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Soil Properties and Nutrient Uptake of Coffee Seedlings as Influenced by NPK Fertilizer Formulations in Ibadan, Southwest, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OSI designed the study, wrote the protocol and wrote the first draft of the manuscript. Author OSOA managed the literature searches, analyses of data and managed the experimental process. Both authors read and approved the final manuscript.

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ABSTRACT

A greenhouse study was carried out at Cocoa Research Institute of Nigeria, Ibadan (Lat.7° 25^{1}N Long. 3° 25^{1}E) in 2010 to determine the effect of NPK fertilizer formulations on soil properties and nutrient uptake of coffee seedlings in Ibadan, Southwest Nigeria. The treatments consisted of NPK-liquid fertilizer (20: 2: 4 + TE-trace elements) applied at rates 0.33 and 0.66 mls/litre of water and NPK- solid fertilizer (15:15:15) applied at 1, 3 and 5 g/coffee seedling) and a control (no fertilizer application). The six treatments were arranged in a completely randomized design with three replications and data on coffee nutrient uptake and soil properties at six months after transplanting were determined. Results revealed that all the fertilizers irrespective of rates of application and types of NPK formulations enhanced the nutrient uptake of coffee seedlings relative to control. Leaf N-uptake was significantly (P=0.05) enhanced due to application of NPK liquid fertilizer applied at 0.33 mls/l of water compared to the control and NPK liquid fertilizer applied at 0.66 mls/l of water. Similarly, the leaf-P uptake was improved significantly (P=0.05) as a result of application

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of NPK solid applied at 5 g/coffee seedling compared to the control and other treatments. The leaf K-uptake also followed a similarly trend in which solid NPK fertilizer at 5 g/plant consistently promoted (P=0.05) the K-uptake of coffee seedlings compared to liquid NPK applied at 0.66 mls/litre of water. The pH of the soil was significantly (P=0.05) affected as a result of application of liquid NPK fertilizer at 0.33 mls and 0.66 mls/l of water compared to NPK solid fertilizer. The organic carbon was not significantly (P=0.05) influenced as a result of NPK fertilizer formulations. The organic carbon decreased in the order of 1g NPK solid< 3g NPK solid<control< 0.33 mls NPK liquid< 0.66 mls NPK liquid. The total N in the soil was not significantly affected as a result of NPK fertilizer types applied. However, the available P in the soil was significantly (P=0.05) increased as a result of NPK-solid applied at 3 and 5 g/plant compared to the control, at 0.33 and 0.66 mls/l of water. The improved growth and nutrient uptake of coffee seedlings through the use of NPK fertilizer formulations particularly liquid NPK provides alternative fertilizer options to farmers as a means of promoting crop growth.

Keywords: NPK fertilizer; coffee seedlings; dry matter; nutrient uptake.

1. INTRODUCTION

Coffee is an important export crop traded globally and is a major foreign exchange earner for many African and South American countries [1,2]. In Nigeria, Robusta coffee (*Coffea canephora* Pierrie ex. Froehner) constitutes up to 96%, while Arabica (*Coffea arabica* Linus) is less than 4% of total national production [3,4]. Coffee was important for the Nigerian economy and for the livelihoods of its many farmers between 1960s and the 1980s. At present, the Nigerian coffee attracts low prices as a result of lack of internationally accepted primary processing method. In addition, production further declined due to old age of plantations, poor yield resulting from poor planting materials, pests and disease attack etc. The market situation became worse for farmers in 1985 after the abolition of the Nigerian Commodity Board. The resultant effects were enormous which included, abject poverty in which Nigerian coffee farmers live in owing to poor farm gate price of the commodity, farm abandonment among others [3,4]. The lack of government attention for coffee farmers on training, rehabilitation and distribution of improved materials make the present scenario worst. In addition, policy support such as compelling Nestle Nigeria Limited to buy Nigerian coffee and build model wet processing in major coffee growing areas are lacking [4,5]. Currently, the coffee market is improving therefore in order to take advantage of this positive trend, there is need to assist the coffee farmers to increase yield through efficient production methods particularly the use of inorganic fertilizers such as NPK fertilizers to boost coffee production. Fertilizers are applied to soils in order to maintain or improve yields [6]. Most soils upon which coffee is grown are generally poor in nutrients such as nitrogen, phosphorus and potassium [7]. In Nigeria, different NPK formulations (liquid and solid) are found in the markets and they are being utilized by farmers for both arable and some tree crops production. Liquid fertilizers are mostly foliar fertilizers that contain high purity NPK and trace elements. One of the most important challenges facing farmers is to provide crops with the optimal quantity of nutrients in the most cost-efficient manner possible that will guarantee high yield and quality crop production [8]. This challenge could effectively be tackled when soluble fertilizers are delivered to crops through foliar spray feeding system and thus ensures plant nutrients such as nitrogen, phosphorous, potash and micronutrients are directed to the plant through foliage in well balanced proportion [9]. Foliar spray is a well-established tool to supplement and to enrich plant nutrition. Countries like China, Vietnam and Indonesia have found liquid fertilizers very helpful in increasing crop productivity particularly tree crops [10]. Nitrogen is an important structural component of many compounds necessary for plant growth and development [11]. It is also necessary for carbohydrate utilization, growth and development. Phosphorus is a key element in the establishment of new plantations. However, in tropical countries where coffee is cultivated, phosphorus is often the limiting nutrient. In fact, coffee soils contain abundant phosphorus, but most of it fixed and unavailable to the plants. Sound management of soil and other resources plays key role in productivity. Phosphorus plays a significant role in cell division and root development [12]. Potassium is vital for cell division, formation and translocation of carbohydrates, activator of several enzymatic systems, and regulation of osmosis or control of water in the plant and enhances the resistance of some plants to certain diseases and insects attack. Hence, this study determined the effect of NPK fertilizer formulations on soil properties and nutrient uptake of coffee seedlings in Ibadan, Southwest Nigeria.

2. MATERIALS AND METHODS

The study was carried out at Cocoa Research Institute of Nigeria, Ibadan (Lat.7° 25 ^{1}N, Long. 3° 25^{1}E) in 2010 to evaluate the effect of NPK fertilizer formulations on the nutrient uptake of coffee seedlings in Ibadan, Southwestern Nigeria. The soil of Ibadan used for the study has been classified as Ferric Luvisols (13)) and Ibadan series Smyth and Montgomery (14) at 122 m above sea level. Top soil (0-30 cm depth) was collected within the coffee plantations at Ibadan and was air-dried and sieved using 2mm sieve. The sieved soil was mixed with river-bed sand at 50:50 ratio and placed in five kilogrammes plastic buckets. The set-up was watered and allowed to equilibrate at field capacity for 48 hours. The treatments consisted of NPK-liquid fertilizer (20: 2: 4 + TE) applied at a rate of 0.33 and 0.66 mls/litre of water and NPK-solid fertilizer (15:15:15) applied at 1, 3 and 5g/coffee seedling and a control (no fertilizer application). The treatments were applied to two months old-coffee seedlings (two-leaf stage) in the greenhouse. The coffee seedlings that received NPK liquid fertilizer treatments were sprayed with the fertilizer dissolved in water using hand sprayer until the seedlings were drenched while the solid NPK fertilizer was applied in a ring form at 2 cm away from the base of each seedling. The six treatments were replicated three times in a completely randomized design (CRD) and data on growth of coffee were taken for six months. Watering was done regularly thrice a week. At the end of the experiment, destructive sampling was done and plant materials were separated into leaf, stem and roots and soil samples collected from each bucket for chemical analysis. The fresh plant samples were oven-dried at 72℃ to a constant weight for the dry matter yield to be obtained.

2.1 Phosphorus Determination in Plant Samples

The oven-dried samples were milled in an electric mill and nutrient analysis carried out for major nutrients in the leaves, stems and roots. Milled plant sample (0.55 g) was digested using tecator digestion system in a 70 ml Pyrex digestion tube. Five millilitres of $HNO_3.HCO_3$ reagent (2:1 v/v) were added into each tube under a fume chamber and allowed to stand overnight at room temperature. The tubes were then transferred into aluminium digestion block inside the fume chamber at a temperature of 150℃. The digestion was allowed for one and a half hours and the tubes removed, allowed to cool and 30 ml of distilled water was added into each tube. Stirring was done with vortex mixer and the content of each tube made up to 75 ml mark with distilled water. Phosphorus concentration was measured colorimetrically using vanado-molybdate method with a Jennway model colorimeter at 882 µm wavelength.

2.2 Total N Determination in Plant Samples

Total N determination was carried out by weighing 0.24 g of milled plant samples into 75 ml digestion tubes, 3.0 ml conc. H_2SO_4 and 2.0 ml of H_2O_2 were added. The mixture was allowed to stand till the reaction ceased. The reaction tubes were placed on pre-heated digestion block at 370℃ for 20 minutes with full end plates. After cooling, 20 ml distilled water was added to make up to 70 ml mark. Thorough shaking was done by inverting the digestion tube end-to-end. Total N (NH_4-N) was determined colorimetrically using the Technicon Autoanalyser II (15).

2.3 K Determination in Plant Samples

Finely ground plant samples (0.55 g of leaf, stem and root) were placed in 30-ml porcelain crucible. The samples were ignited for 7 hours at a temperature of 450℃ and not exceeding 500 ^{o}C. Greyish-white ashes were cooled on top of asbestos sheet and 5 ml of 1 N HNO_3 solution was added. This was evaporated to dryness on a steam bath and returned to the furnace and heated at 400℃ for 10 minutes until a perfectly white ash was obtained. Ten millimetres 1 N HCl three times and made up to volume with 0.1 N HCl solutions. The K-content of the sample was read on a Jennway (PFP7 model) at 766 µm wavelength.

2.4 Nutrient Uptake of Coffee Seedlings

The nutrient uptake was calculated as the product of the nutrient concentration and dry matter yield: Uptake = Nutrient conc. X dry matter yield [16].

2.5 Soil Analysis before Planting

Samples of the soil used for the raising of coffee seedlings was taken from the top soil (0-30 cm), air-dried and sieved for routine soil analysis. The particle size analysis was done using the hydrometer method [17]. The soil pH (1:1 soil/water) was determined using a glass/ calomel electrode system [18]. The organic matter was determined by the [19]. The soil K, Ca and Mg were extracted with IM NH4OAC, pH 7 and their amounts determined on the flame photometer using appropriate element filters. The Mg content was read on an atomic absorption spectrophotometer [20]. The exchangeable acidity (H+ and Al3+) was measured from 0.01 M KCl extracts by titrating with 0.1M HCl (20). Percent N was determined using the microKjeldahl method [18]. Available P was extracted using Bray P1 extractant and the extract was measured with the Murphy-Riley blue method [18] on a spectronic 20 instrument at 882 mm.

2.6 Soil Analysis after the Experiment

At the end of the study, soil samples were taken from each plastic bucket, air-dried, sieved and analysed for nutrient contents as described earlier.

2.7 Statistical Analysis

Analysis of variance was performed on all data to test the treatment effect on different parameters measured using a GenStat 8^{th} Edition. Least Significant difference (P=0.05) was used to separate the means.

3. RESULTS AND DISCUSSION

The physical properties of the soil indicated that the sand, silt and clay fractions were respectively 892, 143 and 165 g/kg soil (Table 1). The soil is a sandy loam. The clay+ silt content of 308 g/kg soil were sufficient to hold enough water for sustainable coffee plant growth and to guard against short duration drought according to Egbe et al. [21] as cited by Ipinmoroti et al. [22]. The pH, organic carbon, total N and available P were 6.5, 9.8 g/kg, 2.0 g/kg and 8.0 mg/kg soil respectively. The exchangeable cations (K^+, Ca^{2+} and Mg^{2+}) of the soil were 0.5, 10 and 2 cmol/kg soil. The pH of the soil was adequate for coffee production. The soil is marginal in terms of nutrient compositions particularly N, P and K [23, 24]. The NPK liquid fertilizer contained 20%, 2% and 4% for N, P, and K with some trace elements (TE) respectively while the solid NPK fertilizer had 15% N, 15% P and 15% K (Table 2). NPK fertilizer formulations had positive influence on the nutrient uptake of coffee seedlings. The leaf N-uptake was significantly (P=0.05) enhanced due to application of NPK liquid fertilizer applied at 0.33mls/l of water compared to the control and NPK liquid fertilizer applied at 0.66mls/l of water (Table 3). This could be as a result of its quick absorption through the leaves unlike when it is applied through the soil. This is in agreement with the views of Haggai and Aliyu [8] and Chittu et al. [9] while analyzing effects of liquid and conventional NPK fertilizers on the growth and yield of maize and Apple respectively. They found that uptake of nutrients through foliage is considerably faster than through roots and foliar spray is preferable when prompt correction of nutrient deficiencies is required [8,9]. However, application of NPK liquid fertilizer at 0.66 mls/l of water seemed to depress the nutrient uptake of coffee compared to the control. Although the manufacturer's recommendation was 0.66 mls/l of water for adult plants in the field particularly for cocoa and other fruit trees, this recommendation might be excessive for seedlings which caused the depression in the nutrient uptake of coffee seedlings. The decrease in nutrient uptake might be due to the fact that some of the soil applied nutrients were immobilized by soil micro-fauna, soil organic matter and other edaphic factors thereby making them unavailable to the seedlings. This observation is similar to the work earlier reported by Ibiremo et.al. [25] in which the drymatter yield of coffee seedlings decreased due to high dosage of NPK fertilizer and the earlier findings of Ibiremo et al. [26] in which NPK fertilizer imposed depression on the growth of cocoa in the field.

However, the leaf-P uptake was improved significantly (P=0.05) as a result of application of NPK solid applied at 5 g/stand of coffee seedling compared to the control and other treatments. The leaf-K uptake also followed a similarly trend in which solid NPK fertilizer at 5g/plant consistently promoted (P=0.05) the K-uptake of coffee seedlings compared to liquid NPK applied at 0.66 mls/l of water. The stem and root N-uptake was significantly (P=0.05) affected due to application of liquid NPK fertilizer applied at 0.33 mls/l of water compared to the control and other treatments (Table 3). The superior performance of NPK liquid fertilizer on nutrient uptake of coffee seedlings could be attributable to the presence of some trace elements (TE) in it as claimed by the manufacturer. The P-uptake in the stem and the root of coffee seedlings was not significantly affected by NPK fertilizer formulations. The stem P-uptake ranged from 0.38 to 0.68 mg/plant in the control and 5 gNPK/plant respectively while root P-uptake ranged from 0.24 in the control to 0.46 mg/plant in NPK solid fertilizer applied at 5 g/plant. Similarly, the K-uptake of stem and root of coffee seedlings was not significantly influenced by the application of NPK fertilizers (Table 3). The stem K-uptake was in the order of 0.66 mls/litre of water NPK liquid fertilizer < control< 1gNPK solid < 3 gNPK solid < 0.33 mls/l of water NPK liquid < 5 g NPK solid. The trend in the root K-uptake was not different from the stem K-uptake. The effect of NPK liquid fertilizer applied at 0.33mls/l of water was comparable to NPK (15: 15: 15) nutrient uptake of coffee seedlings. The earlier reports by Yaduvanshi [27] and Adeniyan and Ojeniyi [28] both agreed that application of NPK fertilizer generally enhanced the nutrient uptake of N, P and K of crops.

Table 1. Physical and chemical characteristics of soil used

Soil properties	Unit	Value
Physical		
Sand	gkg^{-1}	748.00
Silt	"	113.00
Clay	"	138.08
Textural class		Sandy loam
Chemical		
$pH(H_2O)$ 1:1	-	6.08
Organic carbon	gkg^{-1}	3.50
Total nitrogen	"	0.60
C:N		7.25
Available phosphorus	$mgkg^{-1}$	9.60
Exch. Bases		
K^+	$cmolkg^{-1}$	0.12
Ca^{2+}	"	8.09
Mg^{2+}	"	0.91
Na^+	"	0.19
Exch. Acidity Mn^{2+}	$mgkg^{-1}$	0.13
Al^{3+}	"	0.13
H^+	"	0.04
Base saturation	%	96.00

NPK fertilizer formulations did not significantly affect the textural compositions of the soil (Table 4). This is in agreement with the views earlier expressed by Agbede [6] that textural compositions of soil could not be affected within a short period as a result inorganic fertilizer application. The mean values for sand, clay and silt compositions were 765, 139 and 96 g/kg soil respectively. However, the pH of the soil was significantly (P=0.05) affected as a result of application of liquid NPK fertilizer at 0.33 and 0.66 mls/l of water compared to NPK solid fertilizer. This could be attributable to crop removal which induces replacement anions with OH^- of Fe and Al. This observation is consistent with the view expressed by Law-Ogbomo and Osaigbovo [29]. The organic carbon was not significantly influenced as a result of NPK fertilizer formulations (Table 4). The organic carbon decreased in the order of 1 g NPK solid < 3 gNPK solid < control < 0.33 mls NPK liquid < 0.66 mls NPK liquid. The total N in the soil was not significantly affected as a result of NPK fertilizer types applied. The soil N in the control was 43% higher than the soil N in soil those that received NPK fertilizers. The available P in the soil was significantly (P=0.05) increased as a result of NPK-solid applied at 3 and 5 g/plant compared to the control and other treatments. The exchangeable K also followed similar trend in which NPK solid fertilizer applied at 3 and 5 g/plant increased the soil exchangeable K significantly. (P=0.05) compared to other treatments. This may be as a result direct application of solid NPK to the soil particularly when the K test value is not critically deficient as the case of this soil being used for this investigation. The increase in the total N, available P and exchangeable K values is consistent with the findings of Yaduvanshi [27]. The soil C:N ratio was also significantly (P=0.05) affected by the application of NPK liquid fertilizer at 0.66 mls/l of water compared to the control and the NPK solid fertilizer (Table 4).

Table 2. Chemical composition of fertilizer materials used for the study

Fertilizer materials	Chemical composition (%)			
	N	**P**	**K**	**Ca**
NPK(Liquid) + TE	20	2	4	-
NPK(Solid)	15	15	15	-

TE- Trace elements

Source: Brochure of Sidalco Ghana Limited

Table 3. Nutrient Uptake of coffee seedlings as influenced by NPK fertilizer formulations in Ibadan, Southwestern Nigeria

Treatment	Leaf nutrient uptake (mgplant^{-1})			Stem nutrient uptake (mgplant^{-1})			Root nutrient uptake (mgplant^{-1})		
	N	P	K	N	P	K	N	P	K
Control	90.80	1.28	209.70	26.43	0.38	51.45	17.17	0.24	40.12
0.33mls/l NPK- L	143.90	1.45	206.90	56.28	0.56	67.95	37.65	0.38	54.56
0.66mls/l NPK- L	87.10	1.59	185.80	26.24	0.47	46.65	16.91	0.31	36.08
1g NPK-S	123.60	1.79	235.20	34.97	0.50	55.45	23.68	0.34	45.32
3g NPK –S	106.50	1.71	288.80	27.46	0.43	62.10	16.34	0.26	44.08
5g NPK –S	123.90	2.43	319.40	35.93	0.68	75.50	24.00	0.46	64.24
LSD(0.05)	48.56	0.87	95.40	14.07	0.36	39.15	14.10	0.22	28.56
CV (%)	8.90	9.10	10.78	6.50	6.00	5.00	3.40	4.00	4.56

NPK-L (20-2-4+TE liquid fertilizer), NPK - S (NPK 15-15-15 solid fertilizer

Table 4. Soil physical and chemical properties as influenced by NPK fertilizer formulations in Ibadan, Southwestern Nigeria

Treatment	Soil physical properties			Soil chemical properties					
	Sand gkg^{-1}	Clay gkg^{-1}	Silt gkg^{-1}	pH	Org.C gkg^{-1}	Total N gkg^{-1}	Avail. P mgkg^{-1}	Exch. K cmolkg^{-1}	C:N
Control	748.00	139.20	112.80	6.08	0.35	0.06	9.60	0.12	7.25
0.33 mls/lNPK- L	768.00	139.20	92.80	6.23	0.37	0.04	8.60	0.09	9.00
0.66 mls/lNPK- L	768.00	139.20	92.80	6.20	0.46	0.03	9.30	0.10	15.88
1 g NPK- S	768.00	139.20	92.80	6.01	0.26	0.03	14.40	0.15	8.33
3 g NPK- S	768.00	139.20	92.80	5.79	0.32	0.04	21.70	0.18	11.30
5 g NPK- S	768.00	139.20	92.80	5.38	0.39	0.03	28.80	0.21	13.78
LSD(0.05)	ns	ns	ns	ns	ns	ns	12.62	ns	6.55
CV (%)	2.50	2.50	2.02	3.40	28.2	36.3	30.30	11.20	28.60

NPK-L (20-2-4+TE liquid fertilizer), NPK - S (NPK 15-15-15 solid fertilizer)

4. CONCLUSION

The improved nutrient uptake of coffee seedlings through the use of NPK fertilizer formulations particularly liquid NPK provides alternative fertilizer options to farmers as a means of promoting crop growth. Liquid NPK fertilizer could easily be applied in combination with other agro-chemicals such as fungicides and insecticides for enhanced efficiency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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