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Towards Expansion of *Coffea canephora* Production in Tanzania: The Land Suitability Perspective

Suzana Mbwambo*, Godsteven Maro, Harrison Monyo, Epafra Mosi

Tanzania Coffee Research Institute, P.O. Box 3004, Moshi, Tanzania
*Corresponding author: suzana.mbwambo@tacri.org

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Abstract As an effort to generate information that can be used to expand the Robusta coffee production in Tanzania, a study was conducted in six potential districts (Geita, Sengerema, Kibondo/Kakonko, Kasulu/Buhigwe, Uvinza and Mpanda) and two reference districts in Kagera (Muleba and Karagwe/Kyerwa) to assess the quality of land in general and soil fertility in particular. A total of 354 soil samples were taken from 116 survey sites across the study districts and were analyzed for routine soil fertility parameters. Land evaluation (qualitative, parametric method) was done, with climatic data adopted as proxy from nearby weather stations; and other land characteristics (slope, drainage and soil depth) taken from the field. In fertility assessment, soil pH was used to establish the correction factors for available N, P and K (fN, fP and fK). Then relationships were empirically worked out between the correction factors, OC and the amount of total N, available P and exchangeable K to get the total available forms of each in kg ha^{-1} which were converted to kg-equivalent (kE) per ha and summed up. Spatial interpolation was done using the inverse distance weighting (IDW) algorithm under QGIS 3.2. Geita and Sengerema compared fairly well with the reference districts in land suitability for Robusta. In the soil's point of view, they showed to be even more fertile than the reference districts. They are hereby recommended as priority areas in Robusta expansion with the Robusta type of choice being Nganda which appears to be specific to the lacustrine ecosystem. The other four districts could constitute Phase two of the expansion. And because they are farther away from Lake Victoria, investors can adopt the Erecta type which appears to be better adapted to a diversity of agro-ecosystems.

Keywords: *coffea canephora, expansion, soil fertility, Tanzania*

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1. Introduction

Coffee is a significant source of export earnings to many nations including Tanzania. It accounted for approximately US$ 16.5 billion in the global economy in 2010. World production is currently estimated to reach over 130 million 60 kg bags. Brazil and Vietnam lead production and together represent slightly less than half of world volume [1]. The world coffee trade is mainly dominated by two types, Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*). Robusta represents approximately 40% of the total [2]. Ngeze [3] described two types of Robusta coffee grown in Tanzania, namely *Nganda* (the multiple stem bending type) grown only in Kagera, and *Erecta* (the single stem erect type) found in a wide variety of ecosystems.

Robusta coffee is one of the most important crops in the South-east Asia where, according to [4], it was introduced in 1900, after a coffee leaf rust epidemic and slowly replaced or marginalized Arabica. Vietnam is a typical example of the role of Robusta in revolutionarization of a national coffee industry. From a humble start at its reunification in 1975, when there were less than 10 000 ha of coffee planted, there were an estimated 29 500 ha of coffee planted in 1984 and by 2012 the figure had reached 506,500 ha. On average over the last 5 years, Vietnam has been the second largest overall producer of coffee in the world. It is the largest producer of Robusta coffee accounting for approximately 40 percent of total world Robusta production [5].

Agritrade [6] noted that Africa, the origin of Robusta coffee, contributes only 18.9% of global Robusta production according to the 2012 statistics. Robusta coffee in Tanzania is localized in the Kagera area (Muleba, Misenyi, Karagwe and Bukoba), having an estimated production of 21,000 tons of clean coffee per year on an area of about 51,000 ha. This geographical localization is of interest, considering the production targets given in the coffee development strategy [1] and the example of Vietnam [5]. This paper describes an effort to establish land suitability for Robusta coffee in selected areas in the neighbourhood of Kagera, so as to influence the expansion of Robusta production in Tanzania, under the assumption that what was done in Vietnam can also be done in this country.

2. Methodology

2.1. Study Area

The study area comprised of four regions namely Kagera, Mwanza/Geita, Kigoma and Katavi (Figure 1: surveyed locations in blue dots). Two traditional Robusta growing districts were selected in Kagera Region (Muleba and Karagwe/Kyerwa) to act as reference, against which to compare six districts in the neighbourhood (Sengerema, Geita, Kibondo/Kakonko, Kasulu/Buhigwe, Uvinza and Mpanda) believed to have potential for Robusta.

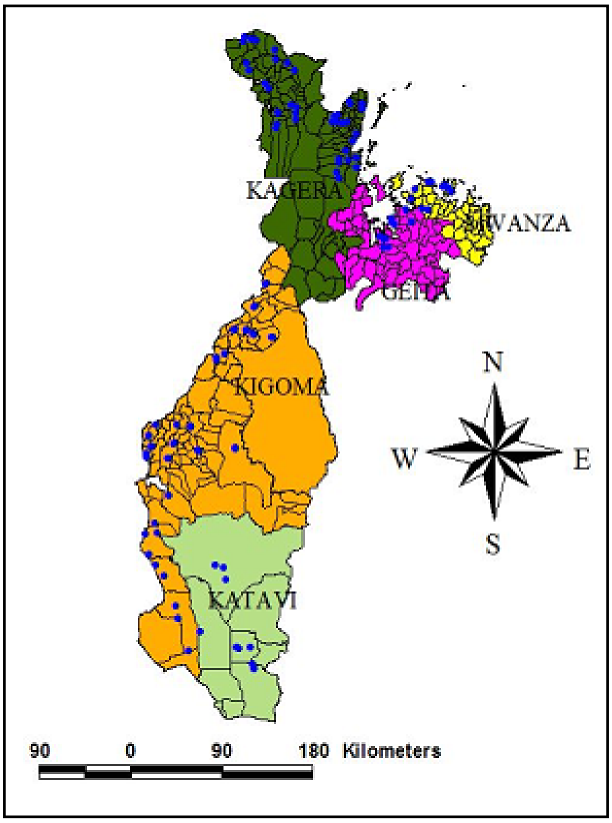

Figure 1. Map of the study areas, Western Tanzania

2.2. Soil Survey

Soil fertility survey was conducted between 2012 and 2013 in the selected districts. The surveyed villages were geo-referenced, surface features described according to [7] and soil samples taken with hand augers at pre-defined depths 0-30, 30-60 and 60-90 cm. A total of 116 sites were sampled. These were not evenly distributed as some areas in Southern and Eastern Kibondo, North Eastern Uvinza and parts of Mpanda constitute uninhabited forest reserves.

2.3. Soil Analysis

A total of 354 bulk soil samples were received at Lyamungu Soils Laboratory from the survey sites. They went through the routine of registration, air-drying, grinding by means of a soil grinder, sieving through the conventional 2 mm sieve and were finally packaged in 1 litre plastic storage bottles. They were analyzed for the routine soil fertility parameters. Soil pH was determined from a 1:2.5 soil water suspension using an electrode pH-meter. Cation exchange capacity (CEC) and cation levels were determined through extraction with NH_4OAc at pH 7 followed by flame photometry for Na and K, and atomic absorption spectroscopy for Ca and Mg. Organic carbon (OC) determination followed the Walkley and Black wet digestion method. Total nitrogen was determined through the semi-micro Kjeldahl method, while phosphorus was determined colorimetrically using Bray & Kurtz 1 method. Further details on these methods can be found in [8,9,10].

2.4. Collection of Climatic Data

Climatic data were adopted from a compilation made from ISRIC database by [11]. The data were all proxy: Muleba and Karagwe represented by Bukoba meteorological station, Sengerema by Mwanza Airport, Geita and Kibondo by Biharamulo station, Kasulu, Uvinza and Mpanda by Kigoma station. The climatic data of interest were precipitation, temperature, relative humidity and insolation, as suggested in the FAO qualitative land evaluation methods [12].

2.5. Qualitative Land Evaluation

Qualitative land evaluation for Robusta coffee was attempted using the parametric approach [12,13]. The climatic data above were assessed against the requirements of Robusta coffee and assigned ratings which were later used to compute the climatic indices (Ic) and ratings (Rc). For purposes of simplicity and ease of comparison, slope, flooding and drainage were assumed to be perfect and assigned the rating 100. Other parameters used were soil depth and texture, apparent cation exchange capacity (ACEC), sum of basic nutrient cations (SBC), pH, and OC. The data were rated according to the soil requirements [14] and assigned ratings. Land Index (I_L) was computed from Rc, R_{slop}, R_{flood}, R_{drain}, R_{text}, R_{ACEC}, R_{pH}, and R_{OC}. For calculating Ic and I_L, the general equation for the square root method [15] was applied as given below, with R_{min} representing the lowest or most limiting rating and R_1, R_2, R_3 etc representing the other ratings.

$$I_L = R_{\min} \times \sqrt{\frac{R_1}{100} \times \frac{R_2}{100} \times \frac{R_3}{100} \times ---}$$

The land indices between 100 and 75 were classified as very suitable (S1), those between 75 and 50 moderately suitable (S2), those between 50 and 25 marginally suitable (S3) and those below 25 unsuitable (N). Then the number of sites in each district falling in those categories was recorded and compared per district and between the study and reference districts, to check if there is any variation in land suitability for Robusta between the two categories.

2.6. Quantitative Soil Fertility Evaluation

In the quantitative approach, soil pH and OC were used as fertility drivers, and N, P and K as primary macronutrients, as in [16]. Soil pH was used to establish the correction factors for available N, P and K (fN, fP and fK). Then relationships were empirically worked out between the correction factors, OC and the amount of total

N, available P and exchangeable K to get the total available forms of each in kg ha^{-1} [17]. The nutrient equivalent factors of 1, 0.175 and 0.875 were derived for coffee as suggested by [18] and used to make the amount of nutrients uniform, and therefore additive. Soil fertility was measured in terms of the total number of nutrient equivalents that one ha of soil can make available to plants. Then the percentages of total number of sites in each district with natural fertility levels of 400 kE ha^{-1} and above were recorded and compared between the test districts and the reference districts.

2.7. Mapping of Soil Fertility Statuses

ArcView GIS Version 3.2 was used to build shape file database from the original Excel spreadsheets. The base map used was the 2012 census map from the National Bureau of Statistics. Attribute data generated during the fieldwork and laboratory analysis were geocoded into GIS-compatible format and loaded into the attribute tables. The shape files were then exported to QGIS Version 3.2 for further processing including spatial interpolation. The total soil available N, P and K, computed in equivalent terms according to [18], was spatially interpolated by using the Inverse Distance Weighting (IDW) algorithm, with resultant raster maps clipped on basis of the boundary polygon shape file digitized from the base map.

3. Results and Discussion

3.1. Land Suitability for Robusta Coffee

A summary of the land suitability for Robusta coffee in the study districts is given in Appendix 1. We note that the number of survey sites (n) differed from one district to another depending on the magnitude of the area in each district that has had any history with coffee. Also, the subdivision of districts after the survey affected the distribution of survey sites per district. Kasulu (18 sites) gave rise to Kasulu itself (6), Kasulu Township (4) and Buhigwe (8). Likewise, Kibondo (16) gave rise to Kibondo itself (14) and Kakonko (2), while Karagwe (20) gave rise to Karagwe and Kyerwa (10 sites each).

The marginally suitable category S3 dominated in both study and reference districts at 55.26% and 55.00% respectively. The reference areas had higher percentage (42.50%) of sites that are moderately suitable (S2) than the study areas (14.48%). The unsuitable category N was higher in the study areas (30.26%) than the reference areas (only 2.50%). Although the R_{min} used in the parametric method was SBC, this is directly related to pH such that the higher the pH the higher SBC and vice-versa. Most of the areas with high unsuitable percentage are the ones known to have low pH (Kigoma, Uvinza and Mpanda); and because this can be corrected by liming, these areas qualify as N1 [12]: unsuitable with a potential to upgrade to marginally suitable under improved management practices. None of the sites in the study or reference districts qualified as suitable (S1); therefore some form of integrated soil fertility management (ISFM) is needed for coffee to grow well and produce optimally. Comparing the districts in terms of the percentages of sites falling under suitable categories (S1+S2+S3), Kyerwa and Karagwe excelled the list with 100%. Others sharing this percentage are Kasulu and Kakonko, but with lesser number of survey sites. Muleba had 95% while Geita and Sengerema had 90% each. Buhigwe trailed the list with only 25% of sites suitable. Overall, the study and reference districts had 69.74% and 97.50% respectively, of sites suitable for Robusta coffee production.

Qualitative land evaluation for coffee in this zone has been attempted before, by using the agro-ecological system [19] and later validated through the parametric approach [13]. All these efforts were however based on Arabica coffee. Therefore, this is the first qualitative land evaluation for Robusta in the zone. This method, much like in [13] and [19], used secondary data. For instance, the climatic database compiled by [11] was adopted in this work, in the apparent absence of better alternatives. These are all proxy data, from stations located outside the study sites, and this might affect the reliability of Ic, which has a profound influence on the I_L. This is one of the cautions that need to be borne in mind when making serious decisions based on the findings of this work.

3.2. Soil Fertility Levels Per District

A summary of the soil fertility indices per district is given in Appendix 2. It includes the percentage distribution of fertility categories per district. As with the qualitative results, the low fertility categories dominated over the higher fertility categories, with many districts not having any site capable of supplying ≥ 600 kE ha^{-1} of N, P and K to plants. The percentage of sites considered of high natural fertility (a potential to supply ≥ 400 kE ha^{-1}) was computed. Geita and Sengerema emerged top of the list by 80% each, followed by Kyerwa (70%), Muleba, Karagwe, Kasulu Township and Buhigwe (50% each). None of the sites in Kasulu, Kakonko or Uvinza could reach the threshold of 400 kE ha^{-1}.

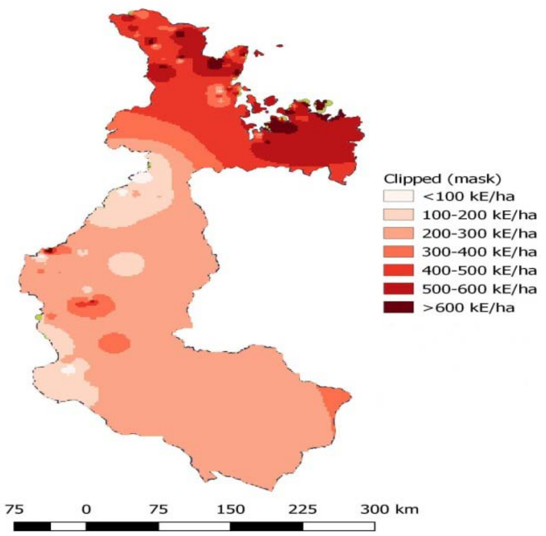

Figure 2. The NPK supply potential of soils in the study districts

In the quantitative soil fertility assessment we used the model adopted by [18] and [20]. The major assumption here, as in [16], was that the role of N, P and K in determining the soil's natural fertility is much greater than those of the other nutrients. This is true to some extent, though the balance between these and other nutrients (Ca and Mg for K and B for P) are also important [21].

The soil fertility information was spatially presented in Figure 2. In this map, the area ≤ 200 kE ha^{-1} covered about 10% of total land area, featuring in Kibondo-Kakonko and some places in Uvinza and Mpanda. Slightly over 60% is between 200 and 300 kE ha^{-1}, covering most of Kigoma and Katavi Regions. The remaining 30% is at the northern end, covering Mwanza (study region) and Kagera (reference region). Geita and Sengerema are well over 500 kE ha^{-1}, while the reference districts in Kagera feature mainly between 300 and 500 kE ha^{-1}. The soil showed to be most fertile in Geita and Sengerema, with average NPK supply potentials of 1,121 and 737 kE ha^{-1} respectively.

In all the methods used, a general view is that Geita and Sengerema, which are also geographically closer to Kagera than the other study districts, and most likely sharing the same lacustrine climate, have been singled out as best bets for Robusta coffee expansion – especially the *Nganda* type popular in Kagera. The presence of the *Erecta* type in diverse ecosystems in Tanzania (Morogoro, Mbozi, and even Lyamungu) suggests that it is a better adapted type than *Nganda*, so this could be tried in Kigoma and Katavi regions [3].

3.3. Implication to the Coffee Development Strategy

This work was conducted in response to the remarks given in the Coffee Development Strategy [1] and also in [22] that Tanzania is rich in abundant arable land suitable for producing high quality Arabica and Robusta coffees, and that only 35% of the potential area for coffee in Tanzania is being utilized [3]. So the purpose was to unveil (at least part of) the 65% untapped potential for the benefits of new investors. According to [1], Tanzania would face very few difficulties in selling larger coffee volumes at highly remunerative prices provided production is increased. Kagera (the reference region in this study) was said to have good quality potential whereas Kigoma was said to have outstanding quality potential. New investments at estate level could boost the national production; and Mwanza, Kigoma and Rukwa/Katavi (the study regions) are among those mentioned as potential for coffee expansion. But [22] quote disincentives to coffee production in the country as lack of access to irrigation systems, ageing coffee trees, volatile coffee prices, poor agricultural practices by the majority of smallholders, limited access to credit, low use of (and inadequate supply of authentic) farm inputs including fertilizers.

3.4. What Tanzania Can Learn from Vietnam

According to [5], the Vietnamese took advantage of the simplicity of Robusta coffee production and processing to ensure high yields which are the key to coffee profitability. From 1980 to 2000, production grew from 8,400 tons to 900,000 tons, a rise of about 26% per year. One of the approaches were to relocate the smallholders in highly populated and marginal areas to the sparsely populated and potential areas in the Central Highlands. This may not be feasible in Tanzania after the failure of the villagization policy in the 1970's; so the strategy could be to encourage serious investors to open up new lands for coffee (like Aviv Tanzania in Songea). Another approach was to subsidize farm inputs and ensure that the intensive coffee system is properly nourished and protected from biotic and abiotic stresses. Here, TCB should coordinate a system such that only the authentic farm inputs get to the market, the government should include coffee in the fertilizer subsidy scheme, and low-interest credit facilities should be in place to ensure farmers access to inputs at the right time. Farmers in Vietnam also benefit from the very transparent and competitive Robusta marketing system where they get over 90% of the FOB prices. In fact, what [22] emphasized was centered here: What percentage of the FOB prices go to the farmer, as an incentive to continue growing coffee? TCB should streamline the value chain and remove unnecessary overheads, which will boost the price percentage that goes to the farmer.

4. Conclusion

Of the six study districts evaluated in this work, Geita and Sengerema compared fairly well with the reference districts (Muleba and Karagwe/Kyerwa) in land suitability for Robusta. In the soil's point of view, they showed to be even more fertile than the reference districts. The two districts are hereby recommended to be considered priority areas in Robusta expansion (with the Robusta type of choice being *Nganda* which appears to be specific to the lacustrine ecosystem). The other four districts (Kibondo/Kakonko, Kasulu/Buhigwe, Uvinza and Mpanda) could constitute Phase two of the expansion. And because they are farther away from Lake Victoria, investors can adopt the *Erecta* type which appears to be better adapted to a diversity of agro-ecosystems.

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Appendix 1. Qualitative land suitability categories per district

Category	District	n	% N	% S3	% S2	% S1	S3+S2+S1
Study	Buhigwe	8	75.0	25.0	0.0	0.0	25.0
Study	Kasulu TS	4	25.0	75.0	0.0	0.0	75.0
Study	Kasulu	6	0.0	83.3	16.7	0.0	100.0
Study	Kibondo	14	28.6	14.3	57.1	0.0	71.4
Study	Kakonko	2	0.0	100.0	0.0	0.0	100.0
Study	Geita	10	10.0	80.0	10.0	0.0	90.0
Study	Sengerema	10	10.0	90.0	0.0	0.0	90.0
Study	Uvinza	10	50.0	40.0	10.0	0.0	50.0
Study	Mpanda	12	41.7	58.3	0.0	0.0	58.3
Ref	Muleba	20	5.0	75.0	20.0	0.0	95.0
Ref	Kyerwa	10	0.0	50.0	50.0	0.0	100.0
Ref	Karagwe	10	0.0	20.0	80.0	0.0	100.0
Total study		76	30.3	55.3	14.5	0.0	69.7
Total ref		40	2.5	55.0	42.5	0.0	97.5
Grand total		116	20.7	55.2	24.1	0.0	79.3

Appendix 2. Quantitative evaluation of NPK supply potential (kE ha^{-1}); percentage by category

District	<200	200-400	400-600	600-800	800-1000	>1000	Total >400
Buhigwe	37.5	12.5	25.0	0.0	12.5	12.5	50.0
Kasulu TS	0.0	50.0	50.0	0.0	0.0	0.0	50.0
Kasulu	33.3	66.7	0.0	0.0	0.0	0.0	0.0
Kibondo	50.0	42.9	7.1	0.0	0.0	0.0	7.1
Kakonko	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Geita	10.0	10.0	20.0	20.0	0.0	40.0	80.0
Sengerema	10.0	10.0	30.0	20.0	0.0	30.0	80.0
Uvinza	50.0	50.0	0.0	0.0	0.0	0.0	0.0
Mpanda	41.7	50.0	8.3	0.0	0.0	0.0	8.3
Muleba	20.0	30.0	30.0	15.0	5.0	0.0	50.0
Kyerwa	10.0	20.0	30.0	20.0	20.0	0.0	70.0
Karagwe	0.0	50.0	20.0	10.0	20.0	0.0	50.0