Spatial-temporal Variability in Under-Canopy Soil Fertility and Nutritional Contents of Cashew Trees in Makonde Plateau of South-Eastern Tanzania

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Abstract
This study was conducted to assess the fertility status of soils under-canopy of cashew trees in the Makonde Plateau of south-eastern Tanzania. Through purposive sampling, seven villages were involved, which are spatially located, but all sharing the same agro-ecology. The composite soil samples were collected under cashew tree canopies with the cashew plant samples collected above the same longitudinal section as the soil. The samples were tested for phosphorus (P), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and micronutrients (iron-Fe, zinc-Zn, and copper-Cu). In addition, organic carbon (OC), organic matter (O.M), and pH were tested in soils. These tests were performed during the wet and dry seasons with soil samples collected at two depths of 0-30 cm and 30-50 cm. Results of the temporal assessment indicated that the Ca, Mg, Na, and Fe differed significantly (P <0.05) between the soil depths, while O.C. and O.M. varied significantly (P <0.05) with soil depths, seasons, and their interactions. In cashew plants, there was a significantly higher nitrogen (P <0.001), phosphorus (P =0.035), and Zn (P =0.029) during the wet season. The N and P were significantly (P =0.010) strong and positively (r =0.95) correlated in cashew plants. Moreover, the correlation effects of N and P revealed statistical variation (p=0.010) with strong positive relationship (r=0.9469) implying synergism effects. These findings suggest that nutrients are one of the limiting factors for cashew production in the study area. Site-specific recommendations and doses of these nutrients need to be established.

Keywords: Plant nutritional status; Nutrients spatiotemporal variability; Sustainable cashew production; Soil health; Tanzania.

1.0 Introduction

The nutritional status of a plant is important for its growth and the predicted yields [1]. Understanding nutritional status of soils and crop plants is one of the pre-requisites that help in decision making on the appropriate strategies regarding protocol preparation for fertilization or soil amendment [2]. Plant and soil nutritional status accounts for the macronutrients (i.e., nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and sulphur (S)) and micronutrients (i.e., iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chlorine (Cl), and molybdenum (Mo) [2, 3]. The nutrients richness is directly related to improve crop plant chlorophyll content, which is associated with plant growth and yield through the process of photosynthesis [4 - 7]. The soil application with fertilizers in turn enriches plant nutritional status and improves plant health leading to improved crop growth and yields [6]. The extent of nutrient requirements by the plant depends largely on the type (species) of the crop, its growth stage in the life cycle, the season for which the crop is growing, and the nutrient status in the soil where the crop is growing [6].

Cashew tree (*Anacardium occidentale*) is a tropical evergreen tree producing cashews as one of the most popular nuts in the world, with the crop being a big business in some countries like the Ivory Coast and India. The global top 10 countries with the highest cashew production (in metric tons) include Ivory Coast (792,678), India (743,000), Vietnam (283,328), Philippines (242,329), Tanzania (225,106), Benin (204,302), Mali (167,621), Guinea Bissau (166,190), and Brazil (138,754) [7]. In Tanzania, cashew is produced largely along the eastern coastal belt and south-eastern zone of the country. The Makonde Plateau in the South-eastern of Tanzania is the mainly characterized belt with cashew farming, plus other important food crops including pigeon peas (*Cajanus cajan* (L) Millsp.), cassava (*Manihot esculenta*), sesame (*Sesamum indicum* L.), and bambara nuts (*Vigna subterranea* (L.) Verdc) [8, 9].

Farmers in the Makonde Plateau engage in agriculture usually through land clearing leaving the bare land, making the soil prone to surface runoff. Moisture conservation in soils is rarely done through mulching. Collection and burning of plant trashes is a common practice in the cashew fields. Whereas the area is suitably used for cashew production, the application of synthetic fertilizers is rarely reported in, the main reasons being unawareness of the importance and high market costs [9, 10,11]. Therefore, the replenishment of deficit or mined nutrients remains one of the constraints in cashew production [12].

Nutrient status of a crop varies with crop phenology, determined largely by the life cycle from which, the elements of weather (temperature and rainfall) also have impact on the crop phenology [13, 14]. The changes in weather conditions also result in wet and dry seasons. Cashew plants become dormant in vegetative initiation and reproductive process but the roots absorb moisture and access nutrients during the wet season [13]. The reproductive phase of cashew for which flowers and nuts are produced is during the dry season. In this season, cashew plants have high requirements of essential nutrients [14, 15]. Besides these physiological differences in cashew plants, the information on temporal nutrient dynamics in soils and in plants during the two contrasting seasons is scarce in the Makunde Plateau of south-eastern Tanzania [16]. The pedological characterization of the soils in the major cashew growing soils of south-eastern agro-ecological zone of Tanzania has been reported [11]. However, the pedological characterization did not consider temporal variability within soils and/or capture soil-cashew nutrient relationships across the two contrasting seasons. Therefore, the objectives of the present study were twofold: - (a) to evaluate the under canopy soil fertility levels at varying depths of 0-30 cm and 30-50 cm during the wet and dry seasons in the Makonde Plateau of south-eastern Tanzania. The primary hypothesis here is that the measured parameters in soils could vary with soil sampling depths and/or between the soil sampling seasons. (b) To assess nutrient levels in cashew leaves in the Makonde Plateau of south-eastern Tanzania during the wet and dry seasons. The primary hypothesis here is that the measured parameters in cashew leaves could vary between the two seasons. The findings of the present study are likely to provide an interesting insight on decision-making in developing appropriate cashew plant and soil management practices through fertilizer application and bridge the knowledge gap related to soils amendment for improved cashew production in the Makonde Plateau of Tanzania and in cashew growing regions with similar characteristics.

2.0 Materials and Methods

2.1 Description of study area

This study was conducted in December and July in Mtwara region. It is located in south-eastern Tanzania (10.3112° S, 40.1760° E) and is characterized by a unimodal type of rainfall, which sets in November or December through April and May [17]. Annual total rainfall ranges from 800 to 1245 mm and the mean annual temperature is 24^{o} C [17]. Soils in this area are mainly sandy to sandy loam [10], which is characterized with high friability and high depth ≥ 2 m with thicket vegetation imbedded on it. The area has little livestock keeping practices conducted; eventually the livestock manure is seldom applied for crops performance. Seven villages from three districts including Tandahimba, Newala and Mtwara Rural were included in the study (Figure 1). The villages included Nanguruwe and Mbawala Juu village in Mtwara Rural, Mtopwa, Mcholi, Namiyonga, and Mahumbika in Newala, and Nanyanga village in Tandahimba district. The selection of cashew fields in each village was purposive based on the similarities in agronomic practices and high cashew production representing the agro-ecology of Makonde Plateau in south-eastern zone of Tanzania.

Figure 1: Map with selected study villages to represent Makonde Plateau in south-eastern Tanzania.

2.2 Study design and sampling of soil and cashew leaves

A reconnaissance survey was conducted across the Makonde Plateau to establish the visible land variability features and set protocol for sampling of soil and plant samples. In the plateau, three districts and their corresponding villages in brackets were identified for the study to be Newala (Mcholi, Mtopwa, Namiyonga, and Maumbika), Tandahimba (Nanyanga), and Mtwara Rural (Nanguruwe and Mbawala Juu). Given that the Makonde Plateau is found within the same agro-ecological zone, it is expected that the variability in the parameters to be assessed in soils and cashew plants will not vary significantly across districts and/or across villages. Therefore, the variability in districts and/or villages was not considered in the present study. However, the soil samples were collected at two depths of 0-30cm and 30-50 cm with both soil and cashew plant samples collected in two seasons (dry and wet). Therefore, two factors (i.e., sampling depths and seasons) are considered for the assessed parameters in soils whereas one factor (i.e., seasons) are considered for the assessed parameters in cashew plants. A standard procedure was deployed in collection of soil and plant samples collection [18]. In cashew plant, at least 16 leaves were collected in a cashew tree from which four leaves were picked following cardinal tree direction (West, East, North and South) to avoid bias that may be caused by the light effects. The leaves from a village in a season were averaged from three cashew orchards to represent a replicate village. The soils were collected targeting rooting depths of at least 5 years old cashew tree with its 75% of feeder roots found in the topsoil/subsoil or extending to soil depth ranging from 30 to 100 cm [19, 20]. Sampling during the wet and dry seasons was important to evaluate the role of soils in feeding cashew plants through the year period [21].

2.3 Laboratory analysis of soil and plant samples

Procedures for soil and plant sample analysis are as per description below;

Description of the laboratory procedures for the analysis of samples

Samples for analysis	Nutrients analysed from samples	Methods of nutrients analysis in lab	Reference
Soils at depth of 0-30 and 30-50cm	TN, P, K, Fe, Mg, Cu, Zn, Na, EC, OC, C:N and pH	▪ TN by Micro-Kjeldahl digestion-distillation ▪ Extractable P by Bray and Kurtz - 1 ▪ Potassium (K) extracted using flame photometer method ▪ Micronutrients after microwave digestion quantified by atomic adsorption spectrophotometer	[22, 23, 24]
Plant tissues	TN, P, K, Fe, Mg, Cu, Zn, Mn,	▪ The grinded powder was digested by the HNO_3 - H_2O_2 procedure and the digests were analysed for the listed nutrient contents using procedure by [24]	[24]

2.4. Weather information from the study area

Weather parameters including rainfall and temperature (maximum and minimum) were collected during both dry and wet seasons at the meteorological weather station of TARI-Naliendele. The changes in weather parameters are related to the availability in nutrients to the root zones of plants [25, 26].

2.5 Statistical data analysis

In assessing the variability of the measured parameters in soils, a split-plot design of the analysis of variance (ANOVA) was performed following the soil sampling depths (0-30 cm and 30-50 cm) and seasons of sampling (wet and dry). The fixed main effects in the design were the seasons of sampling considered as the main-plot and the sampling depths as the sub-plot, whereas the replicate villages were treated as random effect. The significant treatment means was compared using standard errors of differences of means (S.E.D.) at 5% threshold by Tukey's post-hoc multiple comparison. The factors effect model is as shown in Equation 1.

$$Y = \mu + \alpha i + \beta j + (\alpha\beta) ij + \varepsilon ij \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where *Yij* is the observed assessed parameter in the *ijth* factors; μ is the overall (grand) mean of the assessed parameter; α_i and β_j are the main effects of the factors seasons of sampling and soil sampling depths, respectively; $(\alpha\beta)_{ij}$ is the two-way (first order) interactions between the factors seasons of sampling and soil sampling depths; εij is the random error associated with the observation of the assessed parameter in the *ijth* factors.

In assessing the variability in the measured parameters in cashew plants, the data was subjected to one-way analysis of variance (ANOVA) with the seasons forming the main fixed effect (one factor) and the replicate villages were treated as random factor. The significant treatment means were compared through the least significance differences (LSD) of the means at 5% threshold by the Tukey's post-hoc multiple comparison. The factor effect model is as shown in Equation 2.

$$Y = \mu + \alpha i + \varepsilon ij \text{..} (2)$$

Where Yi is the assessed parameter in the i^{th} factor; μ is the overall (grand) mean; α_i is the main effect of the factor seasons; εi is the random error associated with the observation of assessed parameter in the i^{th} factor.

3.0 Results

3.1 Temporal variability in soil parameters

The main significant (P < 0.05) effect was recorded for the soil depths on electrical conductivity, exchangeable calcium, magnesium, and exchangeable sodium (Tables 1 and 2.). The organic carbon and organic matter differed significantly with seasons, soil sampling depths and their interactions (Table 1). In addition, of the assessed micronutrients in soils, only iron differed significantly (P = 0.013) with soil depths such that higher amount of iron (57.4 mg kg^{-1} soil) recorded at a soil depth of 0-30 cm relative to the amount of iron (36.8 mg kg^{-1} soil) recorded at a depth of 30-50 cm (Table 3).

Table 1: ANOVA of some soil parameters measured in two soil depths of 0-30 and 30-50 and two seasons of wet and dry in the Makonde Plateau of south-eastern Tanzania.

Source of variation	d.f	Measured variables in soils and statistical parameters (F.pr.)				
		pH	O.C	O.M	N	C/N
Villages	6					
Seasons	1	0.457	0.01	0.01	0.416	0.452
Residual	6					
Soil depths	1	0.206	<0.001	<0.001	0.134	0.307
Seasons × Soil depths	1	0.229	0.035	0.034	0.81	0.458
Residual	12					
Total	27					

Key: d.f. =degrees of freedom; F pr. = test-F probability; pH = power of hydrogen; P = phosphorus; OC =organic carbon; O.M. = organic matter; N = nitrogen; C/N = carbon to nitrogen ratio

Table 2: ANOVA of some soil parameters measured in two soil depths of 0-30 and 30-50 and two seasons of wet and dry in the Makonde Plateau of south-eastern Tanzania.

Source of variation	d.f.	Measured variables in soils and statistical parameters (F.pr.)				
		EC	Ca	K	Mg	Na
Villages	6					
Seasons	1	0.426	0.216	0.653	0.224	0.233
Residual	6					
Soil depths	1	0.011	0.001	0.264	<.001	0.003
Seasons × Soil depths	1	0.52	0.71	0.454	0.22	0.192
Residual	12					
Total	27					

Key: d.f. =degrees of freedom; F pr. = test-F probability; pH = power of hydrogen; EC = electrical conductivity; Ca = calcium; Mg = magnesium; K = potassium; Na = sodium.

Table 3: **ANOVA for the selected micronutrients measured in two soil depths of 0-30 and 30-50 and two seasons of wet and dry in the Makonde Plateau of south-eastern Tanzania.**

Source of variation	d.f.	Measured micronutrients in soils and statistical parameters (F. pr.)		
		Cu	Fe	Zn
Villages	6			
Seasons	1	0.068	0.551	0.184
Residual	6			
Soil depths	1	0.773	0.013	0.189
Seasons × Soil depths	1	0.494	0.402	0.859
Residual	12			
Total	27			

Key: d.f. =degrees of freedom; F.pr. = test-F probability; Cu = copper; Fe = iron; Zn = zinc.

The significantly higher organic carbon measured with varying seasons, soil sampling depths, and their interactions were 0.23% (wet season), 0.252% at 0-30 cm, and 0.3% at 0-30 cm during wet season. The quantities of organic matter followed the similar trend since it is the derivative of the measured organic carbon. On the other hand, the significantly higher exchangeable magnesium (6.38 $cmol_{(+)}$ kg^{-1}) was only recorded at the soil sampling depth of 30-50 cm relative to a depth of 0-30 cm, but not with the variation ($p>0.05$) in seasons and/or their interactions (Table 4). Similar observation was realized in the measured exchangeable sodium but higher amount (0.07 $cmol_{(+)}$ kg^{-1}) was recorded at the soil sampling depth of 0-30 cm without any significant effect recorded in seasons and/or the interactions between seasons and soil sampling depths (Table 4).

Table 4: Means of the selected soil parameters measured in two soil depths of 0-30 and 30-50 and two seasons of wet and dry in the Makonde Plateau of south-eastern Tanzania.

Factors considered	*Measured parameters in soils and their respective quantities												
Seasons	**pH**	**EC**	**N**	**OC**	**OM**	**K**	**Ca**	**Mg**	**Na**	**P**	**Fe**	**Cu**	**Zn**
		µS cm^{-1}	%			cmol$_{(+)}$ kg^{-1}				mg kg^{-1}			
Wet	6.05	0.04	0.03	0.23	0.40	0.11	1.27	5.75	0.05	10.41	50.7	3.04	0.45
Dry	5.91	0.03	0.04	0.18	0.31	0.14	0.96	5.17	0.06	9.9	43.5	1.93	0.33
S.E.D.	0.18	0.010	0.0096	0.014	0.023	0.05	0.22	0.431	0.01	0.357	11.45	0.5	0.08
L.S.D.	0.28	0.025	0.024	0.033	0.0571	0.13	0.55	1.055	0.01	0.872	28.03	1.225	0.20
P - value	0.457	0.426	0.416	0.01	0.01	0.653	0.216	0.224	0.233	0.202	0.551	0.068	0.184
Soil depths (cm)													
0-30 cm	6.05	0.021	0.04	0.252	0.43	0.09	1.27	4.54	0.07	10.35	57.4	2.57	0.44
30-50 cm	5.91	0.047	0.03	0.158	0.27	0.16	0.96	6.38	0.04	9.97	36.8	2.4	0.35
S.E.D.	0.10	0.009	0.006	0.019	0.033	0.05	0.07	0.293	0.01	0.521	7.07	0.558	0.07
L.S.D.	0.28	0.019	0.014	0.042	0.072	0.12	0.16	0.638	0.01	1.135	15.41	1.216	0.15
P - value	0.206	0.011	0.134	<0.001	<0.001	0.264	0.001	<0.001	0.003	0.484	0.013	0.773	0.189

*Means within the same category (variable) in a column with *P* –value < 0.05 differ significantly; otherwise, they are statistically similar.

3.2 Effect of seasons on the variability of nutrients in cashew plants

The effect of seasons was significant on nitrogen (P < 0.001) and phosphorus (P = 0.035) but without significant (P = 0.052) effect on potassium. Of the studied micronutrients, the significant (P = 0.029) effect of seasons was recorded only in zinc but not for copper, iron, and manganese. The significantly (P < 0.05) higher concentrations of nitrogen, phosphorus, and zinc in cashew plants were recorded during the wet season, other nutrients including potassium, copper, iron, and manganese were also higher during the same wet season, though their quantities were not significantly (P > 0.05) different from their counterparts recorded during the dry season (Table 5). A further correction test among the studied nutrients in cashew plants (not all data presented) shows that only nitrogen and phosphorus had significantly (r = 0.9469; P = 0.010) strong and positive relationship.

Table 5: **Means of the selected nutrients measured in cashew plants during wet and dry seasons in the Makonde Plateau of south-eastern Tanzania.**

Variables	*Measured nutrients and their respective quantities						
	N	P	K	Cu	Fe	Mn	Zn
	%			ppm			
Wet season	1.30	0.03	0.21	0.81	26.50	1.93	0.16
Dry season	0.62	0.01	0.19	0.67	18.40	1.41	0.06
S.E.D.	0.11	0.00	0.01	0.34	3.50	0.55	0.04
L.S.D.	0.26	0.01	0.02	0.82	8.56	1.35	0.09
P - value	<0.001	0.035	0.052	0.685	0.059	0.388	0.029

*Means in a column with P –value < 0.05 differ significantly; otherwise, they are statistically similar.

3.3 Weather parameters in Makonde Plateau

There was a great change in rainfall and temperature in the study area. The mean monthly rainfall was very low (126.5 mm) in 2021 and 2022 seasons (Figure 2). The rains expected to start in January through May decreased during the 2021 season, but the normal distribution was experienced in the 2022 season. The maximum rainfall was 639.9 mm while the monthly maximum and minimum temperatures were 30.6 °C and 22.6 °C, respectively (Figure 2). Dry spells were recorded from June through November.

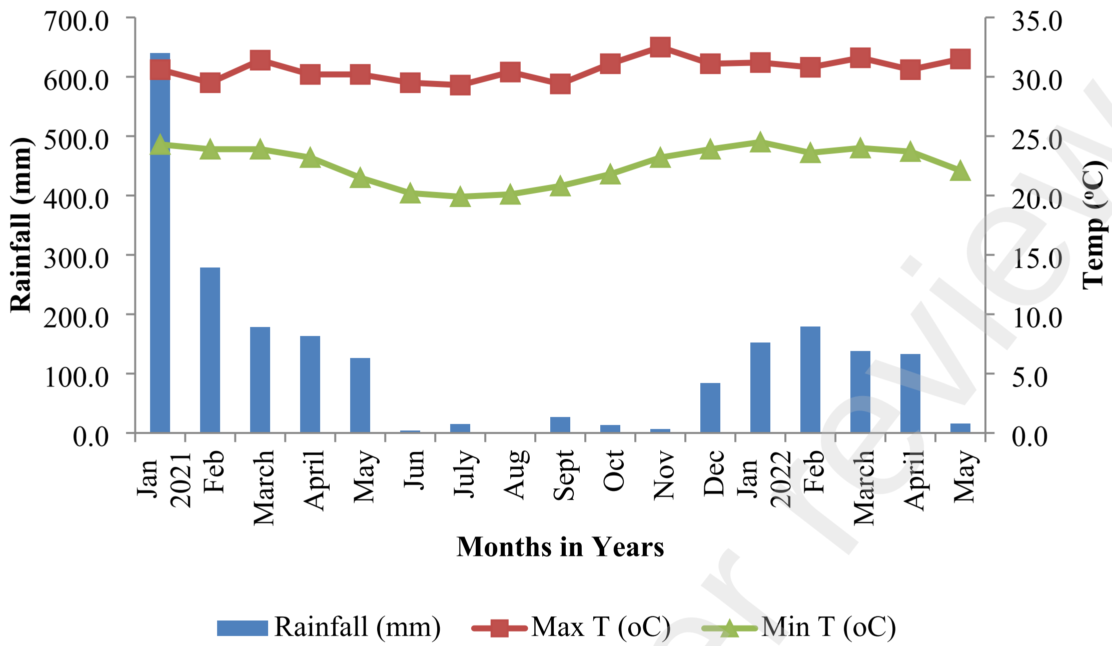

Figure 2: Rainfall and temperature trends in months between 2021 and 2022 seasons

4.0 Discussion

4.1 Temporal variability in soil properties

Generally, high quantities of soil pH, electrical conductivity, organic carbon and organic matter, exchangeable calcium and magnesium, available phosphorus, and extractable micronutrients such as iron, copper, and zinc were recorded in the wet season. In contrast, total nitrogen, exchangeable potassium and sodium were high in the dry season. In assessing the effects of soil sampling depths on the measured soil parameters, the soil depth of 0-30 cm recorded high quantities of soil pH, total nitrogen, organic carbon and organic matter, exchangeable calcium and sodium, available phosphorus, and the micronutrients iron, copper, and zinc. On the other hand, high quantities of electrical conductivity and exchangeable magnesium and potassium were recorded at the soil sampling depth of 30-50 cm.

All soils are characteristically medium acid in reaction (pH 5.5–6.0) through seasons, soil sampling depths and their interactions, which could be attributed to the sandy loam texture. This reaction signals very low levels of exchangeable sodium (< 0.10 $cmol_{(+)}$ kg^{-1}), hence absence of the effects rooting from salinity. The same is demonstrated by the normal electrical conductivity in the studied soils. Similarly, medium acid conditions display constraints related to solubility of micronutrients such as copper and zinc, but increasing the solubility of iron [27]. High solubility in Fe may result in fixation of phosphorus and become unavailable for crop uptake thereby affecting final yields. The variability observed for the micronutrients measured in these soils signify the impact of soil pH as a master of the solubility of micronutrients and the likely availability and/or facilitation to macronutrient phosphorus in soils. A follow-up statement to this are the low levels of available phosphorus recorded from these soils, which are far below threshold of 13 mg P kg^{-1} soil. Whereas phosphorus is a constraint to crop production in these soils, other important primary minerals (e.g., nitrogen and potassium) are limiting, given the hydration potential of potassium [28]. Besides, calcium as a secondary macronutrient seems significantly high (> 0.22 $cmol_{(+)}$ kg^{-1} soil) at the soil sampling depth of 0-30 cm, but its expression is strongly obscured by the deficiencies of other secondary macronutrients, particularly magnesium, which is significantly higher at the soil sampling depth of 30-50 cm. To further stretch the magnitude of the problem in these soils, the contents of organic matter are significantly very low (<1.0%), depicting the low organic substrates that may serve as habitat to beneficial microorganisms and reservoir of plant nutrients [29, 30]. Incorporation with organic substrates or mulching materials to these soils could be necessary to improve organic content for soil fertility and overall soil health [31].

4.2 Nutrients concentrations in cashew plants

From the results, nitrogen and potassium exhibited low to very low (deficiency) as in accordance to the sufficiency ranges of nutrients for cashew by [30, 32]. Nitrogen and potassium can volatilize under high soil temperature and lower soil moisture (rainfall) [29, 33]. The little rain and increasing temperature in the study areas might have contributed to the deficient of nitrogen and potassium. Cashew trees in Makonde Plateau have been grown without being added with fertilizers, probably this has been limiting the replenishing nutrients. Similar suppositions were addressed by [34, 35, 36] on the nutrients roles in replenishing deficient crops for better yields. Furthermore, the low rainfall in Makonde Plateau in 2021/2022 season might be implying the indicator of drought occurrence. The droughts might be threatening the cashew trees' nutritional balance since the limited rainfall could have reduced soil moisture. Limited moisture can reduce plant roots nutrients uptake and soil nutrients availability for crop satisfactions [29].

The significant effects of seasons realized in both nitrogen and phosphorus could be attributed to their synergism in physiological functions they play in plants [37]. These findings suggest that high nutrients concentration in cashew plants is attributed to the dormant vegetative and reproductive systems, which become active during the dry season thereby consuming a large part of the reserved nutrients for plant physiological functions [38, 39, 40]. However, all nutrients were below the critical ranges in plants, an observation which is also in line with the quantities of the same nutrients recorded in soils where the same cashew plants were growing. The significant effect of seasons on the concentrations of nitrogen, phosphorus, and zinc confirms the hypothesis that the measured nutrients in cashew leaves could vary between the two seasons. Because soil nutrients are readily available in damp soils, the nutritional state of plant tissues varies between the wet and dry seasons [37]. When there is enough organic matter, phosphorus (P) can be in permanent form in dry soil capillaries as opposed to damp soil clods [41]. In sandy soils and water retention areas, nitrogen and potassium can easily leach. In water-retaining soils, ATP production can readily be inhibited to facilitate crop roots absorbing nutrients [37]. Diffusion and water flow have a significant impact on the movement of nutrients from the soil to the root zone, where they are then taken up by plant cells [39]. Despite the possibility of drought, a lack of water in soils limits the movement of nutrients and water [29, 42, 43, 44]. Drought stresses (a lack of rainfall) on crops and plants, such as cashews, can cause nutrient deficiencies [18]. Similar circumstances on *Olea europaea* described by [46], in which the drought decreased crop output (yield) and growth [40, 32, 33]. This situation suggests that soils in cashew orchards need to be disturbed through tillage (ridging and or soil clods opening), especially during the rainy or wet season to allow roots to percolate and soil nutrients and water to migrate for the crop's enrichment.

5.0 Conclusions and recommendations

Because of their low fertility, the soils need to be altered in terms of nutrients and physical characteristics in order for crops to grow and develop to their full potential. Since they do not considerably differ in terms of their nutritional level and/or features, the management of these soils may be identical. Compost and farmyard manure are two organic materials that can be added to the soil to improve its chemical and physical composition.

These soils are generally productive but need management options to improve crop production. All field-based and horticultural crops can grow well in these soils but their productivity can only be realized after investment on fertilizer inputs. The practice of incorporating organic substrates and compost will improve aggregation of soil particles and thus improve soil structure. This in turn will improve water-holding capacity, supply nutrients and improve the cation exchange capacity of the soils. Together with the measures recommended above, the identified nutrients as deficient can be added to the soil through application of fertilizers containing specific nutrient elements as per the requirements of the target crop(s). Fertilizers carrying negative charges (e.g. Urea or CAN through nitrates) should be applied in splits as they are prone to leaching given the sandy texture of the tested soils. Deficient micronutrients can also be applied through foliar sprays on plants. As an immediate requirement, NPS fertilizer at a rate equivalent to 25 kg P ha^{-1} (or 125 kg NPS for 19-46-7) can serve for nitrogen and phosphorus deficiencies in these soils. Similar quantities of DAP fertilizer may be applied but serving only for N and P deficits. More of N deficit may be supplemented from urea based on the calculations of a specific soil after application with NPS fertilizer. Acid forming fertilizers like SA (sulphate of ammonium) should be avoided in these soils as these fertilizers may induce more acidity, and make the situation more intense.

Data availability

Some or all data, models, or codes that support the findings of this study are available from the corresponding author with reasonable request.

Author contribution statement

Abdallah R. Makale: Conceptualized the experimental idea; Conceived and designed the experiments; Performed the experiments; analyzed and interpreted the data; Wrote the paper.

Sixbert K. Mourice: Conceptualized the experimental idea; Interpreted the data; Wrote the paper

Fortunus A. Kapinga: Contributed materials, analysis tools or data; Wrote the paper.

Declaration of interest;

Authors declare no conflict of interest in this research work.

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