Open Access Library Journal
2019, Volume 6, e5841
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Gaining Insights in Soil Fertility on Lixic Ferralsols: Linking Banana Productivity to Soil Nutrient Dynamics in Smallholder Farming Systems in South-Western Uganda

Robert Muzira[1], Matthius Wakulira[2], Charles Lagu[3], Steven Natuha[1]

[1]National Agricultural Research Organization, Mbarara, Uganda
[2]Uganda Land Care Network, Kampala, Uganda
[3]National Animal Genetic Resources Center and Data Bank, Wakiso, Uganda
Email: nrmuzira@yahoo.com

How to cite this paper: Muzira, R., Wakulira, M., Lagu, C. and Natuha, S. (2019) Gaining Insights in Soil Fertility on Lixic Ferralsols: Linking Banana Productivity to Soil Nutrient Dynamics in Smallholder Farming Systems in South-Western Uganda. *Open Access Library Journal*, **6**: e5841.
https://doi.org/10.4236/oalib.1105841

Received: October 8, 2019
Accepted: December 16, 2019
Published: December 19, 2019

Abstract

In Uganda, banana (*Musa* spp.) is an important crop supporting different stakeholders along its value chain. However, the increase in banana production under smallholder farming system is a result of the increased area of land under its cultivation. This has escalated land degradation in the form of soil nutrient exhaustion in the banana farming systems. Although, declining trends for banana productivity, has been widely reported, there is limited formidable information on the level of soil fertility decline in the banana-grown fields in relation to annual crop-grown fields, which also support livelihoods of smallholder farmers. Therefore, detailed comparison farm studies were conducted on banana and annual crop grown-fields on lixic ferralsols to gain insights on soil organic matter and chemical parameters of selected fields. While there were no significant differences in soil chemical properties ($p < 0.05$) between banana and annual crop-grown fields, soil organic matter, pH, extractable P and exchangeable K were more skewed to lower values in banana-grown fields compared to annual crop grown-fields. This was an indicator of higher soil nutrient depletion in the banana-grown fields, which could lead to lack of banana production sustainability. Hence, to maintain banana production sustainability, there is a need to intensify soil fertility management practices to offset soil nutrient losses in the banana-grown fields.

Subject Areas

Agricultural Science

Keywords

Soil Fertility, Banana, Annual Crops, Land Degradation

1. Introduction

Uganda has been ranked from the top five in the 2000s to current top ten banana-producing countries [1]. The decline in banana production has been attributed majorly to decline in soil productivity [2]. South-western Uganda is the major banana-producing region in the country [1], where the crop occupies over 75% of the cultivable land. Low banana production, has led farmers to use intensification techniques that involve integrating mosaic of high yielding and exotic clones in the existing cropping systems. Despite the response from farmers to use these intensification techniques, banana productivity has kept low for the past decades [1]. Banana production being the major source of livelihood of small-scale farmers, reduced banana yields have had negative impacts on household food and income security in south-western Uganda. Among other factors such as prolonged drought due to climate variability, banana productivity is on the threat due to soil fertility decline [2]. Soil nutrient exhaustion negatively impacts future livelihood of farmers and other stakeholders along the banana value chain. It also has negative impacts on country's economy as a whole.

While soil fertility decline has been widely reported as one of the major factors affecting banana production, there is limited information on soil nutrient dynamics on soils cultivated with banana. Hence, detailed comparison soil fertility studies were conducted to assess soil fertility levels in the banana and annual crop-grown fields to gain an insight on soil nutrient dynamics that could explain the reduced banana productivity in the region.

2. Materials and Methods

Study area

Major banana producing districts: Isingiro, Mbarara, Sheema, Bushenyi and Ibanda in the south-western agro-ecological zone of Uganda were purposively selected for the study based on the volumes of bananas produced and marketed [1]. The soils of the study area were majorly Lixic ferralsols [3] in smallholder banana farming systems located in the semi-humid zone of the south-western Uganda (**Figure 1**). The soils are deeply weathered and red in color. The soils have diffused horizon boundaries and dominated by low activity clays (kaolinite), high levels of sesquioxides and high levels of residual, resistant primary minerals [4]. Banana production is the major agricultural activity for small-scale farmers. Also grown are bush beans that contribute to household food, nutrition and income [5]. The climate of the three districts is tropical in nature, which is hot and wet with bimodal rainfall ranging between 1000 mm - 1200 mm. Temperatures range from 14˚C to 29˚C and rarely below 13˚C and above 30˚C.

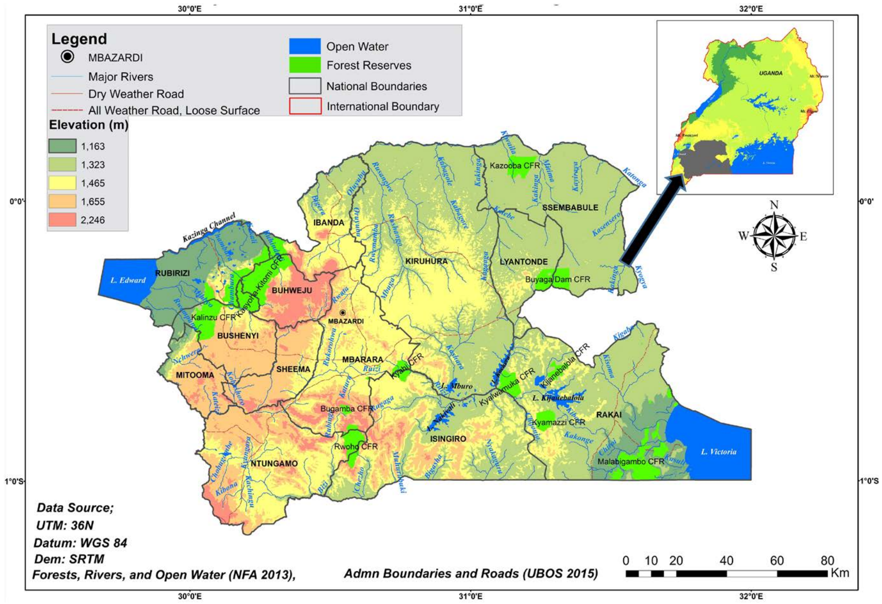

Figure 1. Physical features and location of the South-Western Agro-Ecological Zone of Uganda.

Selection of fields and soil sampling

Fields that had been under banana and annual crop production for at least 20 years were purposively selected with the help of farmers. Individual farmer's fields that were identified for the study were those lying on the same slope position. The soils were obtained from 0 - 20 cm depth and analyzed for chemical properties (pH, total N, extractable P, exchangeable K and total organic matter) as described by [6].

Data analysis

The collected data was entered into Microsoft Excel spreadsheet, for cleaning, correctness and storage. The descriptive statistics was done using R statistical program. Box-and-whisker plots were used to graphically depict soil chemical parameters of fields under banana and annual crop production through their quartiles. The spacing between the different parts of the box-and-whisker plots were used to indicate the degree of dispersion (spread), concentration and skewness in the data, and also showed outliers. Analysis of variance was used to ascertain significant differences of the means of the measured soil parameters between banana and annual crop-grown fields.

3. Results and Discussion

There were no significant differences in the measured soil chemical properties for the banana and annual crop-grown fields ($p > 0.05$). Nonetheless, there were variations among the two categories of fields worth describing.

Soil pH

There was smaller variant (higher level of similarity) in soil pH in annual crop-grown fields compared to banana-grown fields that exhibited high level of dissimilarity (**Figure 2**). Nonetheless, both fields under annual and banana

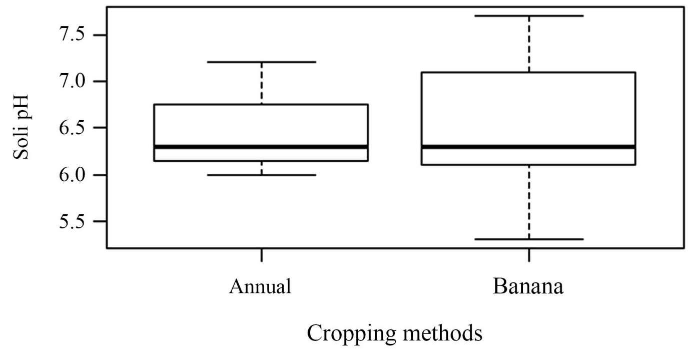

Figure 2. Soil pH.

cropping systems had an average pH 6.4, and pH ranges of 6.0 - 7.2 and 5.3 - 7.7, respectively. The higher soil pH range in the banana-grown fields was associated with array of soil management practices used by smallholder farmers [7]. Soil organic inputs (animal animal) commonly used by smallholder farmers have high potential of increasing soil pH through chelation of Al^{3+} and Fe^{3+}, majorly responsible for low soil pH in Lixic Ferralsols through hydrolysis process [8]. Wood ash which is also commonly used in the nearby fields as household wastes acts on soil acidity through its liming activity. Wood ash is high in Ca content, and therefore has effects of raising soil pH [9]. Nonetheless, wood ash is also a good source of K, P, Mg and micronutrients required for crop growth [9].

Bananas are heavy feeders compared to annual crops, and under low soil fertility management practices, there is higher soil nutrient removal from the banana systems through nutrient uptake compared to annual crop systems [10]. Removal of higher amounts of soil nutrients including bases that controls soil pH, favors increased H^+ ion concentrations that increases soil acidity [11]. Under annual cropping, there is high buffering capacity of the soil due to low amounts of soil nutrients removed from the soil and also the resting time given to the land after the crop removal.

Banana-grown fields with no soil conservation measures are vulnerable to soil nutrient losses through erosion and surface runoff, which exposes sub soil that contains high amounts of Al^{3+} and Fe^{3+} that increases soil acidity. Ferralsols are characterized by high levels of Al^{3+} and Fe^{3+} that play a great role in soil chemical properties [12]. External organic residues such as papyrus reeds and other materials from outside the banana-grown fields are often used as mulching materials. These organic residues may alter soil pH and chemical composition upon decomposition depending on the source of origin and chemical composition. Hence, different soil fertility and conservation practices used by farmers in the banana production led to an array of the observed soil pH.

Total soil organic matter

The minimum and maximum levels of total soil organic matter was higher in annual crop-grown fields (3.6% - 9.7%) compared to banana-grown fields (2.4% - 7.6%) with the average organic matter contents of 5.6% and 4.4%, respectively (**Figure 3**). Farmers' hardly used soil organic inputs in annual crop-grown fields,

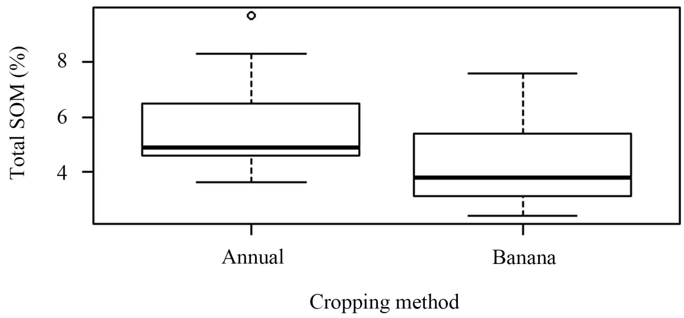

Figure 3. Total soil organic matter.

except those near homesteads. In south-western Uganda, banana-grown fields are given more attention to soil fertility, and hence farmers apply organic residues to such fields [13]. Nonetheless, the amounts of organic materials applied to banana-grown fields depends on several factors such the wealth endowment of the household, availability of organic resources and the costs associated with their usage [14].

Farmers often practice deep cultivation in banana-grown fields during weeding compared to annual-grown fields. Deep cultivation exposes soil organic matter to oxidation [15], thereby reducing its levels in the banana-grown fields compared to annual crop-grown fields. The practice of deep cultivation in banana-grown fields often results into reduced soil organic matter in spite of higher intensification done by farmers through organic matter applications compared to annual crop-grown fields.

Total soil nitrogen

Soil N under low input systems for annual crops and banana production in south-western Uganda, majorly depends on soil organic matter [16]. Annual crop-grown fields had higher soil N (0.26%) compared to banana-grown fields (0.22%) (**Figure 4**). There was higher minimum and maximum soil N in the annual crop-grown fields (0.18% - 0.38%) compared to banana-grown fields (0.14% - 0.33%). Soil organic matter in the banana-grown fields is more exposed to oxidation compared to annual crop-grown fields due deep cultivation done during weeding. Through oxidation soil organic matter in the banana-grown fields are easily mineralized and lost through volatilization, infiltration and uptake by the banana crop, among other processes. There is higher soil N uptake in banana during vegetative growth due to larger banana biomass compared to annual crops. Large accumulation of N in the banana tissue could thus lead to reduced soil N in the banana-grown fields under low input systems.

Extractable phosphorus

There is higher dissimilarity in extraction P in annual crop-grown fields compared to banana-grown fields (**Figure 5**). Annual crop-grown fields expressed high P availability on average (28.44 $mg \cdot kg^{-1}$) compared to banana-grown fields (23.35 $mg \cdot kg^{-1}$) that were more skewed to low P availability. Due to different levels of soil fertility management practices in banana-grown fields, extractable soil P occurred in the higher range (4.3 - 93.4 $mg \cdot kg^{-1}$) compared to

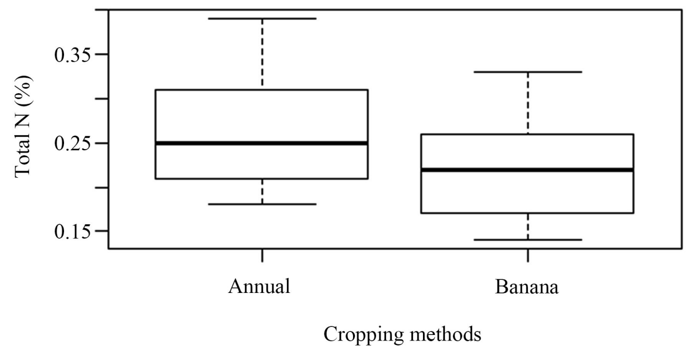

Figure 4. Total soil nitrogen.

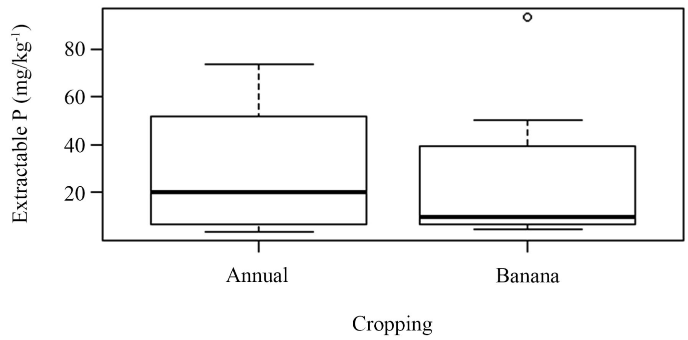

Figure 5. Soil extractable phosphorus (Bray P).

the annual crop-grown fields (3.8 - 73.6 mg·kg^{-1}) with barely no soil fertility inputs. Lixic Ferralsols in the banana farming system in south-western Uganda like any other Ferralsols offers a big challenge with the availability of P for plant uptake [12]. These soils have high levels of Al^{3+} and Fe^{3+} in the soil solution that complex and precipitate out soluble P [11]. Hence, P availability in such soils depends on farmer's soil fertility management innovations used. Nonetheless, soil fertility innovations such as crop residues and farmyard manure used by farmers are low in P, and to offset the P deficient it requires high amounts of soil inputs, which farmers cannot afford. Banana extracts more P than most annual crops such as beans [13], and therefore under low input systems, low extractable soil P is expected.

Exchangeable potassium

Annual crop-grown fields exhibited higher similarity in soil exchangeable K compared to banana-grown fields (**Figure 6**). The high similarity in soil exchangeable K is attributed to lack or minimal use of soil fertility management practices in annual crop-grown fields [16]. Annual crop-grown-fields had higher soil exchangeable K (512 mg·kg^{-1}) compared to banana-grown fields (493 mg·kg^{-1}), which was more skewed to deficiency levels. The higher range of soil exchangeable K exhibited by banana-grown fields was contributed to the array and levels of soil fertility management practices used by smallholder farmers. More commercially oriented farmers often intensified banana production through use of improved soil fertility management and conservation measures.

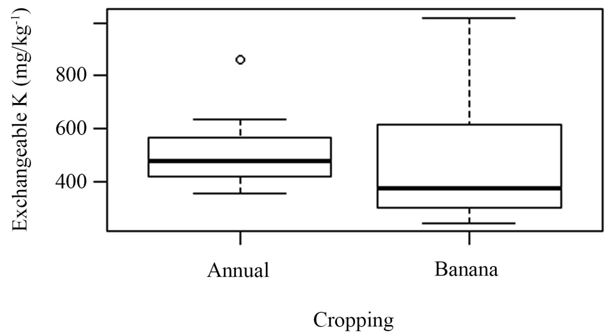

Figure 6. Soil exchangeable potassium.

Such farmers often mulched banana-grown fields with crop residues such as maize and bean wastes; and papyrus reeds whose tissue K easily oozed out with time. Further, farmer placed more emphasis on banana-grown fields located near homesteads by applying household wastes such as wood ash and animal wastes compared to distant fields that were more exposed to soil degradation in form of nutrient depletion, soil erosion and surface runoff.

4. Conclusion

The use of land for either banana or annual crop production, does not significantly change the soil chemical properties under smallholder farming systems in south-western Uganda. While vast land in south-western Uganda is under banana production, its soil nutrient levels are more skewed to deficiency levels compared to annual crop-grown fields. Low input systems used by farmers have apparently led to lower soil nutrient levels in the banana-grown fields on average compared to annual crop-grown fields. This indicates that there are higher soil nutrient losses in the banana-grown fields, which puts sustainability of banana production into a dilemma. Hence, there is a need to intensify soil nutrient management practices in smallholder banana production systems to offset soil nutrient losses that majorly occur in banana harvests.

Conflicts of Interest

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

References

[1] Musapedia-Contributors (2018) ProMusae: Mobilizing Banana Science for Sustainable Livelihoods. Musapedia, the Banana Knowledge Compedium. http://www.promusa.org/Tropical+race+4+-+TR4

[2] De Bauw, P., Van Asten, P., Jassogne, L. and Merckx, R. (2016) Soil Fertility Gradients and Production Constraints for Coffee and Banana on Volcanic Mountain Slopes in the East African Rift: A Case Study of Mt. Elgon. *Agriculture*, *Ecosystems & Environment*, **231**, 166-175. https://doi.org/10.1016/j.agee.2016.06.036

[3] FAO (2019) Uganda Soil Types.

[4] Encyclopædia Britannica, Inc. (2013) Loam.

https://www.britannica.com/science/loam

[5] Osiru, D.S.O. (2006) FAO Transboundary Agro-Ecosystem Management Program (TAMP). A Report on Crop/Farming Systems. Kampala, Uganda.

[6] Okalebo, R.J., Gathua, W.K. and Woomer, L.P. (2002) Laboratory Methods of Soil and Plant Analysis: A Working Manual, Third. Sacred African Publishers, Nairobi, Kenya.

[7] Chikowo, R., Zingore, S., Snapp, S. and Johnston, A. (2014) Farm Typologies, Soil Fertility Variability and Nutrient Management in Smallholder Farming in Sub-Saharan Africa. *Nutrient Cycling in Agroecosystems*, **100**, 1-18. https://doi.org/10.1007/s10705-014-9632-y

[8] Sekhon, B.S. (2003) Chelates for Micronutrient Nutrition among Crops. *Resonance*, **8**, 46-53. https://doi.org/10.1007/BF02834402

[9] Wiklund, J. (2017) Effects of Wood Ash on Soil Fertility and Plant Performance in Southwestern Kenya.

[10] Weinert, M. and Simpson, M. (2016) Sub Tropical Banana Nutrition-Matching Nutrition Requirements.

[11] Swagata, P. (2019) Acid Soils: Formation, Characteristics and Lime Requirement. Soil Management. http://www.soilmanagementindia.com/soil-properties/acid-soils-formation-characteristics-and-lime-requirement/3672

[12] van Wambeke, A. (1974) Management Properties of Ferralsols. FAO Soils Bulletin 23 Food and Agriculture Organization of The United Nations, Rome, Italy.

[13] Nyombi, K. (2013) Towards Sustainable Highland Banana Production in Uganda: Opportunities and Challenges. *African Journal of Food*, *Agriculture*, *Nutrition and Development*, **13**, 7544-7561.

[14] Muzira, R., Tenywa, J.S. and Basamba, T. (2018) Linking Soil Conservation in Potato Production Systems in the Highlands of Southwestern Uganda to Gender and Farmer-Market Types. *Open Access Library Journal*, **5**, e4422. https://doi.org/10.4236/oalib.1104422

[15] Bot, A. and Benites, J. (2005) The Importance of Soil Organic Matter: Key to Drought-Resistant Soil and Sustained Food Production. Food and Agricultural Organization of the United Nations, Rome, Italy.

[16] Woniala, J. and Nyombi, K. (2014) Soil Fertility Management by Smallholder Farmers and the Impact on Soil Chemical Properties in Sironko District, Uganda. *Research Journal of Agriculture and Forestry Sciences*, **2**, 5-10.