Original Research Article

Soil nutrient status assessment under cassava cropping systems using DRIS model in Southern Benin

ABSTRACT

Cassava is one of the widely cultivated and consumed root cropped in Benin. Cassava is also a highly strategic crop for maintaining food security in developing countries like Benin. Cassava production is threatened by declining soil fertility, especially nutritional deficiencies. This study aims to assess nutritional status of soil under cassava cropping system in southern Benin using Diagnosis and Recommendation Integrated System (DRIS). For this purpose, 149 samples of cassava leaves were sampled from farmers' fields in 3 municipalities named Djakotomey, Klouékanmey and Zakpota. Moreover, root yield and nutrients (N, P, K, Ca, Mg, and Zn) content in the leaves were determined for DRIS norms establishment. From DRIS, the order of nutrient deficiency was as follows : K >N > P > Zn > Ca > Mg ; K>Ca > Zn > Mg > N > P and Zn>N > Ca> K > Mg > P for the farmers' fields in Djakotomey, Kloukanmey and Zakpota respectively. These results also showed that K, Ca and N were deficient in the soil and limit cassava yield while P and Zn was often in excess. DRIS could be an important tool for refining the nutritional needs of cassava plants in Benin Republic's cropping systems and also for setting trial for fertilizer recommendation.

Keywords: Soil evaluation, root cropping systems, Nutrient deficiencies, Soil fertility management, cassava nutrition

1. INTRODUCTION

Cassava (ManihotesculentaCrantz), a starchy tropical tuber crop cultivated by smallholder farmers in the marginal lands of Sub-Saharan Africa, Asia and Latin America, provides subsistence as well as cash incomes [1, 2]. In Asia, cassava is mostly produced to meet the demand for dried cassava chips and cassava starch for use in commercial livestock feed and for industrial processing [3,4]. In Africa, where the area devoted to cassava is the largest, the crop is grown mainly on small farms by low-income farmers who use few or no external inputs [4]. The majority of production in Africa is from Nigeria largest producer of cassava worldwide, harvesting over 35 million tons of fresh roots from 3.1 million hectares of land [5]. Cassava is usually grown with other crops, such as maize, rice, legumes, melons, banana and oil palm. About 90% of the production is used for direct human consumption as fresh tubers or after processing into fermented flour products.

Cassava production in Benin is mainly in the hands of small-scale farmers under rainfed conditions. The crop plays a vital role in the food security of the rural economy because of its ability to tolerate drought and give reasonable yield in soils of low fertility [6,7,8], hence the name 'poor man's crop'. But cassava yield remains low, which proves that soil fertility is a challenge to be met if cassava production is to be intensified in a sustainable way ([9]; [8]).

Cassava productivity in African smallholder's farming systems is below the optimal level, although some increases in yields were observed [10]. The current average yield of fresh cassava has increased in Africa from 6 to 10 t.ha-1 over the last 50 years, but remains well below the current average yield of 22 t.ha-1 in Asia [11,12].The same trends were observed in Benin.

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In this context, reducing the gaps between cassava yields under research and farmer-managed cropping systems is a crucial concern in Africa, especially as cassava is moving from a subsistence crop to one of the major cash crops and appears to be one of the promising crops to mitigate drought resulting from climate change [13,14]. Most farmers still believe that cassava can restore the fertility of degraded soils and not need external nutrient inputs to soils [16,17]. To address the yield gap, a clearer understanding of the key factors contributing to low cassava yields is needed, as this can be helpful in designing intensification programmes and prioritising interventions in the context of the limited resources available. As soil fertility is its capacity to provide adequate nutrients for specified plants when other factors are favorable, tissue analysis is considered a more direct method of soil fertility evaluation than soil analysis.

The importance of nutrient balance in determining the yield and quality of crops is well established but there is no means to quantify it other than using the Diagnosis and Recommendation Integrated System (DRIS). In this system, leaf analysis values are interpreted on the basis of inter-relationships among nutrients, rather than the nutrient concentrations themselves [18,19,20]. DRIS method processes the nutrient ratio to eliminate the influence of sampling time, plant growth stage, and leaf tissue position in the interpretation of leaf tissue analysis results regarding individual nutrient levels [21,19, 22]. It is a useful tool for simultaneously identifying and classifying nutrient deficiencies and excesses. Recent investigations have confirmed the effectiveness of DRIS in assessing the nutritional status of rubbers [22], oil palm [23], maize [24]; soybean[25, 26], cotton [27], sorghum [28], peanut [22], yam [29]. The objective of the present study was to set a DRIS model parameters for cassava using root yields and leaves' tissue nutrient concentration data from the farmers' cassava fields in the South of Benin Republic.

2. MATERIAL AND METHODS

2.1. Study area

The study was carried out in the "terre de barre" zone (agro ecological zone 6, Djakotomé, Klouékanmey and Zakpota). In this zone, cassava is one of the main grown crops. The "terre de bare" zone has a subequatorial climate type with two rainy seasons with 900 to 1200 mm of rainfall per year in the West and 1100 to 1400 mm per year in the East. The average annual temperature is 26.5°C and the soil types are Acrisols[30]on clayey-sandy sediment of the continental terminal, with deep profiles and easy to work but chemically poor.

Overall, the soils in the area have a low level of fertility. pH water showed that the soils of the study area were usually ranged from strong to moderate acidic with values ranging from 4.32 to 5.84. Organic matter (OM) showed that soils are poor (10 to 20 g/kg). Total nitrogen content of the sites ranged from poor (0.5 to 1 g/kg) to moderately rich (0.5 to 1.5 g/kg). Potassium levels varied from poor (<0.2 cmolkg). Available phosphorus levels varied from 3 to 12 mg/kg classifying them as poor soils. Exchangeable cation sums are low (< 2.2 cmol/kg). These low levels of CEC resulted in high levels of soil saturation, with values ranging from 44 to 93%. Soils of the study area had a low fertility level, with a slight acidity.

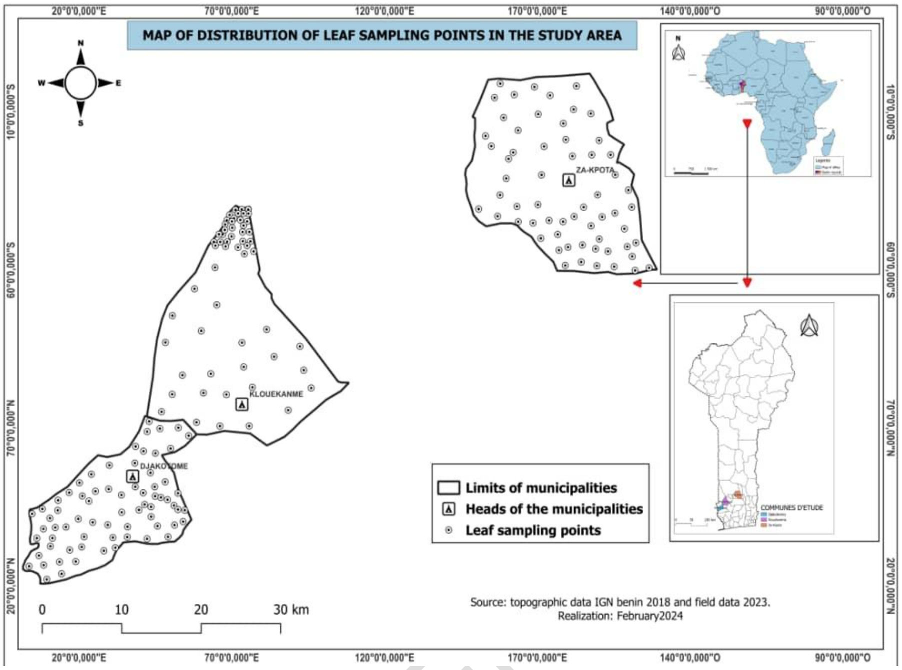

Figure 1 : Study area and sampling point

2.2Cassava leaves sampling and chemical analysis

Leaves sampling were done along two diagonals in each field while respecting 20 m distance from the field edges [31]. Leaves were taken during the full flowering period according to [32]. Three fully developed leaves were sampled at the top of the plant. Samples were collected from 30 cassava plants in each farmers' field. A total of 349 cassava fields were taken in the 6 municipalities. The leaves sampled were healthy, well developed and without physical injury. Leaves from all plants were mixed together to form composite samples to be sent to the laboratory for nutrients analyses. After air drying in the field, plant materials were further dried at 65°C to a constant weight in an oven in the laboratory, grounded by a Brabender mill and stored in dry area. In the fields where leaves' samples were collected, the harvest was done and root yields in each field were assessed according to the formula R = (1000*P)/SI ([22]) where R is the root yield (in kg DM/ha), P, the total weight of root weighed in the field (in kg) and SI: Interpretable area (4 m² in this study).

The sample analyses were completed at the Support Laboratory for the Improvement of Soil Health, Water Quality and Environmental Protection (2A2S2E) of National Institute of Agricultural Research of Benin (INRAB). Total N, P, K, Ca, Mg and Zn were determined in plant tissue. The leaves' samples were digested with H_2SO_4 and H_2O_2 with nitrogen catalyzer composed of 5 g of K_2SO_4, 5 g of $CuSO_4$ and 0.25 g of selenium and N was analyzed according Kjeldahl method [32]. The dry samples were ashed in porcelain crucibles at 450°C in a muffle furnace. The ash was dissolved in concentrated nitric acid to precipitate silicate, then concentrated nitric acid was added again, and transferred in volumetric flasks followed by several rinses with demineralized water. Atomic Absorption Spectrophotometer trademark "AGILENT" was used to determine Ca, Mg, Zn and K [32]. Phosphorous was determined using the molybdo-vanadate blue method [32]. The filtrate was colored with ammonium molydate in the presence of ascorbic acid and the intensity of the color was measured by colorimetry at a wavelength of 600 nm.

2.3Development of DRIS norms

[33] procedure was used in establishing the DRIS norms and the variation coefficient calculated. Root yields were divided into two yield sub-populations using the average yield plus the confidence interval as a subdivision criterion [29]. Therefore, a sub-population with high yields and another sub-population with low yields are used for the continuation of the DRIS procedure. The ratio of nutrients in pairs is calculated for each sub-population and each element appears in the numerator and denominator (e.g. Zn/P and P/Zn). For each of these forms of ratio, the variance in both sub-populations are calculated. Variance ratios for both forms of nutrient ratios are calculated dividing the variance of the ratio for the low-yielding population by the variance of the high-yielding population for the same form of ratio (Payne et al., 1990). For each pair of ratios, the one giving the largest variance ratio is selected for the evaluation of the DRIS norms. Then, the DRIS indices are calculated for nutrients following the generalized equations developed by [34]:

Xindices = [f (X/A) + f (X/B) +... -f (M/X) – f (N/X)] Where f (X/A) =100*[(X/A) (x/ a) - 1]/CV when (X/A) >(x/a) -SD ; f (X/A) = 100*[1 - (X/A) / (x/a)]/CV when (X/A) <(x/a) -SD X/A is the ratio of concentrations of nutrients X and A in the sample, while x/a, CV and SD, are the mean, coefficient of variation and standard deviation respectively for the parameter X/A in the high-yielding population.

To interpret the DRIS indices, the concept of fertilization response potential (Wadt et al., 1998; Serra et al., 2013) was used. Comparison of nutrient index or its absolute value with the nutritional balance index (NBI) was the principle of the method. The nutritional balance index is the average of the distance to zero of all nutrient indices. The index of a nutrient is the arithmetic mean of the ratios obtained after calibration. It is obtained for each individual nutrient in the high-yield sub-population by assigning in the averaging formula the sign (-) to the element which index is to be determined and which is in the denominator of the ratio and the sign (+) when that element is in the numerator. The average of all individual nutrients in the high-yielding sub-population is then the index for that nutrient. According to [33] for n indices, we have: NBI = (|Index A| + |Index B| + ... + |Index n|)/n). According to the authors, for a nutrient N, one could make the following conclusion : Deficient and limiting when IN < 0 and |IN| > NBI and IN is the lowest DRIS index; Probably deficient when IN < 0 and |IN| > NBI; Sufficient when |IN| ≤ NBI; Probably in excess when IN > 0 and |IN| > NBI; In excess when IN > 0 and |IN| > NBI and IN is the highest value DRIS index where IN is Nutrient Index.

2.4Statistical analysis

Descriptive Statistics were calculated using Excel 2016 for cassava root yield, leaf nutrient concentration and nutrient ratio expression. Descriptive statistics included, means, minimum and maximum values, variances were calculated. Cassava root yields in the two sub-populations were subjected to one way (sub-population as a factor) analysis of variance. Comparison of the means of the nutrient concentrations and root yields was done using Fisher's test. Prior to this, the normality of the data was carried out using the Shapiro-Wilk test.

3. RESULTS AND DISCUSSION

3.1 Nutrient concentration in the cassava's leaves

Statistical analysis of root cassava yield and nutrient concentration in the leaves for the 3 municipalities were presented in Tables 1 to 3. Cassava root yield range from 8,000 to 13,000 kg ha-1 with a mean of 10,333.5 kg ha-1 in the sampled fields at Djakotomey (Table 1). 15 out of 51 data points are assigned to the high yield sub-population (root yield ≥ 10,333.5 kg ha-1). AtKlouekanmey (Table 2) and Zakpota (Table 3) cassava root yield range from 7,900 to 13,000 kg ha-1 with a mean of 9,968.5 kg ha-1 and 8,000 to 13,000 kg ha-1 with a mean of 10,378 kg ha-1 in the sampled fields respectively. 16 out of 56 data points are assigned to the high yield sub-population (root yield ≥ 9968.5 kg ha-1) and 15 out of 51 data points are assigned to the high yield sub-population (root yield ≥ 10,378 kg ha-1) respectively at Kloukanmey and Zakpota. In all municipalities, less data size than required would be used to establish the DRIS model parameters regarding the prevalence of low yield data points. However, as already noticed, a preponderance of high-yielding data is not absolutely essential for the DRIS norm establishment. The normality test carried out on nutrient concentrations in all municipalities shows that, the N, P, K and Mg content follow normal distribution ($p > 0.05$). In all municipalities sampled, these data sets are deemed suitable for the DRIS model development. Moreover, the root yields of both sub-populations are significantly different ($p = 0.00001$). This represents a good precision indicator for the DRIS norm established.

Table 1.Mean, coefficient of variation (CV) and variance (VAR) of cassava leaf nutrients in the two yield sub-populations (low and high) and critical nutrient values in the commune of Djakotomey

Parameters	Low yielding sub-population N=[36]					High yielding-sub population N=[15]					Ratio
	Means	VAR	CV	Min	Max	Means	VAR	CV	Min	Max	VAR
Root yields (kg/ha)	9000.0	628571.0	8.8	8000.0	10000.0	11667.0	523810.0	6.2	11000.0	13000.0	1.20
Nutriments (g/kg)											
N	4.2	0.4	15.1	3.1	5.2	2.8	0.4	14.7	3.3	5.4	0.6
P	0.9	0.0	19.8	0.5	1.2	0.6	0.0	18.9	0.6	1.2	1.3
K	1.9	0.6	41.0	0.6	3.1	1.2	0.1	11.0	2.1	3.0	1.5
Ca	1.5	0.1	19.2	1.1	2.3	2.3	0.9	51.9	1.1	4.5	0.5
Mg	1.1	0.0	18.7	0.8	1.7	0.8	1.2	86.7	0.7	4.9	0.3
Zn	0.1	0.0	30.0	0.0	0.1	0.1	0.0	54.5	0.0	0.2	0.4

SD: standard deviation; VAR: variance; CV: coefficient of variation; Min: minimum; Max: maximum

Table 2. Mean, coefficient of variation (CV) and variance (VAR) of cassava leaf nutrients in the two yield sub-populations (low and high) and critical nutrient values in the commune of Klouekanmey

Parameters	Low yielding sub-population N=[40]					High yielding-sub population N=[16]					Ratio VAR
	Means	VAR	CV	Min	Max	Means	VAR	CV	Min	Max	
Root yields (kg/ha)	8270.0	168307.7	5.0	7900.0	9000.0	11667.0	999292.0	8.9	9600.0	13000.0	0.2
Nutriments (g/kg)											
N	3.1	0.3	18.2	1.8	4.1	2.8	0.2	13.9	2.3	4.1	1.6
P	0.8	0.0	24.3	0.4	1.3	0.6	0.1	37.3	0.6	1.6	0.3
K	1.5	0.1	23.2	0.9	2.2	1.2	0.1	20.8	1.0	1.8	1.2
Ca	1.3	0.2	34.2	0.8	3.6	2.3	0.0	15.4	1.0	1.6	5.3
Mg	1.2	0.1	22.8	0.9	2.1	0.8	0.1	23.7	0.9	1.9	0.7
Zn	0.1	0.0	22.2	0.0	0.1	0.1	0.0	19.0	0.0	0.1	1.3

Table 3. Mean, coefficient of variation (CV) and variance (VAR) of cassava leaf nutrients in the two yield sub-populations (low and high) and critical nutrient values in the commune of Zakpota

Parameters	Lowyieldingsub-population N=[36]					High yielding-sub population N=[15]					Ratio VAR
	Means	VAR	CV	Min	Max	Means	VAR	CV	Min	Max	
Rootyields (kg/ha)	9283.0	558571.0	8.1	8000.0	10200.0	11473.0	492095.0	6.1	10500.0	13000.0	1.1
Nutriments (g/kg)											
N	3.7	0.1	9.3	3.0	4.4	3.7	0.2	10.9	3.2	4.5	0.7
P	1.0	0.0	17.6	0.5	1.3	1.0	0.1	27.8	0.7	1.6	0.4
K	2.3	0.4	27.1	1.0	3.5	2.4	0.4	27.8	1.2	3.6	0.9
Ca	1.0	0.0	15.8	0.7	1.4	1.0	0.1	25.4	0.7	1.5	0.4
Mg	0.7	0.0	22.9	0.5	1.1	0.8	0.0	23.2	0.5	1.1	0.8
Zn	0.1	0.0	28.6	0.0	0.1	0.1	0.0	18.6	0.0	0.1	2.4

SD: standard deviation; VAR: variance; CV: coefficient of variation; Min: minimum; Max: maximum

3.2 Binary nutrient ratio statistics and DRIS norms to improve cassava production

The binary nutrient ratio combinations of the six nutrients calculated, and summary statistics evaluated for each of the resulting 30 nutrient ratios for Djakotomey, Klouékanmey and Zakpota were presented in Table 4 to Table 6. The DRIS norms were selected from the statistical data of the nutrient ratio. From the reciprocal expressions e.g. N/P and P/N, the most appropriate nutrient ratio is selected (based on highest value of Vlow/Vhigh). Therefore, 15 means values of nutrient ratio expressions in the high-yielding sub-population involving all nutrients were selected as the diagnostic norms for cassava in each municipality. The norms of paired ratios selected were N/P, K/N, Ca/N, Mg/N, Zn/N, K/P, Ca/P, Mg/P, Zn/P, K/Ca, K/Mg, K/Zn, Ca/Mg, Zn/Ca and Zn/Mg; N/P, K/N, Ca/N, Mg/N, Zn/N, K/P, Ca/P, Mg/P, Zn/P, K/Ca, K/Mg, K/Zn, Ca/Mg, Ca/Zn and Zn/Mg; N/P, N/K, N/Ca, N/Mg, Zn/N, P/K, Ca/P, Mg/P, Zn/P, Ca/K, K/Mg, Zn/K, Ca/Mg, Zn/Ca and Zn/Mg respectively for Djakotomey, Klouékanmey and Zakpota. Nitrogen, K, P and Mg were often present in the binary ratios found for suitable soybean nutritional balance.

Table 4. Mean values of nutrient paired ratios for high and low-yielding sub-populations together with their respective coefficients of variance (CV) and variances (low and high), skewness values for the high-yielding sub-population, and the variance ratios (Vlow/Vhigh) in Djakotomey

Nutrients ratios	Low yielding sub population [n=36]					High yielding sub population [n=15]					Ratio VAR	Ratio selected
	Means	VAR	CV	Min	Max	Means	VAR	CV	Min	Max		
N/P	4.5	2.0	31.3	2.7	8.8	4.7	1.2	22.8	2.8	6.5	1.7	x
P/N	0.2	0.0	26.6	0.1	0.4	0.2	0.0	24.2	0.2	0.4	1.4	
N/K	1.4	0.1	24.5	0.9	2.9	1.5	0.1	18.2	1.1	2.1	1.6	x
K/N	0.7	0.0	20.4	0.3	1.1	0.7	0.0	18.3	0.5	0.9	1.4	
N/Ca	2.5	0.6	29.3	1.0	3.9	2.6	0.8	33.7	1.1	4.1	0.7	
Ca/N	0.4	0.0	38.0	0.3	1.0	0.4	0.0	42.2	0.2	0.9	0.8	x
N/Mg	4.2	1.4	28.4	1.3	5.8	4.3	2.4	35.4	1.0	6.5	0.6	x
Mg/N	0.3	0.0	47.5	0.2	0.8	0.3	0.0	74.0	0.2	1.0	0.4	
N/Zn	72.7	562.3	32.6	29.7	115.6	81.0	1008.5	39.2	28.0	123.8	0.6	x
Zn/N	0.0	0.0	37.7	0.0	0.0	0.0	0.0	55.2	0.0	0.0	0.5	
P/K	0.3	0.0	13.8	0.2	0.4	0.3	0.0	16.3	0.2	0.4	0.7	
K/P	3.1	0.3	16.5	2.5	4.8	3.1	0.3	18.1	2.5	4.5	0.8	x
P/Ca	0.6	0.1	38.8	0.2	1.1	0.6	0.0	34.1	0.2	0.9	1.5	x
Ca/P	1.9	0.7	42.6	1.0	4.1	2.0	0.7	43.1	1.1	4.2	0.9	
P/Mg	1.0	0.1	34.2	0.3	1.5	0.9	0.1	36.3	0.2	1.5	1.0	x
Mg/P	1.2	0.3	47.3	0.7	3.1	1.3	0.9	72.6	0.7	4.5	0.3	
P/Zn	17.1	44.7	39.2	6.2	33.5	17.4	47.8	39.7	6.8	28.9	0.9	x
Zn/P	0.1	0.0	42.4	0.0	0.2	0.1	0.0	48.3	0.0	0.1	0.8	
K/Ca	1.8	0.4	33.2	0.8	3.0	1.8	0.3	30.7	0.7	2.7	1.3	x
Ca/K	0.6	0.1	40.1	0.3	1.3	0.7	0.1	46.4	0.4	1.5	0.7	
K/Mg	3.0	0.8	29.8	0.9	4.3	2.9	1.0	34.9	0.6	3.9	0.8	x
Mg/K	0.4	0.0	52.0	0.2	1.1	0.4	0.1	80.8	0.3	1.6	0.3	
K/Zn	51.5	276.3	32.3	21.2	91.6	54.1	444.2	39.0	18.5	82.6	0.6	x
Zn/K	0.0	0.0	37.9	0.0	0.0	0.0	0.0	53.8	0.0	0.1	0.5	
Ca/Mg	1.7	0.1	18.6	0.9	2.6	1.6	0.1	16.5	0.9	2.1	1.4	x
Mg/Ca	0.6	0.0	20.0	0.4	1.1	0.6	0.0	21.8	0.5	1.1	0.8	
Ca/Zn	31.3	196.1	44.7	10.5	60.2	36.3	692.0	72.5	12.4	116.6	0.3	
Zn/Ca	0.0	0.0	47.4	0.0	0.1	0.0	0.0	58.8	0.0	0.1	0.6	x
Mg/Zn	19.3	118.5	56.4	7.1	64.6	25.2	832.3	114.6	7.8	124.9	0.1	
Zn/Mg	0.1	0.0	44.2	0.0	0.1	0.1	0.0	55.2	0.0	0.1	0.6	x

Table 5. Mean values of nutrient paired ratios for high and low-yielding sub-populations together with their respective coefficients of variance (CV) and variances (low and high), skewness values for the high-yielding sub-population, and the variance ratios (Vlow/Vhigh) in Klouékanmey

Nutrients ratios	Low yielding sub population [n=40]					High yielding sub population [n=16]					Ratio VAR	Ratio selected
	Means	VAR	CV	Min	Max	Means	VAR	CV	Min	Max		
N/P	4.1	1.6	30.3	1.4	6.8	4.0	1.6	32.2	1.7	5.6	1.0	X
P/N	0.3	0.0	43.4	0.1	0.7	0.3	0.0	44.0	0.2	0.6	0.9	
N/K	2.3	0.5	30.8	0.9	3.6	2.3	0.4	26.4	1.4	3.7	1.3	
K/N	0.5	0.0	37.2	0.3	1.1	0.5	0.0	25.6	0.3	0.7	2.4	X
N/Ca	2.5	0.6	29.8	0.7	3.8	2.6	0.4	25.2	1.8	4.3	1.3	
Ca/N	0.5	0.1	52.1	0.3	1.5	0.4	0.0	21.4	0.2	0.5	7.5	X
N/Mg	2.6	0.5	26.3	1.1	3.8	2.5	0.7	32.9	1.4	3.9	0.7	
Mg/N	0.4	0.0	33.8	0.3	0.9	0.4	0.0	30.4	0.3	0.7	1.1	X
N/Zn	48.7	191.0	28.4	26.1	83.0	49.1	131.0	23.3	36.1	74.7	1.5	
Zn/N	0.0	0.0	27.9	0.0	0.0	0.0	0.0	20.8	0.0	0.0	1.9	X
P/K	0.6	0.0	28.4	0.3	1.2	0.6	0.0	25.7	0.4	0.9	1.0	
K/P	1.9	0.2	25.3	0.8	3.5	1.7	0.2	24.5	1.2	2.5	1.3	X
P/Ca	0.6	0.0	33.2	0.2	1.1	0.7	0.1	44.3	0.4	1.6	0.4	
Ca/P	1.7	0.5	41.2	0.9	4.8	1.6	0.3	32.0	0.6	2.3	2.0	X
P/Mg	0.7	0.0	31.9	0.4	1.3	0.7	0.1	36.4	0.4	1.3	0.8	
Mg/P	1.6	0.2	30.5	0.8	2.8	1.7	0.3	31.8	0.8	2.4	0.9	X
P/Zn	13.0	31.0	42.9	5.8	31.5	14.4	63.8	55.4	6.5	35.1	0.5	
Zn/P	0.1	0.0	35.8	0.0	0.2	0.1	0.0	40.6	0.0	0.2	0.9	X
K/Ca	1.2	0.1	29.1	0.6	2.0	1.2	0.1	27.4	0.7	1.9	1.1	X
Ca/K	0.9	0.1	26.5	0.5	1.7	0.9	0.1	27.5	0.5	1.4	0.9	
K/Mg	1.2	0.1	29.9	0.6	2.1	1.1	0.1	32.9	0.7	1.9	1.0	X
Mg/K	0.9	0.1	31.1	0.5	1.7	1.0	0.1	29.0	0.5	1.4	0.9	
K/Zn	23.2	68.4	35.6	12.4	49.1	22.7	61.7	34.6	11.9	40.4	1.1	X
Zn/K	0.0	0.0	33.0	0.0	0.1	0.0	0.0	33.9	0.0	0.1	0.9	
Ca/Mg	1.1	0.1	28.0	0.7	2.3	0.9	0.0	16.5	0.7	1.3	3.9	X
Mg/Ca	1.0	0.0	20.7	0.4	1.3	1.1	0.0	15.5	0.8	1.4	1.4	
Ca/Zn	20.8	61.7	37.8	10.0	49.7	19.5	22.9	24.6	12.6	30.8	2.7	X
Zn/Ca	0.1	0.0	31.1	0.0	0.1	0.1	0.0	22.3	0.0	0.1	1.9	
Mg/Zn	19.5	38.8	32.0	10.9	37.4	21.5	55.7	34.7	11.4	39.5	0.7	
Zn/Mg	0.1	0.0	30.1	0.0	0.1	0.1	0.0	35.0	0.0	0.1	0.9	X

Table 6. Mean values of nutrient paired ratios for high and low-yielding sub-populations together with their respective coefficients of variance (CV) and variances (low and high), skewness values for the high-yielding sub-population, and the variance ratios (Vlow/Vhigh) in Zakpota

Nutrients ratios	Low yielding sub population [n=36]					High yielding sub population [n=15]					Ratio VAR	Ratio selected
	Means	VAR	CV	Min	Max	Means	VAR	CV	Min	Max		
N/P	4.0	0.8	23.3	2.6	7.9	4.0	1.1	26.5	2.6	5.7	0.7	X
P/N	0.3	0.0	19.3	0.1	0.4	0.3	0.0	26.7	0.2	0.4	0.5	
N/K	1.8	0.6	42.7	0.9	4.5	1.7	0.3	32.6	1.0	2.9	1.8	X
K/N	0.6	0.0	29.4	0.2	1.1	0.6	0.0	31.0	0.4	1.0	0.9	
N/Ca	3.9	0.6	20.3	2.4	5.7	4.1	1.3	27.9	2.1	5.6	0.5	X
Ca/N	0.3	0.0	21.5	0.2	0.4	0.3	0.0	33.0	0.2	0.5	0.4	
N/Mg	5.2	1.8	25.7	2.9	7.4	4.9	1.8	27.3	3.0	6.8	1.0	X
Mg/N	0.2	0.0	28.5	0.1	0.3	0.2	0.0	29.0	0.1	0.3	0.8	
N/Zn	63.0	244.9	24.8	26.0	102.8	63.1	163.9	20.3	42.3	85.7	1.5	
Zn/N	0.0	0.0	31.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	2.5	X
P/K	0.5	0.0	41.0	0.2	1.0	0.5	0.0	42.8	0.3	0.9	0.9	X
K/P	2.5	0.7	33.3	1.0	4.4	2.5	0.8	35.4	1.2	3.8	0.9	
P/Ca	1.0	0.1	24.0	0.5	1.8	1.1	0.1	35.8	0.6	2.1	0.4	
Ca/P	1.0	0.1	25.0	0.6	1.9	1.0	0.1	29.0	0.5	1.6	0.8	X
P/Mg	1.3	0.1	25.4	0.7	1.9	1.3	0.2	33.2	0.9	2.6	0.7	
Mg/P	0.8	0.1	29.3	0.5	1.5	0.8	0.0	22.6	0.4	1.1	1.5	X
P/Zn	16.3	15.2	23.9	7.5	25.2	17.0	36.6	35.7	7.9	29.6	0.4	
Zn/P	0.1	0.0	30.6	0.0	0.1	0.1	0.0	37.8	0.0	0.1	0.6	X
K/Ca	2.4	0.6	31.0	1.0	4.7	2.6	0.9	36.2	1.1	4.5	0.7	
Ca/K	0.5	0.0	39.2	0.2	1.0	0.4	0.0	40.3	0.2	0.9	1.0	X
K/Mg	3.2	0.8	28.6	1.6	5.3	3.1	1.2	36.1	1.2	5.7	0.7	X
Mg/K	0.3	0.0	31.9	0.2	0.6	0.4	0.0	45.0	0.2	0.9	0.4	
K/Zn	40.5	275.5	41.0	9.1	81.2	39.8	175.9	33.4	23.2	65.9	1.6	
Zn/K	0.0	0.0	57.7	0.0	0.1	0.0	0.0	32.9	0.0	0.0	3.8	X
Ca/Mg	1.3	0.1	18.8	0.8	2.1	1.2	0.0	14.2	0.9	1.5	2.1	X
Mg/Ca	0.8	0.0	18.9	0.5	1.2	0.8	0.0	14.7	0.7	1.1	1.4	
Ca/Zn	16.6	22.7	28.7	7.5	30.3	16.8	40.1	37.7	9.0	33.3	0.6	
Zn/Ca	0.1	0.0	31.2	0.0	0.1	0.1	0.0	35.2	0.0	0.1	0.8	X
Mg/Zn	12.8	16.0	31.4	5.0	25.7	13.8	21.2	33.3	7.3	22.5	0.8	
Zn/Mg	0.1	0.0	34.0	0.0	0.2	0.1	0.0	33.8	0.0	0.1	1.2	X

3.3 Nutritional status of cassava plants in farmers' fields

DRIS indices calculated for each nutrient are presented in Figure 2 to Figure 4 for framers fields in Djakotomey, Kloukanmey and Zakpota respectively. These nutrient indices were calculated regarding the mean values of nutrient ratio expressions taken as the reference values for each municipally (Table 4 to Table 6). These indices ranged from negative to positive values depending whether to nutrients level (relatively deficient or excessive). Nutrient requirement for cassava production was ranked as K >N > P > Zn > Ca >Mg ; K>Ca > Zn > Mg > N > P and Zn>N > Ca> K > Mg > P for farmers' fields in Djakotomey, Kloukanmey and Zakpota respectively. These results showed also that K, N and Ca were the most limiting nutrient, while N and P could limit cassava production in the study area especially in Djakotomey. The nutritional balances index (NBI) calculated for each farmer's field were 27.3 (Djakotomey), 12.9 (Klouekanmey) and 11.4 (Zakpota). In the cassava cropping system at Djakotomey (Figure 2), K is deficient in the soil and limit cassava yield while P and N are probably deficient. Zn and Ca are sufficient and Mg is in excess. Figure 3 showed that K is deficient in the soil and limit cassava yield in cassava cropping system of Klouekanmey while Ca, Zn, Mg and N and Ca are sufficient and P is in excess. Figure 4 showed that Zn and N are deficient in the soil and limit cassava yield in cassava cropping system of Zakpota while K, Mg and Ca are sufficient and P is in excess.

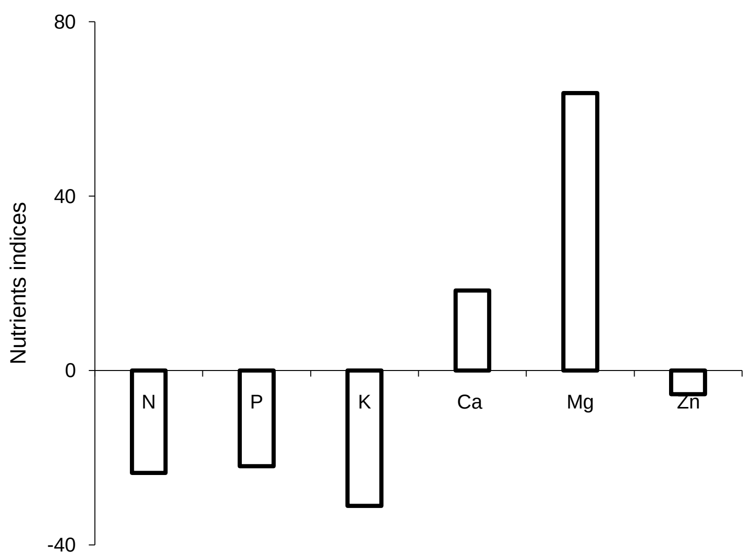

Fig. 2. Nutrients indices for cassava leaves in farmers' fields of Djakotomey

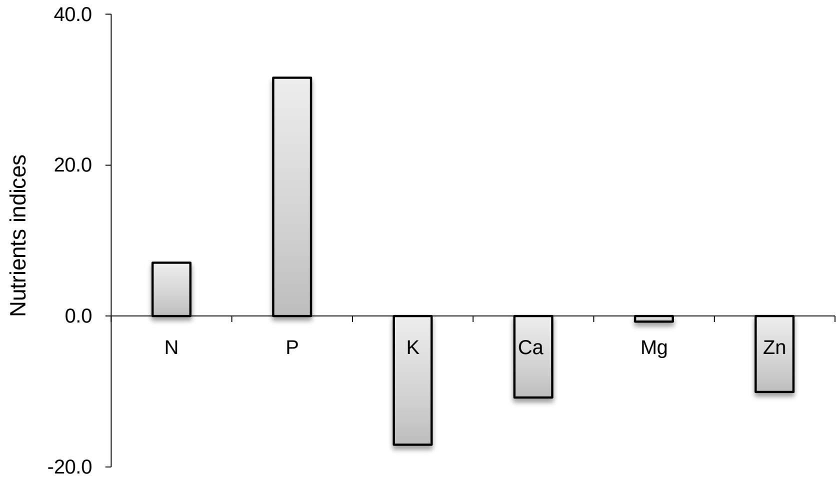

Fig. 3. Nutrients indices for cassava leaves in farmers' fields of Klouékanmey

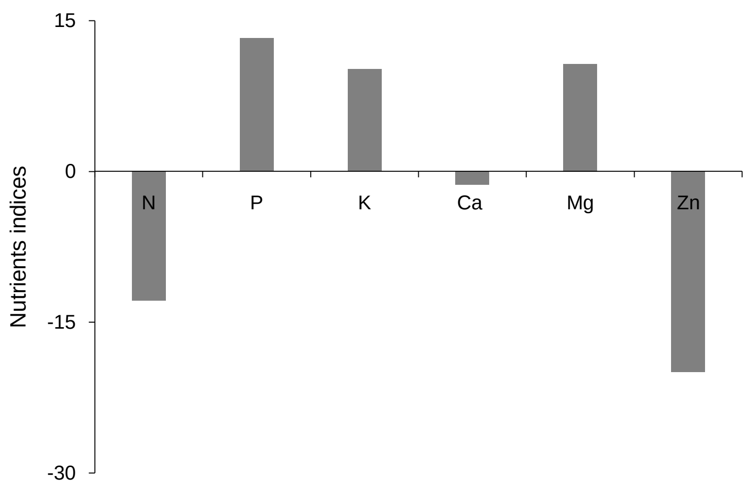

Fig. 4. Nutrients indices for cassava leaves in farmers' fields of Zakpota

4. DISCUSSION

Means and variance of selected nutrient ratios from the sub-populations are different. According to [35], these differences in the nutritional status of high and low yielding sub-populations are indicative of reliability of the DRIS norms developed in the study area. The leaves' nutrient concentration in the high yielding sub-population could had relatively symmetrical distribution. This leads them to provide realistic approximation of the probable interactive influence range of different nutrients on crop productivity [36, 37]. The results showed that in most of the fields surveyed, P and Zn were in excess, while K and N were deficient in the cassava sub-systems surveyed. These excesses of P in soils under cassava cropping systems can be explained by mycrohyzial symbiosis of cassava plants [38]. These symbioses have the advantage of improving the availability of assimilable P to cassava plants [38]. The adequate mineral nutrition of cassava plants requires an in-depth regard in order not to lose both nutrients, especially since the fertilization practices of cassava cropping systems are characterized by a low or no fertilizer use, which could contribute to this nutritional imbalance. The importance of macronutrients for a crop production is largely acknowledged [39, 26, 40]. DRIS norms established indicated that the proper relationship between K and Zn (Zn/K) in cassava leaf to obtain high yield must vary from 2.8 to 3.8 and for the Mg/K ratio must vary from 2.1 to 2.8 and N/K must vary to 1.6 to 1.8 other nutrients such as N, P were required in cassava cultivation. Therefore, the average N/K, Zn/K and Mg/K nutritional relationship would be considered very important in cassava nutritional evaluations. Unfortunately, in cassava cropping systems, fertilizers are not used. Although the importance of K fertilization in cassava cultivation has been reported, the results of this study revealed that other leaves nutrients levels such as N and Mg were more important than K in establishing nutrient balance. These nutrients would only be available to the cassava crop through fertilization or soil content. However, in many places in Sub-Saharan Africa, soils are severely deficient in nutrients, including N, P, K and Ca [41]. These nutrient deficiencies could explain the low yields of cassava observed in farmer's fields. DRIS index averages showed that on the municipality scale, K, N, Mg and Ca were the nutrients deficient in many locations, which suggests fertilization with such nutrients. The main challenge in soil fertility management is to stabilize the required amount of nutrients according to soil type, crop needs and environment. Consequently, the recommendations made on the leaves samples taken in the grid sampling system cannot be generalized to the whole area.

4. CONCLUSION

The DRIS norms established in the current study embraces the six nutrients (N, P, K, Ca, Mg and Zn) analyses in the cassava leaves. Nutrient requirement for cassava production was ranked as Mg >Ca > N > K > P > Zn, K>Ca > Zn > Mg > N > P and Zn>N > Ca> K > Mg > P for the farmers' fields in Djakotomey, Klouékanmey and Zakpota respectively. Negative indices were obtained with K and Ca and the results in this work indicated that K was deficient and limit cassava yield in most of farmers' fields. Moreover, P and Zn were in excess in the soil, and adequate mineral nutrition of cassava plants is required to avoid any nutrient loss. It is suggested that these nutrients together with Mg be included in the fertilizer recommendation for sustainable and environmentally-friendly cassava cultivation.

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