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Determining the limiting nutrients in coffee plantations at Makerere University Agricultural Reseach Institute

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Abstract Coffee is one of the main revenue sources at Makerere University Agricultural Research Institute Kabanyolo (MUARIK) and countrywide but its productivity is declining due to nutrient removal from the soil through harvest and other processes of soil degradation. An experiment was conducted in the coffee plantations at MUARIK to identify the most limiting nutrient(s) in order to plan a fertilizer management regime. Inorganic fertilizers were applied in two consecutive seasons as single or combined nutrient elements of N, P and K. P was applied once for both seasons at a rate of 100kg ha^{-1} yr^{-1} while N and K were applied in two splits at a rate of 150kg ha^{-1} yr^{-1} and 100kg ha^{-1} yr^{-1} respectively. These were compared to a control with no fertilizer added. Ripe coffee berries were harvested starting immediately after the first treatment application and continuously for the next 15 months. Using the cumulative yield values it was determined that N was the most limiting nutrient having resulted in the highest yield increase of 324 kg ha^{-1}. But the expected peak yield of about 6000 kg/ ha was not attained, implying that another production factor could be limiting. Economic calculations revealed that it was not cost effective to apply fertilisers. Based on the experimental data it is recommended that in the management of soil fertility in the coffee plantations at MUARIK, N application should take precedence over other nutrients.

Key words: Coffee, MUARIK, N application

Résumé Le café est une des sources de revenue L'institut de Recherche Agricole de l'Université de Makerere (MUARIK) et dans tout le pays mais sa productivité est entrain d'être réduit a cause l'enlèvement des nutriments de sols à travers la récolte et autre processus de dégradation. Une expérience était conduite dans les plantations de café à MUARIK pour identifier les éléments nutritifs le plus limitatifs pour élaborer un plan de gestion des engrais. Les engrais inorganiques étaient appliqués dans deux saisons consécutives comme des nutriments simples ou combinés de N, P et K. Le Phosphore (P) était appliqué une fois pour les deux saisons a un taux de 100 kg/ha/yr alors que N et K étaient appliqué en deux tranches a un taux de 150 Kg/ha/yr et 100 Kg/ha/yr; respectivement. Celles-ci étaient comparées au contrôle sans engrais ajouté. Les graines de café mures étaient récoltées immédiatement après la première application (traitement) et de façon continue pour les 15 mois suivants. Utilisant les valeurs des rendements cumulées N était le nutriment le plus limitatif ayant résulté a une augmentation de rendement de 324 Kg/ha. Le pic prédit de 6000 Kg/ha n'était pas atteint, impliquant qu'un autre facteur de production est limitatif. Le calcul économique a montré que l'application d'engrais n'était pas nécessaire. Sur base des données expérimentales, il est recommandé que dans la gestion de la fertilité de sols dans les plantations de café à MUARIK, l'application de N devra prendre précédence sur les autres nutriments.

Mots clés: Café, MUARIK, l'application de N

Introduction

Coffee belongs to the genus *coffeea* and is placed in the Ru*biaceae* family. Two thirds of the world's supply of coffee comes from Brazilin South America and the remaining one third is divided amongst all the other coffee producing countries worldwide of which Uganda is one. There are three species that are extensively cultivated namely: *Coffea Arabica, Coffea canephora and Coffea liberica.Coffea arabica* is suitable for highlands because it is vulnerable to pests and diseases at lower altitudes and approximately 80% of the total world exportable coffee production belongs to this species. *Coffea canephora* is widely distributed in the African continent from Guinea and Liberia to the Sudan and the Uganda forest and the commonest forms occur in regions with low altitude. *C. canephora* is commonly known as robusta coffee and it is highly difficult to characterize its varieties. *Coffea liberica is* characteristic of the tall and dense forests.

Of all the beverages worldwide, coffee is the most stimulating and mood elevating non-alcoholic beverage, (Musoli *et al.*, 2001). It is a raw material of great economic and social importance contributing to 1% of the total value of world exports and imports. It is produced by developing countries of the tropics and grown in 80 countries where 50 of them are exporting. It is the main export of Latin America (Colombia, Costa Rica, Brazil) and tropical Africa. (Uganda, Kenya, Ethiopia , Rwanda, Ivory Coast, Cameroon, Democratic Republic of Congo). It provides employment to a large number of small holders in the rural areas.

Coffee is important in the economy of Uganda and over 70% of GDP comes from this sector. Of the foreign export earnings, coffee has contributed about 65%, despite the price fluctuations in the international trade since 1989, hence continues to be the largest foreign exchange earner and major source of income in many rural areas (Wasswa, 1993). Most coffee farmers own gardens of only up to one hectare (Ngambeki *et al* 1992). The planting spacing varies and it is often mixed with other crops like bananas. It is frequently shaded and rarely mulched. Traditionally grown as an inter-crop on small farmer holdings, coffee forms an integral part in the agro-zoning of the traditional cropping /farming systems in Uganda. The coffee-banana system is the largest with coverage of close to 29.54% of the total cultivated area. Coffee/banana/beans cover 3.64%, coffee cassava at 3.5% and coffee/beans at 1.26% (Ngambeki *et al* 1992). Two species are grown Arabica and robusta and 94% of the total area under coffee is robusta. Most of the Arabica producing areas lie between 1500-2300m and those for robusta lie between 1200m-1500m.In Uganda nearly all the robusta and most of the Arabica is grown by local cultivars.

Most farmers in Uganda try to increase coffee production by increasing the acreage for the crop but this is getting difficult because of the raising population pressure on the limited land. Coffee farmers being largely small holders have continued to produce without proper soil management practices. Very few farmers (20%) use some fertilizers in coffee production (Ngambeki *et al.*, 1992). Since coffee is exported the soils under its production are continually depleted of nutrients without replenishment. More efforts are therefore needed to address the problem of soil fertility management in coffee producing areas. Use of inorganic fertilizers is one of the ways of managing soil fertility but the farmers rarely use them due to absence of convincing research demonstrating profitable coffee yield response to fertilizer application. Most farmers have limited access to fertilizers and others are unwilling to incur extra costs.

Makerere University has an Agricultural Research Institute Situated at Kabanyolo. This institute grows many crops among which is robusta coffee and is one of the main revenue sources. The robusta coffee plantations were established more than 40 years ago and are rarely fertilized which has led to fluctuation in yields. The quickest way of maintaining the coffee productivity is by use of artificial fertilizer management practices. The purpose of this study is to determine the most limiting nutrient(s) in coffee plantations at MUARIK and then establish the profitability of applying fertilizers.

The results from this study can be used to establish fertilizer management practices that could be a basis for adaptation to different situations in the country and hence increase coffee productivity during this campaign of increased coffee production.

Materials and methods

The study was conducted at Makerere University Agricultural research Institute (MUARIK) in the existing coffee plantations. The institute is located at $0^0\ 28^1$ N and $32^0\ 37^1$ and lies about 20 km north of The mean annual rainfall is 1160 mm distributed bimodally (March to June: September to November). The mean monthly temperature is 24.5^{o}C.

Four blocks were used in which each of the following nutrient treatments were applied in a y randomized complete block design (RCBD). The treatments were: Nitrogen applied as Urea (150kg N ha^{-1} year^{-1}, Mukiibi 2001),Phosphorus applied as super phosphate (100kg P ha^{-1} year^{-1}),Potassium applied as Muriate of potash (100 K ha^{-1} year^{-1}), combinations of NP, PK, NPK, NK and a control with no nutrients added.

There were at least five trees per plot spaced at 2.6mx3m making a plot size of 108m^2. The treatment plots ran along the slope from top to bottom of the slope to minimize treatment mix up due to erosion. The treatments were separated by guard row coffee trees shared between treatments. Phosphorus was applied in one season while N and K were split into two seasons. The fertilizers were applied in a ring method and thinly worked into the soil using a hand hoe. Manual weeding was done at the beginning of the experiment and subsequent weed control was done by use of herbicides.

Measurements. Composite soil samples were taken from the different blocks for "site" characterization and analyses were done following methods described by Okalebo *et al*, 1993.

Plant foliar samples (fourth pair from top of actively growing and bearing branches) were taken from each treatment plot just before nutrient application and after every six months thereafter to calibrate for the critical concentration of each nutrient.

Coffee berries for each season were picked and sun dried. Later the entire yield for each treatment was added and weighed to determine the total yield. To determine the moisture content in a sample a fresh sample from each treatment taken, weighed and the weight recorded. Then the samples were oven dried at 60^{o}C for seven days to stable moisture content. Weights of the dry cool coffee samples were taken, recorded and the percentage moisture loss for each treatment was calculated using the formula.: Dry sample weight/Fresh sample weight x100 = % moisture loss. The results from this were used to compute the total yield of coffee from each treatment. Finally records of input costs and coffee sales were used to establish the profitability of applying fertilizers.

The data were analysed in Genstat Computer Package and means separated using Fishers Least Significant means. For economic purpose the gross margin was calculated using a formula ; Gross Margin (GM) = Total Revenue (TR) – Variable Cost (VC).

Results and discussion

Site characteristics. The study sites had a relatively normal pH, very low N for coffee production (Table 1) The calcium level boarder lines the critical level. This supposes that there is need to improve on the soil fertility management for optimum coffee production. Since N is low it means that its addition to the soil could improve on the development of the items, leaves and fruits thus productivity.

Phosphorus was above the critical value required by most plants, in the topsoil (Table 1). However; the level was far below in the subsoil. The high value of P in the topsoil could be attributed to the addition of poultry manure, which was applied the previous season.

Phosphorous being immobile there is high chance that it was still in the topsoil. Therefore, its application is not likely to affect the coffee yield. The rest of the minerals were fairly adequate (Table 1).

Foliar analyses. The foliar results show that the nutritional status of the coffee plants was good except for magnesium, which showed marginal (Mg) values (Table2). The low value of Mg could directly affect the yield of coffee, as the element is essential in green plants as part of chlorophyll and activator of many plant enzymes. (Cambroy, 1992) Probably lack of enough Mg was reflected in reduced yield in all treatment vis-à-vis normal yield of coffee (6tons ha^{-1} $year^{-1}$). Cambroy, 1992. But Mg was out of the scope of this experiment.

Effects of different inorganic fertilizer application on the cumulative coffee yield. Addition of NPK did not cause any significant difference (P- 0.05) (Fig. 1). The coffee plantations at MUARIK were established as early as 1953. The age of the bushes is very important, since yield increases from three years to eight years, then becomes stable and finally falls off after 15 years (Cambroy, 1992). Therefore, it is probable that there were no significant yield differences due to the age of the plantations. Similar observations were made by Onzima (1996) who narrated

Table 1. Study site characteristics.

Item	pH	% OM	% N	Av. P	K	Ca	Mg	Texture class
0-15 cm	5.5	3.9	0.075	18.9	1.64	3.6	0.9	Sandy
15- 30 cm	5.4	2.9	0.05	6.9	1.28	3.5	0.85	Clay
C. value	5.5	3	0.2	15	0.22	4	0.5	

Source C = critical.

Table 2. Coffee foliar nutrients before and 15 months after inorganic fertilizer application.

Treatment	%N		%P		% K		%Ca		%Mg	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
N	3.3	3.0	0.29b	0.17	3.49	1.65	0.43	0.26a	0.33	32b
P	2.4	2.3	0.15a	0.15	2.82	1.83	0.31	0.13a	0.24	0.28a
K	2.4	2.5	0.16a	0.18	2.67	1.85	0.28	0.15ab	0.22	0.23a
NP	2.5	2.8	0.14a	0.17	2.92	1.68	0.29	0.29a	0.24	0.18a
PK	3.2	2.6	0.21b	0.14	3.80	1.98	0.40	0.45b	0.32	0.21a
NK	2.8	2.5	0.18a	0.16	3.0	1.88	0.27	0.14ab	0.23	0.29a
NPK	2.3	2.3	0.16a	0.15	2.07	1.45	0.26	0.24a	0.23	0.23a
Control	2.4	2.4	0.21a	0.16	3.56	1.85	0.37	0.23a	0.30	0.12
LSD	NS	NS	0.11	NS	NS	NS	NS	0.26	NS	
C. Value	3.3		0.18				1.50		0.36	

Source: C= Critical; 1st = Foliar analysis before treatment application; 2nd = Foliar analysis after treatments application.

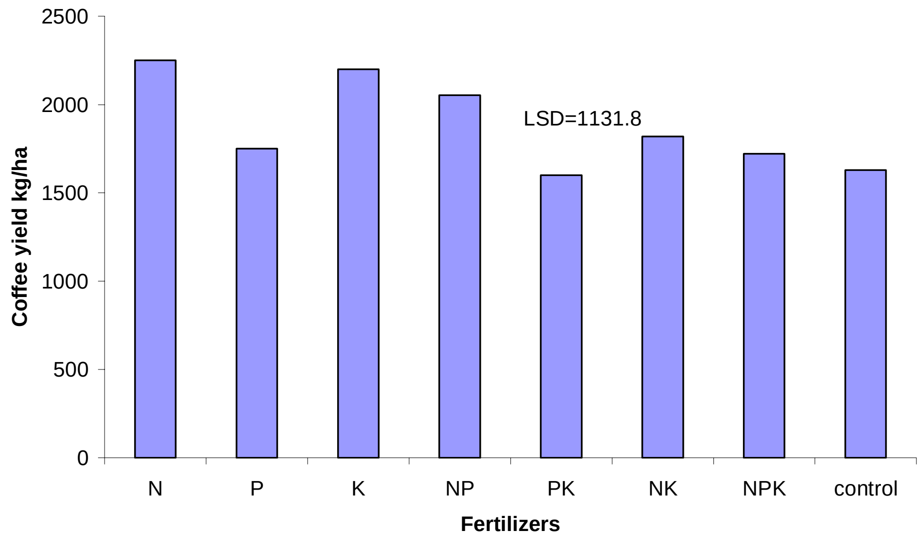

Figure 1. Effect of different inorganic fertilizer application on the cummulative coffee yield.

Table 3. Effect of inorganic fertilizer application on the coffee profitability at MUARIK.

Treat	Gross revenue	Variable costs	Gross margin
N	1,192,400	936,806	255,594
C	957,550	1,446,955	-489,405
P	1,128,600	976,102	152,498
PK	1,060,950	1,683,066	-622,116
NK	866,800	1,084,334	-217,534
K	1,031,800	1,084,334	-52,534
NKP	1,022,450	1.919,177	896,727
NP	1,014,200	720,344	293,856

that when trees are very old nutrients are not efficiently utilized since old trees have primaries and small heads, which affect the uptake of fertilizers. The old trees are etiolated, the lower primaries are self-pruned and the remaining primaries have short internodes with little space for cherry formation and development. This affects the yield and once the yield is low, it means even the application of inorganic fertilizers cannot increase the yield significantly.

Effect of inorganic fertilizer application on the coffee profitability at MUARIK. The variable coasts included the cost of weeding (both mechanical and chemical), pruning, fertilizer application, picking, drying, weighing, fertilizer costs, supervision and transport.

The gross margin realized from the sales of coffee was low to negative across all treatments (Table 3). It is profitable to apply: NP, N and P. This suggests that NP should be applied to old coffee if at all we are to realize any positive gross margin. Similar observations were made by Muyeti and Tumuhimbise at Kawanda Agricultural Research Institute (Unpublished 2004).

Conclusion

The coffee bushes are too old to efficiently utilize the fertilizers. Nitrogen appears to be the most limiting nutrient in coffee production at MUARIK

Recommendations

Based on the experimental data it is recommended that in the management of soil fertility in the coffee plantations at MUARIK, N application should take precedence over other nutrients. Further studies should be carried out to determine the effect of different fertilizer application on stumped coffee yield.

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