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Response of Selected Tall Hybrid *Coffea arabica* Varieties to N, P and K Nutrients in Tanzania

Suzana Mbwambo*, Godsteven Maro, Emmanuel Nkya

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

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Abstract The growth and yield response of some of TaCRI's improved tall *Coffea arabica* hybrids to applied N, P and K were assessed in this work; since, in addition to resistance to CBD and CLR, they are also high yielding (up to 3 t ha^{-1} against 1.5 t ha^{-1} of the traditional varieties) and assumed also to be highly nutrient demanding. A split plot RCBD was applied with three replications, five coffee varieties (N39-8, N39-9, N39-11, N39-12 and KP 423 old variety check) as main factors and 4 fertilizer rates (75, 112.5 and 150 g $tree^{-1}$, together with 37.5g + 10 kg of FYM) as sub factors. Each rate was applied three times per year except FYM which was applied once in two years. Data on canopy width, stem girth, number of bearing primaries, plant height, berry clusters and yields were collected and subjected to ANOVA using Statistica V7 software with means separated using Fisher LSD method at $\alpha = 0.05$. Variety KP 423 showed a significantly ($p<0.05$) wider canopy and more berry clusters than the test varieties. N39-8 excelled in number of branches, stem girth and tree height. It also gave higher yield (1894 kg clean coffee ha^{-1}) which was significantly different ($p<0.05$) from other varieties. Plant height, stem girth and yield response to the fertilizer options showed an asymptotic relationship with the turning point at 112.5 g $tree^{-1}$. Interaction between Variety N39-8 and 37.5g $tree^{-1}$ + FYM resulted into significantly higher yield (2436 Kg clean coffee ha^{-1}). It is tentatively concluded that the assumed high nutrient demand for the new varieties is unlikely, at least in the first four years. As such, 37.5g $tree^{-1}$ of NPK (20:10:10) applied three times per year + 10 kg of FYM per tree applied once in two years; or 75g of NPK (20:10:10) per tree if applied three times per year is enough for the test varieties under this age.

Keywords: *NPK nutrients, Farm Yard Manure (FYM), Coffea arabica, Tanzania*

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1. Introduction

Coffee is Tanzania's largest export crop. It contributes approximately $ 115 million to export earning, and provide employment to some 400,000 families. About 95% of coffee is grown by smallholders on average holdings of 1-2 hectares and 5% is grown on estate [1,2]. In the past years the Tanzanian coffee farmers used to grow traditional tall coffee varieties N39, KP162, KP 423 and H 66. These are susceptible to coffee berry disease (CBD) and coffee leaf rust (CLR) which are mainly managed chemically by use of fungicides. However, the use of inorganic fungicides is very expensive especially to smallholder resource-poor farmers and is also not environmentally friendly. To overcome this challenge, Tanzania Coffee Research Institute (TaCRI) developed and released 19 hybrid Arabica coffee varieties (15 tall and 4 compact) that are resistant to the two diseases and produce high yield of up to 3 t ha^{-1} against 1.5 t ha^{-1} of the traditional coffee varieties [3]. High plant growth and yield are function of better root and shoot systems with the former enhancing more nutrient and water uptake from the soil [4]. It is therefore assumed that, by virtue of being so high yielding, they will automatically demand more nutrients than the traditional varieties.

There are two sources of nutrients (inorganic and organic) that can be applied in coffee field. The use of inorganic fertilizers has been a significant contributor to increased crop productivity [5]. However, coffee in many parts of Africa is said to be "organic by default" not only due to the high cost and uncertain accessibility of inorganic fertilizers, but also due to a common assumption that coffee, as originally a forest crop [6], can survive naturally through organic nutrients from litter fall [7]. This can pose a challenge to the adoption of the improved varieties because, if the rule of thumb that "a bigger sink requires a bigger source" applies in this case, these high yielding varieties may not survive the strictly organic regime, and overbearing dieback will be a sure bet. The need for renewable, locally available and cheaper options for supplying nutrient to crops is increasingly becoming important because of the need for sustainable agriculture [8,9]. Therefore, the aim of this study was to assess the response of some of the new tall *Coffea arabica* varieties to inorganic nitrogen, phosphorus and potassium fertilizers, applied alone or in combination with organic matter.

2. Materials and Methods

2.1. Description of the Study Area

The field experiment was set up at TaCRI Lyamungu (Field 46), latitude 03º14.699'S; longitude 37º14.762'E with a mean altitude of 1268 m a.s.l. The climate is classified as tropical with bimodal rainfall pattern: short rains from October to December, and long rains from March to June. Average annual rainfall is about 1250 mm. The soil is classified as a Haplic Nitisol [10] with a pH ranging from 4.8 to 5.7.

2.2. Experimental Design

The experiment was established in December, 2012, following a split plot randomized complete block design with three replications. Five coffee varieties (N39-8, N39-9, N39-11, N39-12 as test varieties and KP 423 as an old variety check) constituted the main factor while 4 fertilizer rates (75, 112.5 and 150 g of NPK 20:10:10 per tree, and 37.5g of NPK + 10 kg of FYM) constituted the sub factor. Each rate was applied three times per year with exception of FYM which was applied once in two years. The experiment was run for four years up to June, 2017.

2.3. Data Collection

2.3.1. Growth Indicating Parameters

Growth characteristics were measured at the end of second and third year after planting. The plant height was measured from the base of the stem to the plant apex using graduated ruler. The diameter of the main stem was measured at full fruit bearing stage, 5 cm above the ground using Vernier Caliper [11,12]. The length of bearing primary branches was measured from the point of attachment to the main stem to the apex using graduated ruler as an average value of four longest bearing primaries per plant. Total number of bearing primary branches was estimated by counting the total number of bearing primaries per plant at full fruit bearing stage [13].

2.3.2. Yield and Yield Components

Number of berry clusters or fruiting nodes was determined as an average number of clusters per plant from four heavily bearing primaries at the middle of the canopy towards all four directions [14]. Yield was obtained by harvesting mature red cherries to get fresh weight per plot using gravimetric scale. Transformation of cherry weight to clean coffee weight was done using the conversion factor of 0.16 for Arabica coffee as recommended by [15].

2.4. Data Processing and Analysis

Data were subjected to ANOVA using Statistica V7 software and means were separated using Fisher LSD method at 0.05 significance level. The means were also descriptively and graphically compared.

3. Results and Discussion

3.1. Effects of Coffee Varieties on Growth Indicators

Table 1 shows the growth parameters per variety. It shows that KP-423 check resulted into significantly ($p<0.05$) higher length of bearing branches and higher number of berry cluster compared to N39-8, N39-9 and N39-11. On the other hand, N39-8 resulted into significantly ($p<0.05$) taller trees with higher number of bearing branches; while stem girth was strongest but not significantly so. The behavior of different varieties under different fertilizer regimes was so irregular that it was not possible to attribute the variation directly to genotype. There could be local environmental factors which were not part of the experiment such as soil depth, but this needs to be explored further.

Table 1. Effect of varieties on growth parameters

Variety	Growth parameters				
	Stem girth	Tree height	Branch number	Branch length	Berry clusters
KP423	3.64a	173.40ab	38.81b	168.23b	11.98c
N39-12	3.48a	178.75bc	42.18ab	166.33ab	10.92b
N39-11	3.42a	161.88a	42.82a	151.23a	9.81a
N39-9	3.63a	168.00ab	45.00ac	155.63a	10.92b
N39-8	3.67a	179.35c	47.02c	154.10a	9.81a

*Means with different letters in the same column differ significantly at $p \leq 0.05$ according to Fisher LSD

3.2. Effects of Fertilizer Options on Growth Indicators

Table 2 summarizes the mean response of all the varieties to the given fertilizer options. They showed no significant difference ($p>0.05$) in terms of number of berry clusters, the number and the length of bearing branches. In the first two, 37.5 g $tree^{-1}$ combined with 10 kg FYM $tree^{-1}$ excelled the list whereas it came out second in the length of bearing branches. Significant variation was noted with tree height and stem girth ($p<0.05$), again with the organic-inorganic combination excelling the list. However, there was an unexpected drop between 112.5 and 150 g $tree^{-1}$ which does not appear to have immediate explanation.

Table 2. Effect of fertilizer choice on growth parameters

Fertilizer (g/tree)	Growth parameters				
	Stem girth	Tree height	Branch number	Branch length	Berry clusters
75	3.52a	171.9b	41a	157.6a	11a
112.5	3.59b	173.3b	42a	160.7a	11a
150	3.53a	166.0a	43a	155.1a	11a
37.5+FYM	3.63b	177.8c	44a	158.0a	11a

*Means with different letters in the same column differ significantly at $p \leq 0.05$ according to Fisher LSD

3.3. Effects of Varieties x Fertilizer Interaction on Growth Indicators

As for the effect of variety-fertilizer interaction on growth parameters, highest number of berry clusters was recorded in KP 423 at 150g, 112.5g and combination, with respective figures of 12.67, 12.58 and 12.25; followed by N39-8 at 150g and combination (11.25 each). At the lower end, N39-11 performed poorly at almost all fertilizer options. The implication here is that the check variety (traditional) is more responsive than the hybrids in terms of berry clusters, which could be the results of longer bearing branches. A combination between inorganic and organic fertilizer resulted into higher number of bearing branches in N39-8 and 39-9 with respective figures of 48.0 and 51.67. This conforms to the standard minimum number of bearing branches in coffee production which is 30-35. Therefore all the varieties obtained the number of bearing branches that were above the standard. There was no significant difference ($p>0.05$) in the length of bearing branches between inorganic and a combination between organic and inorganic fertilizer. The highest canopy width was 177.75cm which was observed in N39-12 variety applied with 112.5g of N.P.K, followed by KP 423 variety when applied with various fertilizer options.

3.4. Effects of Coffee Varieties on Yield over 3 Years

Variety N39-8 resulted into significantly ($p<0.05$) higher yield from the second year to the third year as compared to other varieties (Figure 1). This could be associated with the higher number of bearing branches observed in the same. On the other hand, there was no significant difference ($p>0.05$) in yield during the first year among the four tested hybrids, though they all differed significantly from the non-hybrid check.

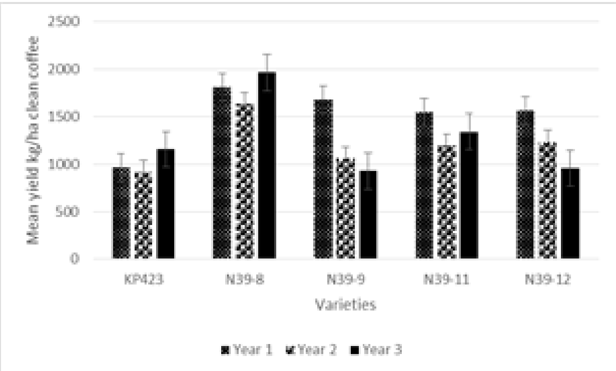

Figure 1. Mean yield kg ha^{-1} for three years.

3.5. Effects of Coffee Varieties on Average Yields

Variety N39-8 resulted into highest average yield (1894 kg clean coffee ha^{-1}) which was significantly different ($p<0.05$) from other test varieties. The other improved varieties were not significantly different in yield among themselves, but were significantly different from the check, which had the lowest average yield of 1014 kg ha^{-1} clean coffee.

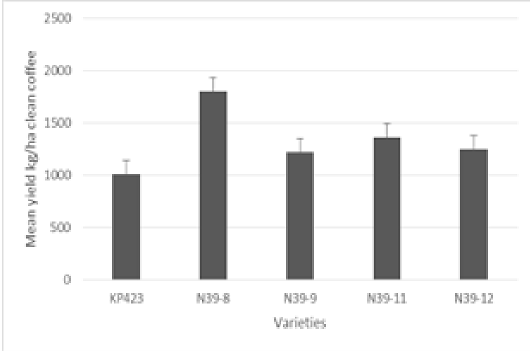

Figure 2. Average yield (Kg ha^{-1}) comparison by coffee varieties

3.6. Effects of Fertilizer Options on Average Yields

The average yield response to fertilizer options (Figure 3) reflected those of tree height and stem girth (Table 2). In this case the combination had the highest yield of 1696 kg ha^{-1}, followed by 112.5 g $tree^{-1}$ (1675 kg ha^{-1}). We note that the shift from 112.5 to 150.0 g $tree^{-1}$ resulted into shorter (173.3-166.0 cm) and more slender (3.59-3.53 cm) plants which yielded less (1675-1619 kg ha^{-1}). No concrete explanation can be made to this, and we suspect something to do with the nutrient response curve [16,17]. The curve is asymptotic with a definite turning point in areas of low natural soil fertility [16]. We assume therefore, in the study area, this turning point is 112.5 g $tree^{-1}$, hence the depression in both tree height, stem girth and yield at higher dosages.

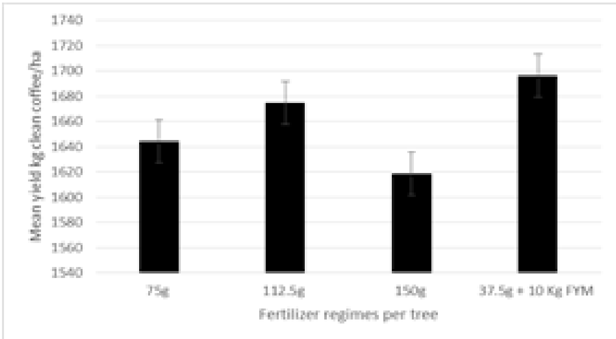

Figure 3. Average yield (Kg ha^{-1}) comparison by fertilizer options

3.7. Effects of Varieties x Fertilizer Interaction on Average Yields

The interaction between varieties and fertilizer (Table 3) resulted into significant ($p<0.05$) difference in yield among the five tested varieties. The highest yield (2436 kg clean coffee ha^{-1}) was obtained on N39-8 x 37.5g + 10 Kg of FYM, followed by KP 423 x 150 g (1951 kg ha^{-1}), N39-8 x 112.5 g (1894 kg ha^{-1}), N39-12 x 75 g (1863 kg ha^{-1}) and N39-9 x 37.5g + 10 Kg of FYM (1852 kg ha^{-1}). At the lower end we had N39-11 x 112.5 g (1358 kg ha^{-1}), KP 423 x 37.5g + 10 Kg of FYM (1351 kg ha^{-1}) and lastly N39-11 x 37.5g + 10 Kg of FYM (1308 kg ha^{-1}). As regards varieties, N39-8 has distinguished itself as the highest yielding variety, topping the list and appearing twice within the top five. KP 423 (old variety check) appears to do better at 150 g $tree^{-1}$, which puts into question the assumption that the new varieties are more nutrient-responsive than the old ones. The same variety featured in the bottom list as second-from-last, interacting with 37.5g + 10 Kg of FYM.

As regards the fertilizer options, 37.5g + 10 Kg of FYM has shown to be the most promising, topping the list and appearing twice within the top five. This underscores the potential benefits of using organic nutrient sources as part of coffee ISFM, in line with previous studies which identified cattle manure as one of the promising organic sources [18,19]. The standard dosage of 75 g tree^{-1} combined well with variety N39-12 (one of the new hybrids) to be the fourth in the list, implying that, in the study area, it can be used equally well for old and new varieties, and it could be regarded as the most cost-effective inorganic fertilizer rate, if one is not to approach the turning point. Organic and inorganic sources of nutrients are in complementary. Whereas organic matter improves physical, chemical and biological processes in the soil [17], its mineralization and nutrient release patterns may be manipulated through application of inorganic fertilizers [20]. The impact of this complementarity is higher yields, as noted by [21] for maize in Kenya.

Table 3. Effect of variety-fertilizer interaction on yield

Fertilizer (g/tree)	Variety				
	KP423	N39-12	N39-11	N39-9	N39-8
75	1681ae	1863de	1428ad	1433ad	1816be
112.5	1837cde	1678ae	1358abc	1607abc	1894de
150	1951e	1447ad	1721ae	1543ae	1432ad
37.5+FYM	1351ab	1534ae	1308a	1852de	2436f

*Means with different letters in the same column differ significantly at p≤0.05 according to Fisher LSD.

4. Conclusion and Recommendations

In this study, four new tall hybrid varieties (N39-8, N39-9, N39-11 and N39-12) with an old variety check (KP 423) were treated with 75, 112.5 and 150 g tree^{-1}, and also a combination of 37.5 g with 10 kg FYM and evaluated in terms of growth characteristics and yield. It can be tentatively concluded that 37.5g of NPK (20:10:10) applied 3 times per year in combination with 10 kg of FYM applied every after two years; or the check rate of 75g of NPK (20:10:10) if applied tree times per year will be sufficient for the four hybrids under the age of four years. This implies that, within the study situation, the high yielding new varieties are not necessarily highly nutrient responsive, as earlier assumed. The use of integrated soil fertility management is the most appropriate option in the study area given that it reduces costs of inorganic fertilizers to about 50% without compromising efficient coffee growth and yield. Researchable issues remain about the access and related costs if any, of using the organic nutrient sources as part of ISFM strategy, followed by a holistic cost-benefit analysis. We also think that a longer experimental period is necessary to satisfactorily monitor the response of these new coffee varieties above the age of four years assuming that at a later age the coffee tree will have reached its maximum production and so more nutrients will be needed to support the crop. As such, we will extend the experiment for two further years.

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