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Soil Fertility Status of Kagera Region and the "Organic-by-Default" Coffee Paradigm: A Meta-Analysis of Existing Database

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Abstract Coffee farmers in Kagera Region do not believe in application of industrial fertilizers in their farms, calling their produce "organic by default". They claim that their soils are too fertile to need industrial fertilizers. TaCRI undertook to verify this claim. Soil fertility data for the region were extracted from the national coffee soil database built in 2015. A total of 73 georeferenced sites had seven parameters (pH, Ca, Mg, K, CEC, OC and total N) rated from zero (poor) to 4 (good). The average ratings were computed and categorized as 0-1, 1-2, 2-3, 3-4 and 4-5 as poor, marginal, moderate, satisfactory and good fertility respectively. A subsample of 27 sites were additionally assessed for available P and particle size. Attributes of the 73 sites were loaded into ArcMap 10.7.1, whereby pH, CEC, BS, OC and C:N ratio were interpolated using the IDW algorithm and clipped on basis of the regional boundary shapefile extracted from the 2022 census polygon shapefile. The soils were marginally (34, 47%) to moderately (39, 53%) fertile where only seven parameters were assessed. With fewer sites and more parameters, the respective figures were 11 (41%) and 16 (59%). pH was increasing from northeast (Bukoba, Misenyi and Muleba) to southwest (Biharamulo, Ngara and Southern Karagwe). CEC was lower in Kyerwa, Karagwe and Muleba than Bukoba, Ngara and Biharamulo. The western half of Kagera had higher OC than its eastern counterpart. C:N ratios were generally less than 30, which is normal. This work has revealed that soils in Kagera are not as fertile as purported, thus disproving the "organic-by-default" paradigm. As such, farmers' mind sets should be changed in favour of industrial fertilizers if we are ever to improve coffee productivity and approach the set national target of producing 300,000 metric tons of clean coffee annually by 2025/26.

Keywords: *soil fertility, organic by default, meta-analysis, database, Kagera region*

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1. Introduction

Coffee is a significant source of export earnings to many nations including Tanzania. Its importance is well described by [1,2,3] among others. World production in 2020 was estimated to reach over 165 million 60-kg bags. Brazil and Vietnam lead production and together represent slightly less than half of world volume [4]. The world coffee trade is mainly dominated by two types, Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*). Robusta represents approximately 40% of the total output [5].

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 [6]. This works down to 412 kg ha^{-1} and, at the standard spacing of 3m x 3m, give approximately 400 g $tree^{-1}$. Farmers usually have at least a couple of coffee trees on their farms, intercropped with bananas, maize, beans, cassava or yams. Production in the area is said to be "organic by default" because farmers do not apply fertilizers or pesticides [7]. Organic nutrient sources include manure, kitchen refuse and mulch. This "organic-by-default" paradigm is inculcated into the minds of the farmers, so much so that they do not want to hear anything about applying industrial fertilizers.

Both the Tanzanian ruling party manifesto and the coffee industry development strategy have set the target of increasing the coffee production from what it was in 2020 (55,000 metric tons - mt) to as high as 300,000 mt by 2025/26. To reach or approach such a target, the industry needs to capitalize on varieties and GAPs (including proper plant nutrition). During the National Coffee Conference held in June 2022 in Dodoma, TaCRI suggested an industrial fertilizer regime for Kagera (NPKS 22:6:12:3, 80g $tree^{-1}$ applied 3 times per year; Minjingu Rock Phosphate 50g $tree^{-1}$ and foliar 20:20:20 both applied 2 times per year). This had been derived from [8] and TaCRI's own soil fertility database [9]. The suggestion was met with a fierce resistance, even from intellectuals. They claimed that the soils of Kagera are sufficiently fertile, and the introduction of industrial fertilizers would damage those soils. This prompted a reassessment of the available data for Kagera, to see if the soils are as fertile as purported; so as to correctly advise the farmers.

2. Materials and Methods

2.1. Study Area

Kagera region is located in the extreme northwestern corner of Tanzania (Figure 1). It lies just south of the equator between latitudes 1^{o}00’ and 2^{o}45’ south, longitudes 30^{o}25’ and 32^{o}40’ east. This includes large part of the water of Lake Victoria. The landmass lies between 30^{o}25’ and 31^{o}48’ longitudes east. It covers a total land area of 40,838 sq.km [10]. It experiences a bi-modal rainfall pattern, March – May and October – November, with average annual rainfall of 500 – 2000 mm. Rainfall is higher along the shores of Lake Victoria and decreases inland away from the lake and also with altitude, varying from 2000 mm a year near Bukoba to 500 mm in the west [7]. Temperatures range between 20^{o}C – 28^{o}C.

The region consists of series of hills running North-South, parallel to the lakeshore. Its lithology is affected by the Karagwe-Ankolean rock system of the Proterozoic eonothem, featuring sericite schists and quartzites; and the more recent Bukoban system of the Phanerozoic eonothem, featuring mainly sandstones, quartzites and shales [11,12]. Soils are mainly Leptosols (most of Ngara, Karagwe and Kyerwa), Cambisols (Bukoba, Muleba, parts of Misenyi and Biharamulo), with associated Gleysols (Misenyi) and Phaeozems (parts of Biharamulo) [13]. These are not the best soils in terms of natural fertility.

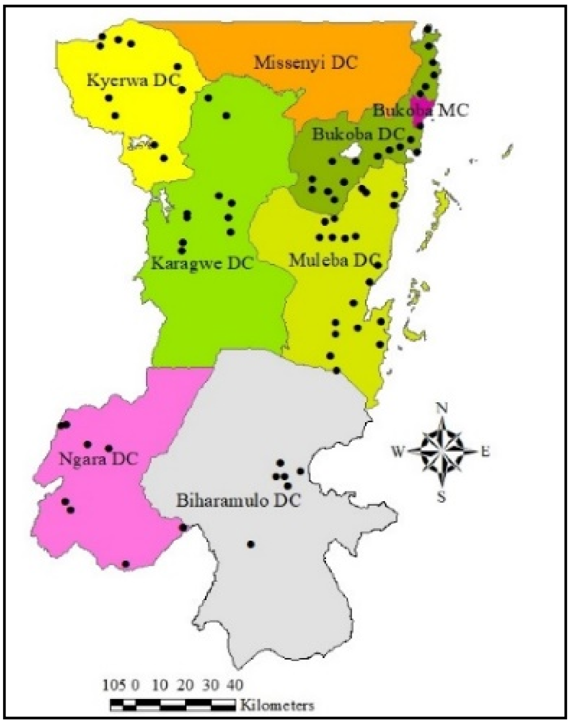

Figure 1. Map of Kagera Region showing the sources of data (in blue dots)

2.2. Data Extraction

Soil fertility data for Kagera Region were extracted from the country-wide database developed in 2015. The extracted data had originated from the soil survey carried out in Bukoba (Rural and Urban), Muleba, Karagwe, Ngara and Biharamulo districts in June 2012 and reported to the RAS Kagera via Soil Survey Report No. TCR 8/2013 [14]. The database involved a total of 73 georeferenced sites analyzed for the routine soil fertility parameters pH, CEC, %OC, %N, Exch. Ca, Mg, Na and K. A subsample of 27 sites had their analysis extended to include also available P and particle sizes.

2.3. Statistical Analysis

A total of seven parameters (pH, Ca, Mg, K, CEC, OC and total N) from the 73 sites were rated from zero (poor fertility) to 4 (good fertility) based on the ratings suggested by [15,16,17]; and the average of the ratings computed. These average ratings were assigned categories 0-1, 1-2, 2-3, 3-4 and 4-5 for poor, marginal, moderate, satisfactory and good fertility respectively. A separate rating was accorded to the subsample of 27 sites, in which the additional parameters (available P and particle size) were also assessed.

2.4. Spatial Analysis

The soil fertility data were exposed to the geographic information system (GIS) for further analysis [18]. Attributes of the 73 sites were loaded into ArcMap 10.7.1 and configured to follow the WGS84 reference coordinate system in line with the intended vector base map, which is the NBS Census Map polygon shapefile [19]. A regional base map was extracted from the country-wide district and town council map and saved. The soil shapefile was overlaid onto the base map whereby pH, CEC, BS, OC and C:N ratio were interpolated in turns. The inverse distance weighting (IDW) algorithm [20,21] was used, with the nearest neighbours set at 12 and the power set at 2. The resultant rasters were clipped on basis of the regional base map, and the trends in the key soil fertility indices were visually assessed.

3. Results and Discussion

3.1. Statistical Results

Statistical results are shown in Table 1 below. The left part of the table shows that the soils are marginally (34, 47%) to moderately (39, 53%) fertile where all the 73 entries were involved but only seven parameters were assessed. With fewer sites (27) and more parameters (9) in the right part, the respective figures were 11 (41%) and 16 (59%).

None of the sites were of satisfactory or good fertility, thus disproving the claim that the soils in Kagera are sufficiently fertile. On the other hand, none of the sites were of too poor fertility to grow coffee. This is not surprising because, using the Haya terms cited by [7], the sampling was skewed to the *bibanja* and a bit of *bikamba* that grow coffee. Neither the *rweya* (the shallowest and poorest-fertility Leptosols mainly used for extensive grazing) nor the forest reserve areas like the area of Burigi between Muleba and Biharamulo, were involved.

Table 1. Statistical analysis for soil fertility categories, Kagera

Category	n = 73		n = 27	
	Value	%	Value	%
Poor (0-1)	0	0	0	0
Marginal (1-2)	34	47	11	41
Moderate (2-3)	39	53	16	59
Satisfactory (3-4)	0	0	0	0
Good (4-5)	0	0	0	0

3.2. Spatial Interpolation Results

The spatial interpolation results are shown in Figures 2, 3, 4, 5 and 6. Figure 2 shows that pH was increasing from northeast to southwest. Most of the coffee areas in Misenyi, Bukoba and parts of Muleba may need liming, which should be applied according to the lime requirement of individual fields [22]. Most of Karagwe, Kyerwa and Ngara can alternate CAN with ASN at fruit setting. The alternation in Biharamulo should be two seasons ASN and one season CAN. In Figure 3, CEC was generally good, mostly well over the threshold of 16 cmolc kg^{-1} [15]. It was higher in Bukoba, eastern Misenyi, Ngara and Biharamulo. Base saturation (Figure 4) was higher in Karagwe, Kyerwa and Muleba. The two parameters showed contrasting trends, which could be explained by the former being the denominator in computations of the latter.

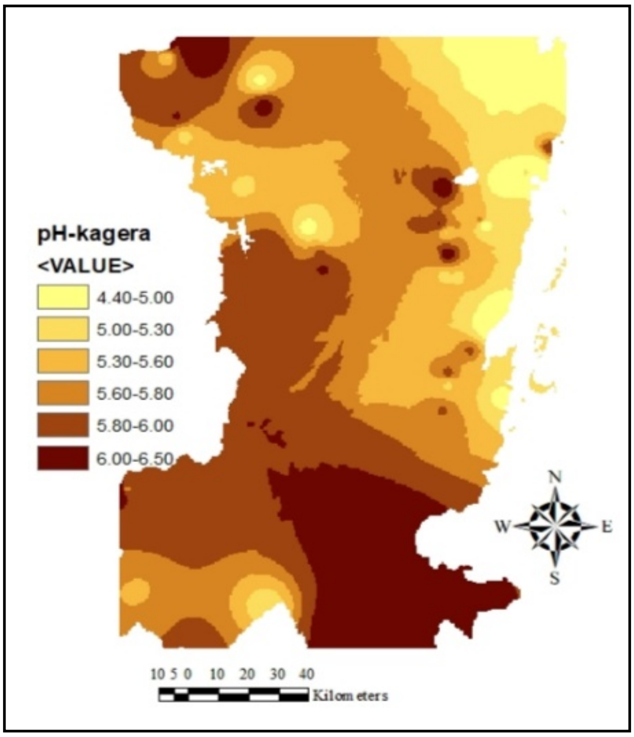

Figure 2. Variation in soil pH over Kagera Region

Figure 5 shows the western half of Kagera having higher organic matter content than its eastern counterpart. The low organic matter content in Muleba, Bukoba and Misenyi is rather difficult to explain, given the intensity of mulching practiced there (see Figures 7 and 8). The likeliest assumption is that the straw used as mulch is not decomposing readily due to its having too high C:N ratios [23]. On the other hand, the C:N ratios of soils (Figure 6) were generally less than 30, which is normal for agricultural soils [24]. Trends for OC and C:N ratio were similar, as the former is a numerator in computations of the latter.

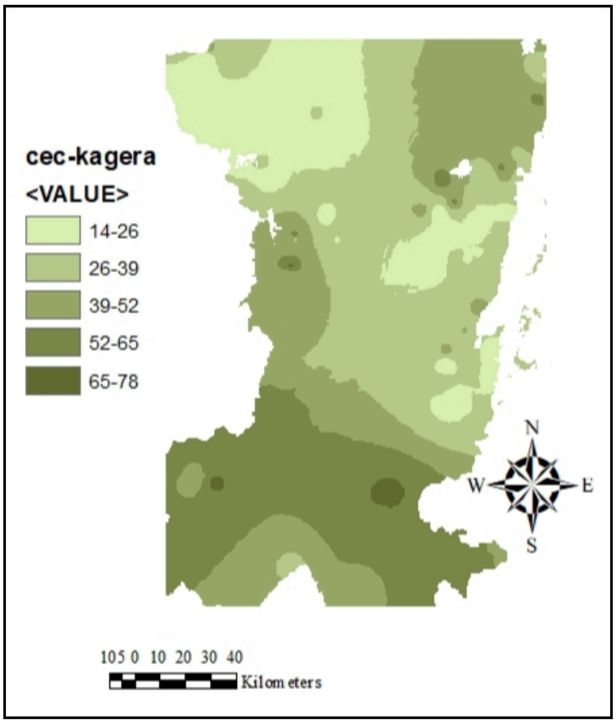

Figure 3. Variation in CEC over Kagera Region

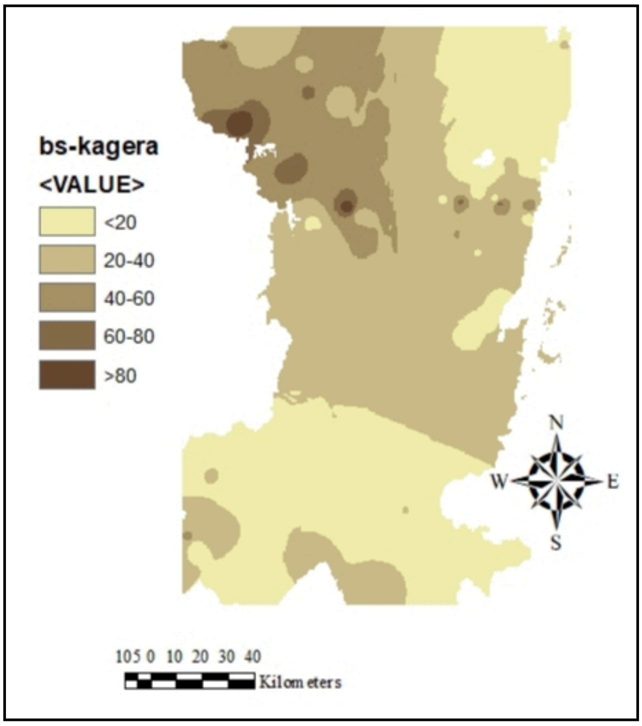

Figure 4. Variation in base saturation over Kagera Region

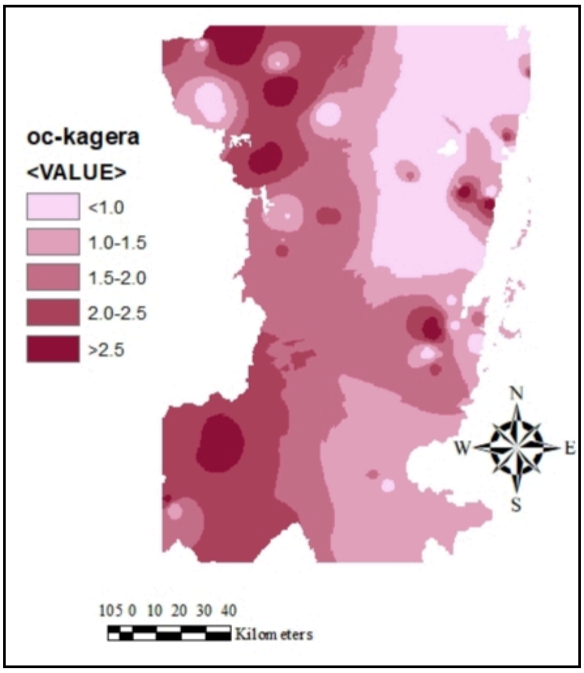

Figure 5. Variation in organic carbon over Kagera Region

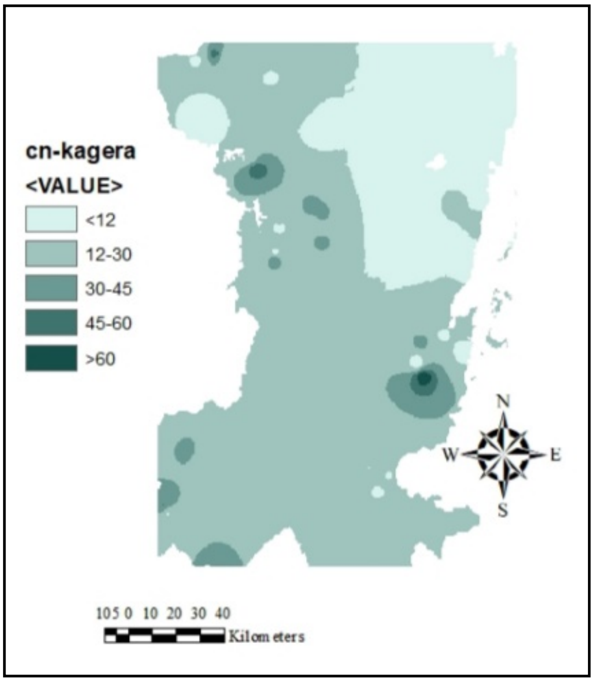

Figure 6. Variation in C:N ratio over Kagera Region

3.3. General Discussion

3.3.1. Origins of Coffee and the Organic Perception

By origin and nature, coffee is a forest crop. Arabica has roots in Ethiopia where, even today, forest coffee is still a common feature. Robusta is said to have roots in the equatorial forests around Kagera, Uganda and Eastern DRC [25,26]. The forest coffee mentality seems to have affected many farmers, not only in Kagera (though, of course, here it is too much).

Maro and others [27] noted reluctance of many farmers to apply inorganic fertilizers in coffee, in the pretext that coffee is originally a forest crop which can yield optimally with organic nutrients only. On the other hand, domestication and commercial farming have brought with them varietal adaptation to certain physiographic and edaphic conditions. One such condition is shade versus open [28], whereby more yield of lesser quality coffee is realized with the open culture. Commercial value brought demand for higher yields that could not have been realized in the forest; and breeders have done a good job of breeding for higher yields and, impliedly, higher nutrient demands. Even if the "organic-by-default" system once worked in the past, with ample land and a sizeable population, things have changed. Land scarcity resulting from population pressure has reduced the area that can be reserved for mulch. The supply of pasture to livestock has decreased as well, causing a decrease in manure produced. The consequence is reduction of manure available for applying to the farms and eventually, a decline in crop yield [7]. This coffee production system is therefore becoming unsustainable.

Figure 7. A heavily mulched field, Bukoba District

Figure 8. A heavily mulched field, Muleba District

3.3.2. Soil Classification, Lithology and Fertility

From [13], the old Karagwe-Ankolean Leptosols make about 70% of total land in Kagera. They are very shallow soils over hard rock or in unconsolidated very gravelly material. Recommended best land uses are extensive grazing, stone quarrying, forestry and nature conservation. Coffee is grown in small associations with sufficiently deep soils whose fertility is questionable. The younger, Bukoban Cambisols make about 20%, and are soils with incipient soil formation showing weak, mostly brownish discolouration and/or structure formation below the surface horizon. The Cambisols are used for (mixed) arable farming and as grazing land, and are of significantly better fertility than Leptosols due to soil depth advantage. Incidentally, Cambisols occur in the zone receiving the highest amount of rainfall and are characterized by low pH. Liming or CAN and MRP application could double the current production level. Gleysols constitute the wetland soils of the Kagera River basin (Misenyi), and are of less interest for coffee. So are the Phaeozems which constitute a strip that runs north-east to south-west along Biharamulo, whereby periodic drought and wind and water erosion are the main limitations. From soil classification point of view, none of these soils can be termed as ideal for coffee production. This work has also proved that soils of Kagera are not as fertile as purported, and coffee production will benefit much from use of industrial fertilizers.

3.3.3. Do Industrial Fertilizers Really Damage Soils?

This is one of the claims by intellectuals from Kagera. It is possible for industrial fertilizers to damage the soil if the “four Rs” of nutrient stewardship suggested by [29,30] are not adhered to. This is: applying the Right fertilizer type to the Right soil, in the Right dosages and at the Right time. Start with the soil. “Know your farm” as the TaCRI slogan goes, and make informed decisions thereon. If, for example, an uninformed farmer decides to apply an acidifying fertilizer like SA in already acidic soils like those of Misenyi, Bukoba and Muleba (Figure 2) the fertilizer will render the soil too strongly acidic to grow crops for a considerable time period. In many parts of Kagera, people simply don’t know the importance of using industrial fertilizers in coffee, and this is largely attributable to the unavailability of, or inaccessibility to, information on their soil types. This paper and its predecessor were meant to give an overview of soil health in Kagera based on which informed decisions on the second Right (fertilizer types) can be made. The TaCRI Soils Laboratory offers such services, and links can be made through its substation at Maruku.

3.3.4. The Sustainability of Organic Certification

Some farmer groups and/or cooperatives, with the “organic-by-default” mentality, have initiated processes of formally certifying themselves as such [7]. It was noted by [31] that smallholder farms with no access to external inputs often produce less than 300 kg ha^{-1} $year^{-1}$ green coffee beans, while intensively managed plantations of arabica coffee at conventional spacing may annually yield 2 mt ha^{-1} averaged over several years and Robusta coffee plantations up to 3.5 mt ha^{-1} Nitrogen is regarded as one of the key factors limiting productivity. Organic farming systems have the potential to supply large amounts of N but there is poor synchronization of N availability versus crop demand. Composting of manures and plant residues causes a significant reduction in available N, due to volatilization and transformation into stable organic forms. Generally, in agronomic terms, organic farming has no significant advantage over conventional (ISFM) farming; it reduces yields and the premium prices offered cannot offset the (opportunity) cost of organic certification and practices. This was also noted by [32] who saw organic certification as a poverty trap.

3.3.5. The Task of Increasing Production

The target of increasing coffee production from what it was in 2020 (55,000 mt) to as high as 300,000 mt by 2025/26 [4] is an uphill task by all standards, and cannot be attained by sticking to traditions. We need to change our mind set. There are two ways to increase production, namely varieties and GAPs. On the variety side, TaCRI has done its job of developing 19 Arabica and 4 Robusta coffee varieties [33,34] with best attributes, including high yield (about 3 to 5 times as much as the traditional varieties). These are widespread in many coffee growing areas including Kagera. We need to sensitize farmers to adopt those varieties, thereby improving productivity per tree. Plant nutrition is a component of GAPs. From [29] [35,36], expected yields have been the basis for fertilizer recommendations and because, as a rule of thumb, a bigger sink requires a bigger source, the new varieties will require over two times as much of the nutrients as the traditional ones, a requirement not attainable with organic nutrient sources only. We therefore need to train farmers on the importance of using industrial fertilizers in coffee, the right types of fertilizers to the right soils, the right dosages and at the right times [29]; in addition to adherence to other recommended GAPs, for sustainable coffee production.

4. Conclusion and Recommendations

A statistical and spatial meta-analysis of routine soil fertility data from 73 georeferenced sites in Kagera Region was done, so as to check the scientific validity of the claim that soils are fertile and do not need industrial fertilizers. The soils showed to be marginally to moderately fertile, thus disproving the “organic-by-default” paradigm long held by farmers in Kagera. Interpolation trends in five selected parameters indicate that pH was increasing from northeast (Bukoba, Misenyi and Muleba) to southwest (Biharamulo, Ngara and Southern Karagwe). CEC was lowest in Kyerwa and highest in Ngara and Biharamulo. Base saturation was highest in Karagwe and Kyerwa, and lowest in Bukoba, Misenyi, Ngara and Biharamulo. The western half of Kagera had higher organic matter content than its eastern counterpart. C: N ratios were generally less than 30, which is normal for agricultural soils. This work has revealed that soils in Kagera are not as fertile as purported.

Subsequent discussion brings to light the origin of coffee as a forest crop (which is also the origin of the “organic-by-default” paradigm), how it evolved into a high-value commercial crop and associated transformations. Land scarcity due to population pressure has reduced the mulch reserve areas. The supply of pasture to livestock has decreased as well, cutting short the usual supply of manure. These contribute in making the naturally organic system unsustainable. The discussion also relates to the uphill task facing the coffee industry in Tanzania to increase the coffee production to 300,000 mt per year by 2025/26, a task that cannot be attained by sticking to traditions, calling for a change of mind set. Adopting the TaCRI’s 19 Arabica and 4 Robusta varieties with best attributes, including high yield (about 3 to 5 times as much as the traditional varieties) is one of the approaches. The other is adopting GAPs, including ISFM; and here, use of industrial fertilizers (together with the organic ones) is inevitable.

The change of farmers' mind sets requires a concerted effort. First, the elites must change their own mind set, and this paper is intended for them. TaCRI and other partners (TCB and coffee supporting NGOs) should collaborate in delivering the right messages to intellectuals, policy makers, parliamentarians, agricultural officers at the LGA levels, teachers at all levels, etc. These, once brought on board, will help to trickle down the right information. We believe that, if the farmers in Kagera (the Robusta growers) adopt the industrial fertilizer regime as part of ISFM, with the higher productivity of Robusta versus Arabica, the journey to 300,000 mt by 2025/26 will be easier.

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Statement of Competing Interests

The authors declare that they have no competing interests in this work.

Abbreviations

ASN: Ammonium sulphate nitrate; **BS**: Base saturation (in percentage); **CAN**: Calcium ammonium nitrate fertilizer; **CEC**: Cation exchange capacity of a soil; **DRC**: The Democratic Republic of the Congo; **GAPs**: Good agricultural practices; **GIS**: Geographic information system; **IDW**: Inverse distance weighting interpolator; **ISFM**: Integrated soil fertility management; **LGA**: Local government authorities; **MRP**: Minjingu rock phosphate; **mt:** metric ton; **NBS**: National Bureau of Statistics in Tanzania; **NGOs**: Non-governmental organizations; **NPKS**: Compound fertilizer containing nitrogen, phosphorus, potassium and sulphur; **OC**: Organic carbon (a measure of organic matter); **RAS**: Regional Administrative Secretary; **TaCRI**: Tanzania Coffee Research Institute; **TCB**: Tanzania Coffee Board.

References

[1] Carr, M. K.V., Stephens, W., Van der Vossen, H.A.M. and Nyanga, A. (2003). Tanzania Coffee Research Institute: Strategic Action Plan 2003 to 2008, Contributing Towards a Profitable and Sustainable Coffee Industry in Tanzania. International Centre for Plant Sciences, Cranfield University, Silsoe, UK. 142pp.

[2] Baffes, J. (2003). Tanzania Coffee Sector: Constraints and challenges in Global environment. The World Bank, Washington, DC. 56pp.

[3] Hella, J.P., Mdoe, N.S. and Lugole, J.S. (2005). *Coffee Baseline Report for Tanzania Coffee Research Institute.*Bureau for Agricultural Consultancy and Advisory Service, Sokoine University of Agriculture, Morogoro, Tanzania. 40pp.

[4] Tanzania Coffee Board (2020). *Tanzania Coffee Industry Development Strategy 2020/2025.* Government Document, Moshi, Tanzania. 57pp.

[5] Montagnon, C. and Brouwers, S. (2013). Strategic Action Plan III and Strategic Business Plan 2013-2018 for Tanzania Coffee Research Institute (TaCRI). RD2 Vision/Efficient Innovations, March 2013, 102pp.

[6] Mbwambo, S.G., Maro, G.P., Monyo, H.E. and Mosi, E.J. (2020). Towards expansion of Coffea canephora production in Tanzania: The land suitability perspective. World Journal of Agricultural Research Vol 8 (2), May 2020: 52-56

[7] Mbogoni, J.D.J. and Nyaki, A.S. (2006). GIS database for the lower Kagera River basin in Tanzania. Diagnostic study report for the Tanzanian component of the TAMP Programme. March, 2006: 64pp.

[8] Cordingley, J. (2010). *Soil Fertility Survey of Tanzania's Smallholder Coffee Sector for Developing Lime and Fertilizer Recommendations.* Report to Tanzania Coffee Board. Crop Nutrition Laboratory Services, Nairobi, Kenya. 60pp.

[9] Maro, G. P., Mbwambo, S.G., Monyo, H.E., Nkya, E.O. and Mosi, E.J. (2018). Generating soil fertility database for coffee growing areas in Tanzania. Proc. 6th Annual National STI Conference and Exhibitions, COSTECH, 4-6 July 2018, Mlimani City, Dar es Salaam.

[10] National Bureau of Statistics (2018). Kagera Region socio-economic profile 2015. Government Document, Dar es Salaam, April 2018: 243pp.

[11] Howard, A.E. (2011). A brief introduction to the geology and mining industry of Tanzania. SIKA Resources Inc, Toronto, Ontario, Canada, October, 2011: 15 pp.

[12] Lupogo, K. (2013). A review of engineering geology in Tanzania. International Journal of Research in Engineering and Science Vol 1 Issue 8, December 2013:48-55.

[13] Mlingano Agricultural Research Institute (2006). Soils of Tanzania and their potential for agriculture development. A MAFSC-DRT Report, November, 2006. 33pp.

[14] Maro, G.P. (2013). Soil fertility report for coffee growing districts in Kagera Region. Soil Survey Report TCR 8/1013, Coffee Soil Database Project (TASP I), February 2013: 47pp.

[15] Sys, C., Van Ranst, E. and Debaveye, J. (1993). *Land Evaluation Part III Crop Requirements.* General Administration for Development Cooperation, Agriculture Publications, Brussels, Belgium. 199pp.

[16] Thiagalingam, K. (2000). Soil and plant sample collection, preparation and interpretation of chemical analysis: A training manual and guide. ACNARS/PNG for AusAID, Adelaide, Australia. 49pp.

[17] Hamza, M.A. (2008). Understanding soil analysis data. Resource management technical report 327, Department of Agriculture and Food, Western Australia. 59pp.

[18] Kyariga, A.T. (2001). GIS as a decision-making support tool for urban planning and management: A practical case of Tanzania. CORP2001, Vienna University of Technology:101-106.

[19] National Bureau of Statistics (2020). The population census map of Tanzania at ward level. Online GIS database, National Bureau of Statistics, Dar es Salaam, Tanzania.

[20] Altaweel, M. (2022). GIS and spatial interpolation methods. Spatial Analysis, GIS Lounge, October 2022. gislounge.com/gis-spatial-interpolation-methods/ accessed 06 April, 2023

[21] Wu, X.H. and Hung, M.C (2016). Comparison of spatial interpolation techniques using visualization and quantitative assessment. In: Hung, M.C. (Ed), Applications of spatial statistics. Nov, 2016.

[22] Uchida R. and Hue, N.V. (2000). Soil acidity and liming. In: Silva, J.A. and Uchida, R. (eds): Plant nutrient management in Hawaiian soils: Approaches for tropical and subtropical agriculture. CTAHR, University of Hawaii at Manoa. Pp. 101-112.

[23] Hofman, G. and Salomez, J. (2004). Chemical soil fertility management: Partim Fertility Management. Lecture notes, Fac. Agric & Appl. Biol. Sci., Ghent University. 55pp.

[24] Van Ranst, E. (1997). Tropical soils: Geography, classification, properties and management. Lecture notes. International Centre for Physical Land Resources. Lab. of Soil Sci., Ghent University, Belgium.310pp.

[25] Tumuhairwe, J. B., Rwakaikara-Silver, M.C., Muwanga, S. and Natigo, S. (2007). *Screening Legume Green Manure for Climatic Adaptability and Farmer Acceptance in the Semi-Arid Agro-*

Ecological Zone of Uganda. In: Advances in ISFM in Sub-Saharan Africa: Challenges and opportunities. (Edited by Batiano, A.),Springer, Amsterdam, The Netherlands: pp. 255 – 259.

[26] Ngeze, P. B. (2015). Kahawa Tanzania. Tanzania Educational Publishers Ltd, Bukoba, Tanzania. 286pp

[27] Maro, G. P., Monyo, H.E., Nkya, E.O. and Teri, J. M. (2006). The soil fertility status of coffee growing areas in Tanzania. In: *Proceedings of the 21st ASIC Conference,* 9– 14 September 2006, Montpellier Cedex, France. pp. 1419 – 1422.

[28] Maro, G.P., Teri, J.M., Magina, F.L. and Nkya, E.O. (2012). Effects of shade on yields of selected improved hybrid Coffea Arabica varieties in Tanzania. Proc. ASIC 24, San Jose, Costa Rica, 11-17 November, 2012: 1203-1207.

[29] Oberthur, T., Pohlan, J. and Soto, G. (2012). *Plant Nutrition Sustainable Nutrient Management*. In: Oberthur, T. *et al.* (Eds.), Specialty coffee managing quality. International Plant Nutrition Institute, South Eastern Asia Programme, Penang, Malaysia.149pp.

[30] Wairegi, L., Van Asten, P., Giller, K.E. and Fairhurst, T. (2014). Banana coffee system cropping guide. African Soil Health Consortium, Nairobi, Kenya: 121pp.

[31] Van der Vossen, H.A.M. (2005). A critical analysis of the agronomic and economic sustainability of organic coffee production. *Experimental Agriculture* 41: 449 – 473.

[32] Valkila, J. (2009). "Fair Trade Organic Coffee Prouduction in Nicargagua -- Sustainable Development or a Poverty Trap?" Ecological Economics 68.12 (2009): 3018-025. Academic Search Complete. Web. 15 Nov. 2011.

[33] Tanzania Coffee Research Insitute (2018a). “Kanuni za kilimo bora kwa kahawa ya Arabika” (GAPs for Arabica coffee), 2nd Edition, TaCRI, June, 2018: 110pp.

[34] Tanzania Coffee Research Insitute (2018b). “Kanuni za kilimo bora kwa kahawa ya Robusta” (GAPs for Robusta coffee). TaCRI, December, 2018: 87pp.

[35] Wrigley, G. (1988). *Coffee: Tropical Agriculture Series*. Longman Scientific and Technical, John Wiley and Sons Inc., New York, USA. pp.1 – 60.

[36] Wintgens, J.N. (2012). *Coffee: Growing, Processing, Sustainable Production: A Guidebook for Growers, Processors, Traders, and Researchers.* Wiley VCH, Weinheim, Germany. 1022pp.