accumulating free salts. Salinity inhibits plant growth by reducing the osmotic pressure gradient between the plant and the soil solution, restricting the ability of the plant to absorb water and consequently, reduces the amount of plant available water stored in the soil [40,25]. Moreover, soil salinity has unfavorable effect on soil fertility and nutrient uptake in plants [41,42], reducing crop growth and production significantly [43]. Nevertheless, the threshold value differs from crop to crop [44]. Although the salinity level was rated as medium at Nkolodom, the yield of maize did not appear to be reduced, which may be a reflection of the ability of maize to be slightly tolerant to salinity, although more sensitive crops, such as peas would suffer. It is recommended that further soil sampling and sub-soil sampling be conducted at Nkolodom over different times of the growing season to ensure that salinity is not a cause for concern at this site. The selection of more salt tolerant varieties may be necessary.

**Table 5: Soil pH and Electrical conductivity (EC) at the two study sites**

| Soil property | NKOLODOM | NKOLBISSON |
|---------------|----------|------------|
| pH 1:5 (water) | 6.59 | 5.32 |
| pH 1:5 (CaCl2) | 6.0 | 5.2 |
| EC 1:5 (mS/m) | 90 | 15 |
| ECe 1:5 (mS/m) | 810 | 135 |

1 pH from Laboratory (n=3);
2 pH from field (n=10)

**Table 6: Salinity Rating used for EC (1:5) mS/m and ECe (1:5) mS/m**

| Rating | EC (1:5) mS/m | ECe (1:5) mS/m | Effect |
|--------|---------------|----------------|--------|
| Low | <50 | <400 | Minimal effect on plant growth |
| Medium | 50-200 | 400-1600 | Plant growth is inhibited |
| High | >200 | >1600 | Plant growth is severely restricted |

Source: [40]

**Soil organic matter, organic carbon, total N and available P**

The levels of organic matter (OM) were high at Nkolodom (4.05%) and medium at Nkolbisson (2.25%) (Table 7). These values were reflected by the levels of organic carbon (OC) at each site (2.35% and 1.30%, respectively), which according to [45] would indicate that soil at Nkolodom would have good nutrient
storage and stable structure. Once OC levels fall below 1%, soils are characterised by poor nutrient storage and unstable structure. The high levels of OM may somewhat offset any effect of salinity on plant growth at the Nkolodom site.

| Soil property | NKOLODOM | NKOLBISSON |
|---------------|----------|------------|
| OM (%)        | 4.05     | 2.25       |
| OC (%)        | 2.35     | 1.30       |
| OC rating     | High (>2%) | Medium (1-2%) |

Source: IRAD soil laboratory Report, Yaoundé; Organic C ratings based on Scheffer and Schachtschabel (1966)

Table 7: Soil property of the two study sites

The concentrations of total N and P at each site are given in Table 8. The Bray 2 extraction method is an estimate of the level of available P for plant uptake. The concentration of available P was high at Nkolodom (1715 mg/kg) and moderate (400 mg/kg) at Nkolbission, as per [46] Bray P ratings. Nkolodom has more available P in soils than Nkolbission, though both are considered sufficient at each site. The high concentrations of total N at each site would not indicate N deficiency. The ratio of carbon to nitrogen (C/N) provides an indication of the source and state of decomposition of soil OM. Low values (<10) of C/N indicate that OM is being lost at both sites [24]. This could be caused by continuous cropping without replenishment and the removal of plant material on soil. The C/N level of both sites was low being 8.3:1 and 7.6:1 at Nkolodom and Nkolbission, respectively.

| Soil property | NKOLODOM | NKOLBISSON |
|---------------|----------|------------|
| Total N (%)   | 0.29     | 0.17       |
| C/N ratio     | 8.3      | 7.6        |
| P Bray2 (mg/kg) | 1715     | 400        |

Source: IRAD soil laboratory, Yaoundé

Table 8: Total N and P values for the two sites tested

Exchangeable cations (Ca$^{2+}$, Mg$^{2+}$, K$^+$ and Na$^+$)

According to [45], clay loam soils, as in this study, have good nutrient storage. The CEC measures the total cations that can be held in the exchange complex of the soil and is influenced by the clay content. A CEC of less than 5 cmol (+)/kg is considered low with a poor capacity to store nutrient cations [46]. Soils from both sites were measured to have good capacity to store cations. The CEC rating was high at Nkolodom and medium at Nkolbisson, being 21.30 cmol (+)/kg and 15.85 cmol (+)/kg, respectively (Table 9). Low levels of cations, such as Ca$^{2+}$, Mg$^{2+}$ and K$^+$ can reduce plant growth [39,45]. [46] indicated that Ca$^{2+}$<5 cmol/kg, Mg$^{2+}$<1 cmol/kg and K$^+$<0.5 cmol/kg are considered low with deleterious effects on plant growth. Nkolbisson was characterised by relatively low levels of exchangeable cations: Ca$^{2+}$, Mg$^{2+}$ and K$^+$ indicating that other cations, such as Aluminum (Al$^{3+}$) may form the majority of cations at this site. The CEC is also dependant on the pH of the soil because when soil acidity increases, more H$^+$ ions are attached to the colloid and other cations such as Al$^{3+}$ are displaced. It can be seen that Nkolbisson was characterised by low levels of exchangeable Mg$^{2+}$ and K$^+$ and these nutrients need to be investigated further to ensure they are not limiting plant growth.

| Soil cation(cmol(+)/kg) | Nkolodom | Nkolbisson |
|-------------------------|----------|------------|
| Ca$^{2+}$               | 7.79     | 4.19       |
| Mg$^{2+}$               | 1.59     | 0.83       |
| K$^+$                   | 0.75     | 0.12       |
| Na$^+$                  | 0.11     | 0.12       |
| Total CEC               | 21.30    | 15.85      |

Source: IRAD soil laboratory, Yaoundé

Table 9: Exchangeable cations for the two sites tested

Output and productivity of maize

Based on maize production at each site, the average yield in 2013 across each farmers paddock (low to high yielding areas) was estimated to be 2.5 t/ha at Nkolodom and 2.1 t/ha at Nkolbisson. The yield declined steadily further from the house. These yields were lower compared to maize yields at the Yaoundé Institute of Research and Agricultural Development field station, (~ 3.5 t/ha) and indicate that farm yields for small-scale farmers in peri-urban areas are below the potential yield of the region [18]. The amount of N applied in chicken manure applied by farmers in the study (7.8 kg N/ha/pa) is well below that removed in crop harvest given that one ton of maize grain removes approximately 16 kg N/t. Although N may not be the limiting factor at both sites, similar mass balances can be calculated for all nutrients applied.

Badu-Apraku B and Dhliwayo T [48,49] reported that within SSA, the yield of maize was estimated at 4.4 t/ha for early maturing varieties and 5.3 t/ha for late maturing varieties. In general, there is a potential to improve crop production by introducing new management practices. It has been reported that in SSA continuous maize production without integrated soil nutrient management reduces soil fertility over time and decreases the yield [50-52]. However, it is unknown by this study if the inability to achieve potential yield is due to soil constraints or other management issues such as pests and diseases. Although the study focused on soil constraints, there are several other factors that farmers need to manage to improve yield, such as good crop management, appropriate land preparation and fertilizer, optimal plant density, improved varieties, weed, pest and disease control. Moreover, suitable intercropping in the Yaoundé valley beds need to be practiced. Soil fertility management practices to maintain soil fertility including the use of fertilizer at the right rate will close the yield gap in this region and increase production. One alternative is to make better use of composting the excess maize stubble to replenish these valley bed soils [50-54].
Conclusion and Recommendations

The two peri-urban valley bed regions of Yaoundé investigated in this study showed many similarities in terms of demographics, soil texture and depth to water-table and cropping practice that followed a traditional maize-legume rotational practice, shifting cultivation and fallow; yet differed in several properties that may affect crop growth. Crop yields are approximately 50% below the potential yield of the region, being generally lower at Nkolbisson than at Nkoldom. The levels of N and P soil appear adequate for crop growth at both sites; however, soil acidity, aluminum toxicity and low exchangeable Ca²⁺, K⁺ and Mg²⁺ could be potential constraints to crop growth at Nkolbisson. At Nkoldom, soil salinity could be a constraint to crop growth. Further research should be done to confirm the extent of soil salinity, including measuring the concentrations in subsoil and river systems. The main source of fertilizer applied by farmers at each site was chicken manure (200 kg/ha), which may contribute a small amount to the maintenance of N, P and other nutrients for plant growth and build OM, though unlikely to replace all nutrients removed by the crop. There is a need to calculate the effect of chicken manure on overall nutrient budgets over time in these study areas to improve soil management practices affecting crop yield. This could be achieved by conducting strip experiments using a range of macro and micro-nutrients and/or plant tissue testing in order to identify deficiencies and hence recommend better fertilizer practices. Given the proximity of both sites to the river, it is imperative that fertilizer is not applied in excess and washed into the river system. Peri-urban valley bed regions have the potential to increase the source of food close to regional areas, though constraints to production need to be addressed.

Acknowledgments

The authors express sincere thanks and gratitude to Australian Department of Foreign Affairs and Trade for funding this research. We also thank Curtin University, Perth, Western Australia.

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