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Economic Optimization of Nutrient Application to Coffee in Northern Tanzania Using SAFERNAC

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Authors' contributions

Author GM designed the study, performed the analysis and wrote the first draft of the manuscript. Author BJ contributed in design and conduct of the study. Authors BJ, BM and JM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this work, as an extension to SAFERNAC model, was to establish economically optimum combinations of N, P and K application to Arabica coffee in the Northern coffee zone of Tanzania. The study was conducted in Hai and Lushoto districts between 2010 and 2012. Prices of nutrient inputs and those of parchment coffee were introduced into the original SAFERNAC model, which was used to obtain yields from a soil of known properties receiving different levels of input N, P and K from both organic and inorganic sources (ISFM). The costs of these were derived from experience in Northern Tanzania, while coffee prices were estimated to range between 1250 and 2500 TZS kg^{-1}. The result was economically optimum N:P:K ratios that give highest net returns and value : cost ratios in situations of low, medium and high soil fertility. It was also shown that farmers' decision to deviate from the optimum and the allowable level of such deviation, depend much upon the prices of nutrient inputs in equivalent terms. In the medium-fertility situation (which applies in the study districts), the highest yield increment was noted with the maximum amount of N and P. The optimum application rate was 310

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kg N and 200 kg P per ha, where the profit margin (the gap between gross returns and costs) is highest. This is an indication that soil-available K is likely to suffice the needs of the crop for optimum productivity, but this is largely dependent on the K fluxes in different soil types. The optimum rates were tested with actual soil data in the two study districts, against 5 tons of farmyard manure and a combination of the two. At both the coffee prices of 1250 and 2500 TZS kg^{-1}, ISFM intervention (combination of organic and inorganic inputs) was more profitable than the other options, while coffee production showed to be more profitable in Hai than Lushoto.

Keywords: Coffee yield model; gross returns; nutrient equivalent; nutrient inputs; value cost ratio.

ABBREVIATIONS

Short form	***Definition/ long form***
Ea	*Nutrient application equivalent*
Ex	*Real cost per unit inputs, corrected for their extra handling costs*
FYM,	*Farmyard manure*
GR	*Gross returns (to the inputs applied)*
HCx	*Extra handling costs of the inputs (storage, transport, application)*
HCy	*Handling costs of the extra yield: harvesting, processing, storage, etc*
ISFM	*Integrated soil fertility management*
MOP	*Muriate of potash (a kind of fertilizer)*
NR	*Net returns (to the inputs applied)*
Px	*Price of fertilizer inputs*
Py	*Farmgate price of parchment coffee*
QUEFTS	*Quantitative evaluation of the fertility of Tropical soil*
S	*Supply (of nutrients to a plant)*
SAFERNAC	*Soil analysis for fertility evaluation and recommendation on nutrient application to coffee*
SOP	*Sulphate of potash (a kind of fertilizer)*
TaCRI	*Tanzania Coffee Research Institute*
TC	*Total costs*
TZS	*Tanzanian Shilling*
Vy	*Real value per unit yield, corrected for its extra handling costs*
X	*Input (fertilizer, manure, etc)*
Xopt	*Economically optimum nutrient application rates*
Y	*Yield (of parchment coffee)*
ΔY	*Differential yield attributed to the application of nutrient x.*

1. INTRODUCTION

Coffee farming follows the principles of production as described economically by [1,2] and [3], among others. It is an entrepreneurship that involves decision making and risk taking. Application or otherwise of farm inputs, including organic and inorganic sources of plant nutrients is one such decision that a farmer has to make. The decisions are often based on former experiences and on common sense. There are, however, scientifically sound techniques to assess the profit of nutrient applications. They require knowledge about the prices per kg coffee, fertilizer N, P and K and the costs of other nutrient sources like animal manure and green manure. Also costs of application of the various nutrient sources and of crop husbandry measures related to the extra coffee yield must be estimated [4]. The difference between the gross financial value and the production costs of the harvested coffee represents the balance of crop production. The difference in net financial value between fertilized and non-fertilized crops represents the net return to the nutrient sources. The economic optimum is found where the net return is at maximum.

The first paper [5] described a quantitative approach to fertilizer advice and yield estimation for coffee in Northern Tanzania, and proposed a fertilizer-yield model called SAFERNAC, developed by calibrating QUEFTS for coffee. The basic structure of the model was described, where some chemical soil characteristics, nutrient inputs and maximum yields per tree and per ha are model inputs and coffee yield is the model output. The current paper describes some additional steps to the model whereby the economics of ISFM are included.

2. MATERIALS AND METHODS

2.1 Use of SAFERNAC Model

The new model SAFERNAC (Soil Analysis for Fertility Evaluation and Recommendation for Nutrient Application to Coffee) was used in this work to obtain yields from a soil of known properties (baseline situation) receiving different levels of input N, P and K from both organic and inorganic sources (ISFM). The economic analysis required a price component for both input (organic and inorganic fertilizers) and output (parchment coffee sold at farm gate).

2.2 Estimating the Costs of Inputs and Price of Output

The costs of animal manure were estimated as follows: One truck of manure costs TZS 10,000, and contains 160 tins (estimates adopted from TaCRI). One tin corresponds to 2.5 kg dry matter. So one truck contains 400 kg dry matter. The costs of animal manure is 10,000/400 = 25 TZS per kg dry matter, or 25,000 TZS per ton dry matter. Because the substitution values of N and P in animal manure are set at 0.6 and 0.87 [6], the prices of available N and P in animal manure are roughly 70 and 115 TZS per kg. A survey of three famous farm input stockists in Moshi (Tanganyika Farmers Association, RafikiKilimo and Kibo Trading Company) was done for the period 2007/08-2010/11, and average prices for N and P sources were used for calculating the prices per kg element N, P and K. The price of K had to be calculated indirectly as no single K fertilizers were available at the time. As a result, the price of K is rather high compared to the price of N. The calculated prices of nutrients are much lower for animal manure than for chemical fertilizers (Appendix 1).

The price of coffee strongly fluctuates, as shown in the example given in Table 1. In this work, the minimum price was set at 1250 TZS (equivalent to US$ 0.78) per kg of parchment coffee, close to the lowest figure of 1263.61 TZS recorded between 1996/97 and 2005/06 seasons [7] and the maximum was set at twice that value, that is 2500 TZS (or US$ 1.56) per kg.

Table 1. Variations in Mild Arabica coffee prices over 10 years

Season	Price of parchment coffee kg^{-1}		Season	Price of parchment coffee kg^{-1}	
	TZS	US$		TZS	US$
1996/97	1418.70	0.887	2001/02	1453.15	0.908
1997/98	1677.35	1.048	2002/03	1671.12	1.045
1998/99	1936.00	1.210	2003/04	1800.00	1.125
1999/2000	1486.60	0.929	2004/05	2593.50	1.621
2000/01	1263.61	0.790	2005/06	3429.00	2.143

2.3 Calculation of Economic Optimum

The mathematical expressions of production adopted in this work follow the principles of [8] and [9]. The relation between yield (Y) and the supply (S) of a nutrient is usually described by a non-linear equation, most often by a parabola, as in Equation 1:

$$Y = a + b*S - c * S^2 \quad (1)$$

With ‘a’ representing the y-intercept, which is the baseline yield obtained without the application of the given nutrient. The yield increase (ΔY) brought about by the application of a certain quantity of nutrient (X) is then described as in Equation 2:

$$\Delta Y = b*X - c * X^2. \quad (2)$$

The gross financial value of the extra yield is found by multiplying ΔY with P_Y, the price per unit of Y. Similarly, the costs of the applied nutrient are the product of X and P_X, the price per unit of X. The extra expenditures farmers have to make for the production and handling of the extra produce imply that the value of the coffee for farmers is less than P_Y. Subtracting a factor HC_Y (handling costs of Y) from P_Y, the real value per unit of Y is indicated by V_Y. The extra costs of transport, storage and application of nutrients make the costs the farmer has to incur to apply the nutrients higher than $X * P_X$; so adding a factor HC_X, the real expenses per unit of X are indicated by E_X [10].

The gross return (GR) to nutrient application and the cost of nutrients are described by equations 3 and 4 respectively:

$$GR = (bX - cX^2) * V_Y, \quad (3)$$

$$TC = X * E_X. \quad (4)$$

The net return (NR) to nutrient application is the difference between GR and TC, expressed in Equation 5:

$$NR = (b* V_Y - E_X)*X - c * V_Y * X^2 \quad (5)$$

Maximum net return is obtained when the first derivative of this equation for NR is zero, so when $dNR/dX = b* V_Y - E_X - 2c * V_Y * X = 0$, the corresponding optimum quantity of applied nutrient (X_{opt}) is expressed in Equation 6:

$$X_{opt} = (b* V_Y - E_X)/ (2c * V_Y). \quad (6)$$

The above calculations of ΔY, NR and X_{opt} are also described in [11] and are not too difficult when only one nutrient is applied. The equations may become complicated, when two or more nutrients are applied [12]. This is always the case with organic manures and compound fertilizers. These problems are avoided by the use of the concepts of nutrient uptake equivalents [13], nutrient availability equivalents and nutrient application equivalents. As explained in [5], in a situation of balanced nutrition, nutrient uptake equivalents of N, P and K have equal effects on yield. It was also noted that the uptake of 1 kg N has the same effect on coffee yield as the uptake of 0.175 kg P or of 0.875 kg K.

A theoretical example was run for demonstration purposes, with prices set at 1250 TZS per kg of parchment coffee, and at 1000, 2500 and 2500 TZS per kg N, P and K, respectively. A zero baseline situation was assumed, and the yield data (which also represent □Y) and the nutrient availability data referring to input nutrients, were calculated. For convenience, HC_Y and HC_X were not considered. Yields and net returns related to the availability equivalents which vary by 30 units were calculated and optimum input ratios established for N/P, NP and NPK.

For the calculation of the economically optimum application, soil properties shown in Table 2 were used to represent low, medium and high soil fertility. The regression lines of the response to the most limiting, the most and the next most limiting, and three most limiting nutrients were determined, and for each of them the optimum application rate was calculated. ΔY was plotted against total E_a to satisfy Equation 2 within the 3 ranges and the resulting regression coefficients used to satisfy Equation 6 for the optimum rates.

Table 2. SAFERNAC parameters used to define low, medium and high fertility

Parameter	SOC	SON	P Bray	K exch	pH water
low	10	1	2	6	4.6
medium	26	2.6	52	20	5.2
high	46	4.6	120	80	6.5

2.4 Application to Actual Soil Data, Hai and Lushoto Districts

Average soil data for 9 divisions in Hai and Lushoto districts were adopted from the soil fertility evaluation work done earlier [14] and used in testing the model. Comparing the data used in the examples Table 2 and real data from Hai district, soil pH and OC (average 6.09 and 39.7 g kg^{-1} respectively) showed to be close to the high fertility category, while the rest of the parameters were close to the low category. As for Lushoto, only pH was close to high category with the average of 5.93. The rest of the parameters were low, thus confirming once again that soils of Lushoto are less fertile than those of Hai. As none of the combinations was perfect enough for infinite categorization of the real-time fields as of low, medium or high fertility, the medium fertility scenario was used with the economically optimum rates of nutrient inputs adapted from the theoretical example. SAFERNAC was run four times using the average soil data for the three divisions (Hai) and six divisions (Lushoto). The two modules were tested: the baseline module (soil nutrients alone) and ISFM module, the latter run three times; with fertilizer alone (optimum rates from the example), manure alone (5 tons) and a combination of the two.

3. RESULTS AND DISCUSSION

3.1 The SAFERNAC Model with Economics

Fig. 1 is a schematic representation of the model, with economic loops added. The modules SOIL and PLANT have been summarized from [5], because they both constitute the baseline (no-input) approach. The module INPUT which constitutes the ISFM approach, has been further expounded to include organic and inorganic inputs and prices of each.

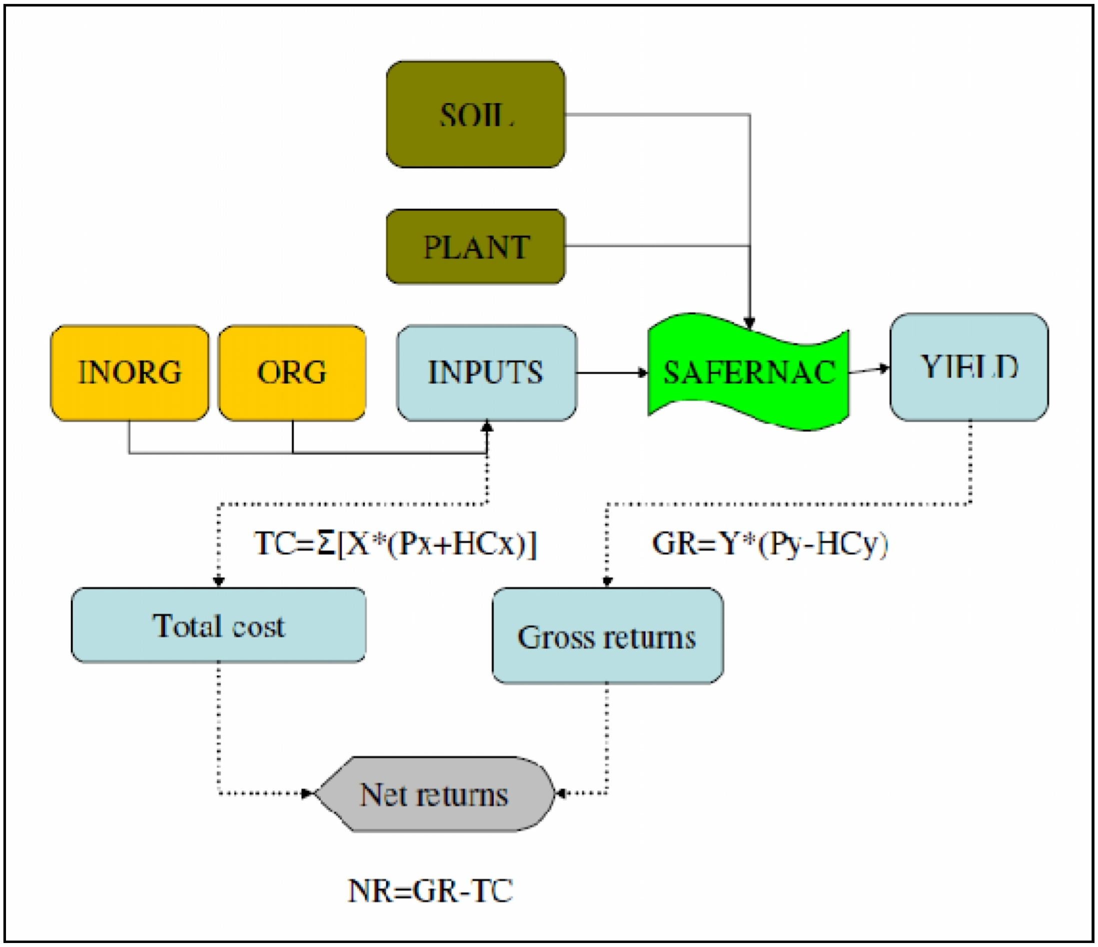

Fig. 1. SAFERNAC model with economic loops (costs and returns)

3.2 Yields and Net Returns in Relation to Nutrient Availability Equivalents

A summary of the calculated yields and net returns is given in Appendix 2 which shows yields as a function of the optimum N:P ratios at each of the six levels of K, with optimum N:P:K ratios in bold underlined. The yields at optimum ratios are always higher than the other yields with the same total quantity of availability equivalents. Appendix 2 also shows the corresponding net return (NR) to nutrient application which is the difference between gross financial value of the extra yield (ΔY) and costs (again optimum NPK ratios in bold underlined). The net returns at the optimum ratios are always higher than the net returns obtained with other N, P and K combinations with the same total quantity of availability equivalents.

The yield calculations gave an implication that inputs deviating from the balanced situation by the same quantity of availability equivalents result in equal yields (regardless of which nutrient deviates), but those of net returns did not give similar implication. The reason is that the prices per availability equivalent of N, P and K are not equal. They are found as the product of kg N, P and K per application equivalent (1.429 N, 1.75 P, 1.25 K) and the price per kg N, P and K (1000 N, 2500 P, 2500 K). The prices per application equivalent of N, P and K are 1429, 4375 and 3125 TZS, respectively.

A demonstration of the consequences is given in Appendix 3, comparing yields and net returns for different combinations of N, P and K, summing up to 360 availability equivalents. Balanced nutrition gives the highest yields as well as the highest net returns and value/cost ratios. Combinations deviating from the balanced situation by 30 availability equivalents have higher yields, net returns and value/cost ratios than combinations deviating from the balanced situation by 60 availability equivalents. The fertilizer costs are relatively low when N is higher or P is lower than in the balanced NPK-combination, and relatively high when N is lower or P is higher than in the balanced situation. They reflect the differences in prices per application equivalent of N, P and K. In the case of extreme differences in fertilizer prices, e.g. by a factor of four, it may be profitable to apply more of the cheapest fertilizer than in the balanced situation. Otherwise balanced nutrition is to be preferred.

3.3 Economics of Nutrient Inputs in Relation to Soil Data

The soil nutrient supplies are rarely balanced, and one of the aims of ISFM intervention is to correct the imbalance. From [5,15], N is the most limiting nutrient, and should first be applied, then NP according their optimum proportions, and finally NPK (at low fertility levels however, P showed to be most limiting, as it gets fixed to unavailable forms at low pH). It was shown in the above sections that economically optimum application of one nutrient (X_{opt}) can be calculated with: $X_{opt} = (b^* V_Y - E_X)/ (2c * V_Y)$. The coefficients of the three equations in Fig. 2 substituted “b” and “c” in the equation.

The nutrient applications and calculated ΔY have different reference points. In the case whereby only the most limiting nutrient is applied, the baseline yield of 1086 kg is the reference. Where N and P are applied, the reference yield is 1952, obtained at the starting point of NP balance. Where N, P and K are applied, the reference yield is 2937, obtained at the starting point of NPK balance.

In the case of medium soil fertility and only N application, the optimum lies above the maximum application rate, while in the case N, P and K are applied the optimum has a negative value. The soil is so rich in K that application of K would be a waste of money. The best application rate is found in the part where N and P are applied. The same rule seems to apply even in soils of low and high fertility, but somewhat less clearly.

In Fig. 3, costs and gross return for the total application of fertilizers is shown. Also the optimum application rate is indicated; at that point the distance between gross return and costs is at maximum. The optimum rate is 332 application equivalents, of which 217 (65%) are spent on N and 115 (35%) on P. The corresponding rates expressed in kg are 310 kg N and 200 kg P per ha. This seems to be the absolute optimum rate because it is lower than the corresponding optima of 401 and 418 at low and high soil fertility respectively.

3.4 Results from Actual Soil Data, Hai and Lushoto

Fig. 4a and b give the estimated yields and delta yields respectively for the nine divisions studied. Baseline yields showed a clear difference between soils of Hai and Lushoto, the former yielding well over 500 kg ha^{-1} and the latter hardly reaching it. With the exception of Bumbuli, where response to manure and fertilizer is practically the same, all other divisions showed a stepwise increase in the order FYM<NP<Combination.

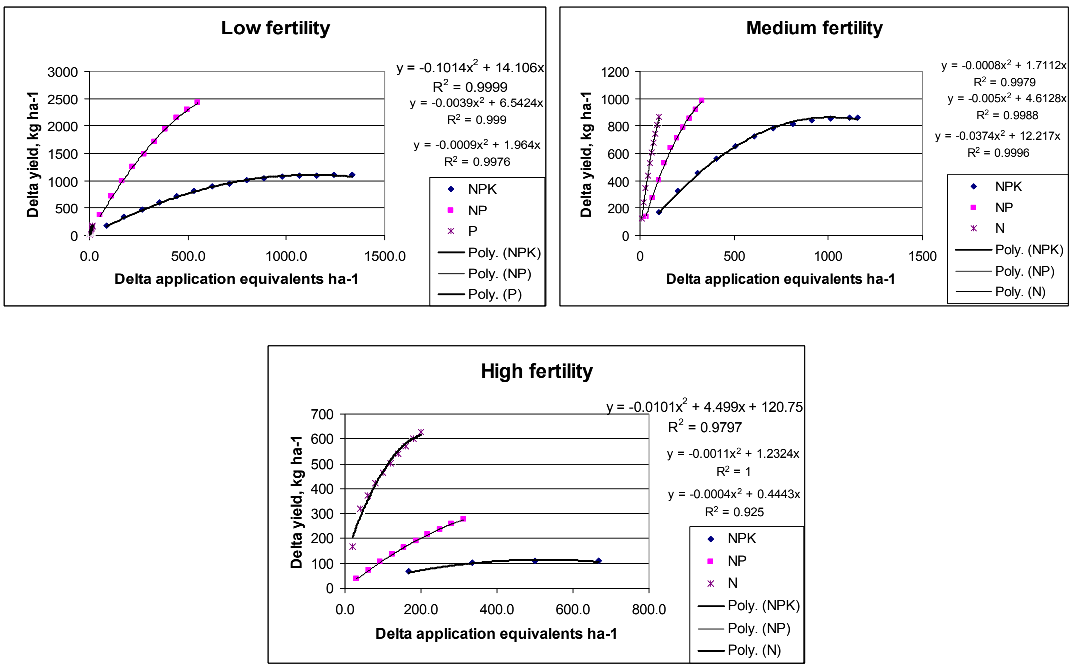

Fig. 2. Relation between calculated Δ coffee yields and Δ application equivalents for low, medium and high fertility, and the three input ranges (N/P, NP and NPK)

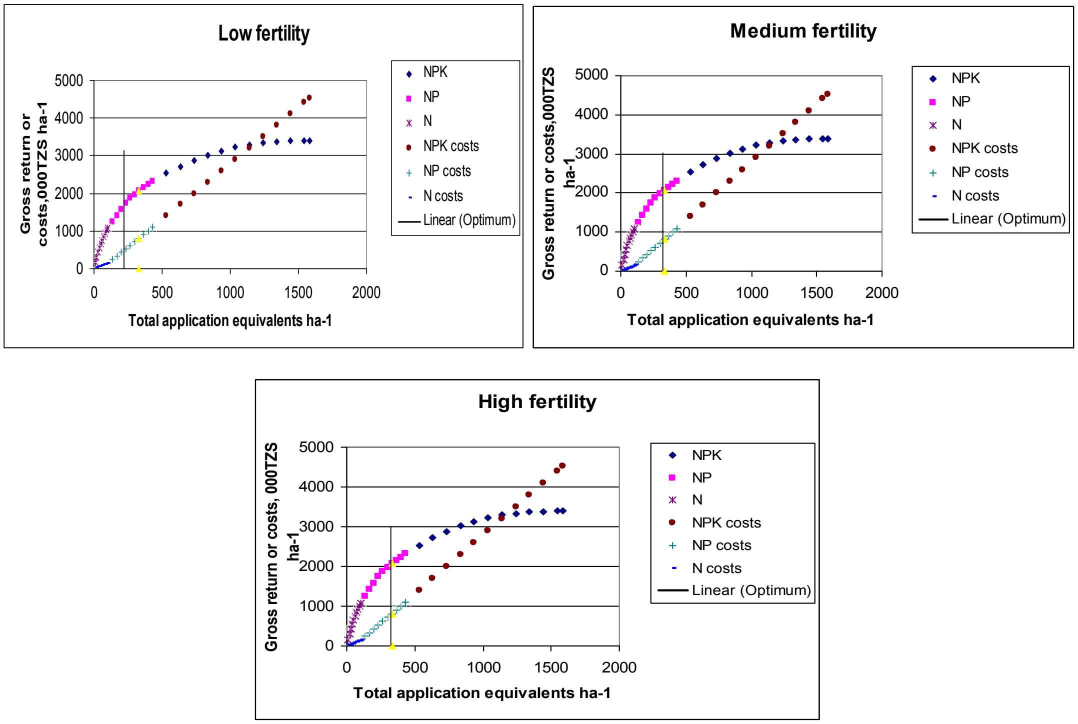

Fig. 3. Relation between gross return to and costs of nutrient application for soils of low, medium and high fertility and three nutrient input ranges

In Fig. 4b, response to manure steadied at around 270-300 kg ha^{-1} throughout the study areas. N and P changed the yield difference at least two-fold, with an average around 700 kg ha^{-1}. As expected, the combination of manure and fertilizers excelled the list, oscillating around the 1200 kg line. Similar results were seen in [16].

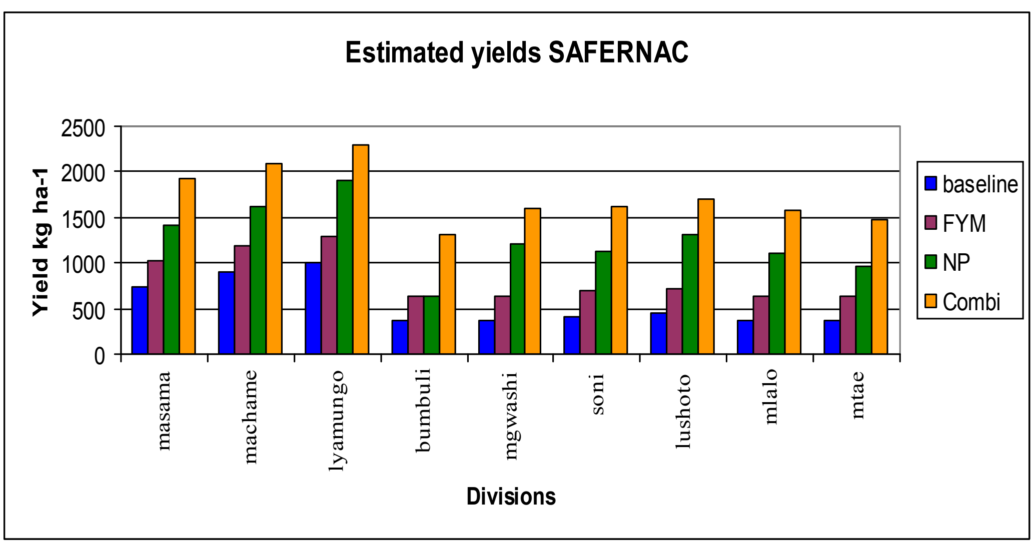

Fig. 4(a). The estimated yields for the nine divisions

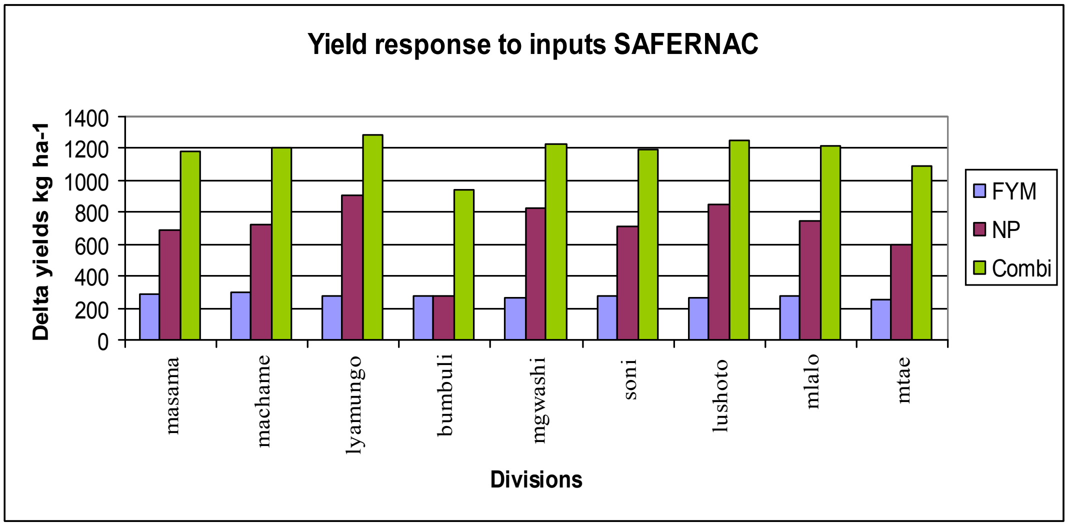

Fig. 4(b). The estimated delta yields for the nine divisions

The value-cost ratios for the 9 divisions at coffee prices of 1250 and 2500 TZS per kg of parchment are shown in Fig. 5a and b respectively, as calculated from SAFERNAC. The trends were more or less the same, with the three divisions of Hai recording about twice as much value-cost ratio where only FYM was applied at 5 tons per ha. Lyamungo division showed to be most profitable, followed by Machame andMasama. The other divisions in Lushoto did not differ significantly among themselves.

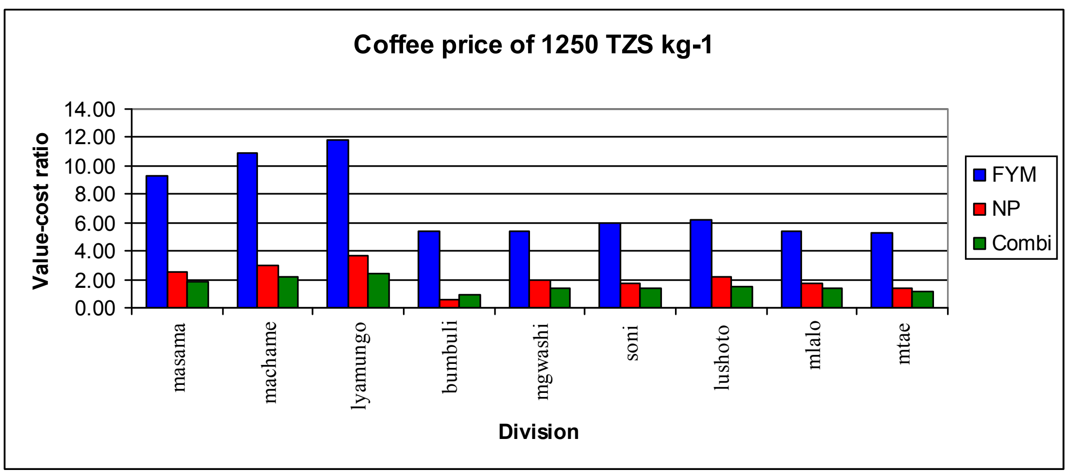

Fig. 5(a). The value-cost ratios at coffee prices of 1250 TZS per kg

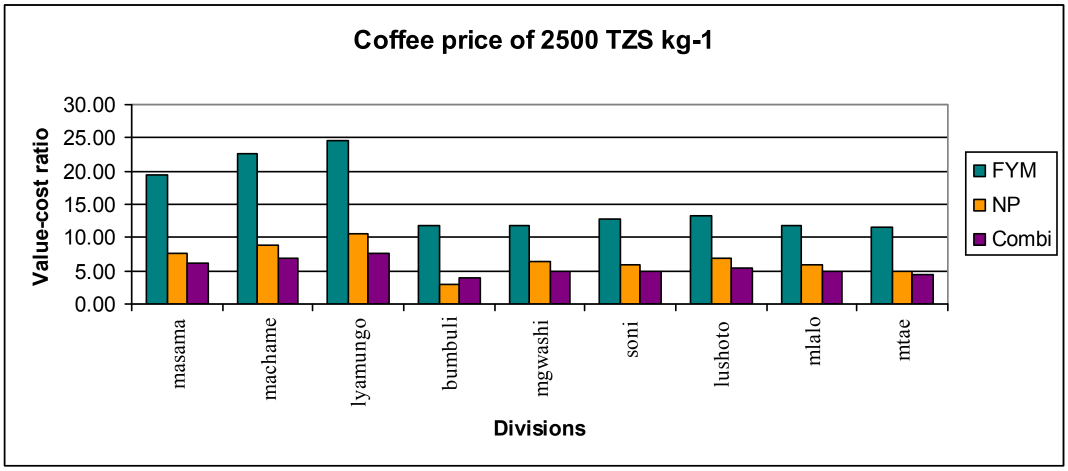

Fig. 5(b). The value-cost ratios at coffee prices of 2500 TZS per kg

3.5 Discussion

The economics of agricultural production have been covered by many authors in different crops like rice [17], plantains [18], cowpeas [19] and groundnuts [20]. Most of these, however, took a more holistic approach, examining all factors of production rather than just fertilizer input as applies in this work. Their attention is therefore centred on efficiencies of resource use. Roberts [21] made a cautious note that nutrient use efficiency should not be overemphasized at the expense of effectiveness and productivity. That's why the emphasis of the economic extension of SAFERNAC is the value of coffee yields against the value of nutrients applied for soils of low, medium and high fertility.

The theoretical calculations used in this model, as suggested by [8,9] are simple and understandable. The model needs to be run twice; first as a baseline module and secondly as an ISFM module. The ISFM module is usually run with progressively increasing amounts of "x" until ΔY approaches zero. Then P_Y and HC_Y are used to calculate V_Y and P_X and HC_X to calculate Ex as suggested by [10] and the difference between (ΔY*Vy) and (X*Ex) gives the net returns to ISFM intervention, with economic optimum reached where this is maximum. In the example used in this work, HC_Y and HC_X were not considered because these differ from farmer to farmer depending on location and infrastructural capability. This, coupled with the fact that the theoretical soil was assumed to have zero nutrients, make the situation represented by the example an oversimplification of the model, serving only to clarify the concept of economically optimum nutrient application. A real-time farmer, however, must be able to estimate HC_Y and HC_X for calculating real-time profitability.

The estimation of the market price of parchment coffee was rather difficult due to fluctuating prices, and it was considered safe for modelling purposes to use the minimum (or threshold) market price, stretched over a period of 10 years. The same applies to the estimated costs of fertilizer inputs, which were based on the 2010/11 data, and these may have changed in course of time. In the calculations of economic values of FYM, many assumptions had to be made regarding prices and composition of animal manure, the latter depending on the type of animal, feed composition and level of organic matter decomposition. This means that all these parameters must be determined on location basis for the model to be realistic. It was also shown that costs of fertilizer inputs are an important factor in farmers' decisions on deviation from the optimum, and the allowable extent of such deviations, as also observed by [22].

The calculations at the three input ranges (N alone, NP and NPK) and medium soil fertility have established the economically optimum N:P:K ratios that give highest net returns and have also indicated that net returns and value: cost ratios tend to decrease as the input ratios get further away from the optimum. They also show that the highest yield increment is achieved with the maximum amount of N and P. The optimum application rate also showed to be located where the profit margin (the gap between gross returns and costs) is highest, and this corresponds with NP application.

At medium soil fertility (like the one used in this example), soil-available K, which corresponds with 20 $mmol_c$ of exchangeable K per kg of soil, is likely to suffice the needs of the crop for optimum productivity where N and P are optimum. This does in no way undermine the importance of K in coffee nutrition as noted by [23,24]. The implication of sufficient soil K at medium soil fertility may have been over-emphasized in this work by the fact that the cost of K was indirectly estimated. The reason was that no stockist around the study areas has been dealing with straight K fertilizers (either Sulphate of Potash- SOP, or Muriate of Potash – MOP). It is interesting to note that during the soil fertility evaluation exercise [14], the K levels in Hai were about a half of the level of 20 $mmol_c\ kg^{-1}$ used in this example, and Lushoto less than a quarter. There is a need, therefore, to fine tune the methods of fertilizer cost estimation, particularly as regards K, for better model results.

In estimating Y and ΔY for the nine divisions studied, baseline yields showed a clear difference between soils of Hai and Lushoto. Response to input use showed a generally stepwise increase in the order FYM<NP<Combination. The slight edge shown by NP over FYM is expected because the former is usually in more readily available forms than the latter, which depends on the level of decomposition of organic materials at the time of application. The combination of manure and fertilizers excelled the list because, as NP is taken up by plants, FYM slowly mineralizes and provides nutrients over a longer time in the crop cycle [23]. The value-cost ratios in this work suggests Lyamungo as a division where ISFM interventions would be most profitable, followed by Machame and Masama. The other divisions in Lushoto did not differ significantly among themselves, and were less profitable than the Hai divisions.

4. CONCLUSION

An extension of SAFERNAC model has been devised for the determination of net returns to ISFM intervention and related coffee profitability. It was used to determine the economically optimum N:P:K ratios that give highest net returns and value : cost ratios for Hai and Lushoto Districts, Northern Tanzania. The model showed that, once the optimum application ratios are known, the decision to deviate from the optimum and the allowable extent of such deviation depend largely on fertilizer costs. In the medium-fertility situation which was the best fit in Hai and Lushoto districts, the highest yield increment was noted with the maximum amount of N and P. The optimum application rate was 310 kg N and 200 kg P per ha, where the profit margin (the gap between gross returns and costs) is highest. This is an indication that soil-available K is likely to suffice the needs of the crop for optimum productivity where N and P are balanced, but this is largely dependent on the K fluxes in different soil types. The optimum rates were tested with actual soil data in the two study districts, against 5 tons of farmyard manure and a combination of the two. At both the coffee prices of 1250 and 2500

TZS kg^{-1}, ISFM intervention (combination of organic and inorganic nutrient inputs) was more profitable than the other options, while coffee production showed to be more profitable in Hai than Lushoto.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Appendix 1. Prices of chemical fertilizers urea, triple superphoshate (TSP) NPK 20:10:10, and of animal manure. Calculation of rounded prices per kg of elements N, P and K

Percentages of	Urea	TSP	NPK 20:10:10	Animal manure
N	46		20	13
P_2O_5		46	10	
K_2O			10	
P		20	4.4	6
K			8.3	14
Prices of				
Fertilizer per bag[a], TZS	23000	25000	26000	
Fertilizer, TZS/kg	460	500	520	25
N, TZS/kg	1000	2500	1000	40[c]
P, TZS/kg		2500	2500	100
K, TZS/kg			2500[b]	100

*[a]A bag contains 50 kg, [b] Calculated as: 520 – 0.2 * 1000 – 0.044 * 2500, [c] It is asssumed that prices of N, P and K in animal manure are in the same proportions as in chemical fertilizers, and that possible additional value of FYM has no price.*

Appendix 2. Optimum coffee yields (kg ha^{-1}) and corresponding net returns (000 TZS ha^{-1}) in relation to N and P at different K levels (in availability equivalents per ha). The bold and underlined figures refer to optimum NPK ratios

K	P	N	Yield	NR	K	P	N	Yield	NR
30	30	30	**<u>377</u>**	204	120	30	30	519	99
30	60	60	527	217	120	60	60	893	393
30	90	90	593	126	120	90	90	1212	617
30	120	120	619	-16	120	120	120	**<u>1509</u>**	**<u>815</u>**
30	150	150	629	-179	120	150	150	1705	885
30	180	180	630	-351	120	180	180	1866	913
60	30	30	446	196	150	30	30	534	25
60	60	60	**<u>755</u>**	**<u>408</u>**	150	60	60	942	360
60	90	90	933	456	150	90	90	1280	609
60	120	120	1054	434	150	120	120	1591	823
60	150	150	1135	361	150	150	150	**<u>1887</u>**	**<u>1019</u>**
60	180	180	1187	251	150	180	180	2086	1094
90	30	30	491	158	180	30	30	537	-65
90	60	60	832	410	180	60	60	981	316
90	90	90	**<u>1132</u>**	**<u>611</u>**	180	90	90	1339	589
90	120	120	1321	674	180	120	120	1663	820
90	150	150	1468	683	180	150	150	1969	1028
90	180	180	1582	651	180	180	180	**<u>2264</u>**	**<u>1223</u>**

Appendix 3. Comparison of fertilizer costs, coffee yields, net returns and value-cost ratios obtained with a number of N, P and K combinations. In all combinations the total quantity of availability equivalents is 360, all supplied by fertilizers. Deviations from the balance 120-120-120 are 30 or 60 availability equivalents

Deviation	N	P	K	Fertilizer costs	Yield	Net return	Value/ cost
	Availability equivalents ha^{-1}			'000 TZS ha^{-1}	Kg ha^{-1}	'000 TZS ha^{-1}	
0	120	120	120	1071	1509	815	1.76
30	150	120	90	1021	1386	712	1.70
	90	150	120	1160	1386	573	1.49
	120	90	150	1034	1386	699	1.68
60	180	120	60	876	1122	432	1.45
	60	180	120	1248	1122	154	1.54
	120	60	180	996	1122	406	1.41

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