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Full Length Research Paper

Analysis of optimal agroforestry enterprise mix under production risk in Mbooni West district, Kenya

[1]Kaseva DM[*], [2]Mulwa RM and [1]Irungu P

[1]Department of Agricultural Economics, University of Nairobi, P.0.Box 29053, Nairobi, [2]Centre for Advanced Studies in Environmental Law and Policy (CASELAP), Environmental Policy division, University of Nairobi, P.0.Box 30197, Nairobi.

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Most arid and semi arid regions of Kenya have been experiencing deterioration in agricultural productivity translating to food insecurity and low levels of farm revenues. As a mitigation strategy, different agroforestry technologies have been innovated and disseminated to farmers in different agro-ecological zones. Since agricultural production is a risky activity, production risk should be taken into account, otherwise the policy briefs will be of little importance in real life. In a study sought to analyze the optimal agroforestry enterprise mix under production risk in Mbooni West district, first, it was necessary to evaluate the influence of production risk on net returns of various agroforestry enterprises. Then, the trade-off between the variability of net returns and expected returns to farm resources in the study area was determined. Multi-stage sampling was used and a semi structured questionnaire was administered through direct interviews. The paper applied an analytical procedure that made use of the conventional linear programming, and the Minimization of total absolute deviations (MOTAD) as the major tools. The results indicated that farmers in the study area are sensitive to production risk which influences their choice of farm enterprises and resource allocation. It was also confirmed that the farmers' production decisions were not optimal but rational in the sense that they are risk minimizing. The study recommended the establishment of appropriate organizations and institutions that would cushion the small scale farmers against various forms of production risk.

Keywords: Agroforestry, production risk, trade-off, MOTAD, Mbooni West.

INTRODUCTION

In most sub-Saharan African countries, sustainable use of existing natural resources and agricultural land is becoming increasingly imperative. This is due to the growing food demand triggered by population increase and the need for a healthy environment (Franzel *et al.*, 2003). As a result, several development strategies and policies have been put in place including the Millenium Development Goals (MDGs), Agricultural Sector Development Strategy (ASDS) and Kenya's Vision 2030, which provide the framework to improve agricultural productivity and growth (Jama and Zeila, 2005). To address the need for increased food production and related production constraints, farmers are shifting from extensive agricultural production systems towards resource-intensive production systems, such as intercropping practices, mixed farming systems, various agroforestry systems, among others (Molua, 2003).

Even though the shift to resource-intensive systems is crucial, it should be noted that agricultural production is typically a risky activity and agricultural risks impose a burden to small scale farmers especially in developing countries. This is because small scale agriculture is practiced in a risky environment associated with variability of the biophysical factors of production and

*Corresponding author E-mail: dmkaseva@yahoo.com

market prices. Farmers therefore are confronted with volatile input and output prices and variable yields, which influences both their production possibilities and optimal farm plans (Olarinde *et al*., 2008).

The Kenyan agricultural sector is predominantly small-scale based and is characterized by poor farmers who seem to be caught in the vicious cycle of low investment, low productivity and low incomes. The farmers also face various exogenous risks emanating from the biophysical and socio-economic environment in which they operate. These risks, coupled with farm specific resource endowments and constraints affect the level and variability of farm revenues (Kuyiah *et al*., 2006). According to Rice (2008), agroforestry acts as a sustainable farm diversification strategy hence reducing farmers' exposure and loss from these production risks thus its significance to resource poor small scale farmers in developing countries.

Typically, agricultural production is a risky business since farmers are faced with uncertainties in most of their production plans and decisions. Farmers recognize a variety of input and output prices, variability in yields due to climatic and biophysical factors in their immediate environment, as well as resource risks all of which determine their production possibilities and optimal resource allocation decisions (Bruce and McCarl, 1998). Given that farmers are assumed to maximize farm returns, these risks affect the level and variability of household resource use and income. Therefore, it is important for the farmers to know the specific enterprise combination that has the highest returns under the prevailing production risk situation.

In Kenya, more than 70 percent of the population depends on agriculture either directly or indirectly (MoA, 2004). Over the years, there has been a reduction in the productivity levels in different sub-sectors within the agricultural sector (Thorlakson, 2010). This can be attributed to poor diversification methods in agricultural production, technological aspects, poor soil management, environmental degradation as well as other economic aspects within the agricultural production environment (Tsunehiro, 2010). To overcome some of these problems, different production technologies, including agroforestry, have been developed and assimilated at the farm level (Thorlakson, 2010).

Past studies show that agroforestry practices have the potential of reversing and restoring soil health, degraded/denuded land, thus ensuring increased land productivity, providing more farm employment opportunities and therefore food security as well as improving farm incomes (Thorlakson, 2010; Molua, 2003; Tsunehiro, 2010). Agroforestry can also be used as a complementary or alternative agricultural practice especially where others are limited by climatic conditions. Currently, land degradation, soil erosion and declining soil fertility has constrained sustainable use of existing agricultural land thus leading to the increased need to practice agroforestry (Franzel *et al*., 2001). This paper aims to evaluate the influence of production risk on net returns of various agroforestry enterprises, and, determine the trade-off between the variability of net returns and expected returns to farm resources.

Analytical model

Optimization theory postulates that agricultural households allocate their production resources to optimize the trade-off between mean income and its variability in the presence of production risk (Janvry and Sadoulet, 2003). To model this, different approaches have been employed. The Target Minimization of Total Absolute Deviation (T-MOTAD) is an approach in resource allocation and risk analysis that incorporates a target (safety level of) income while also allowing negative deviations from that safety level (Boisvert and McCarl, 1992). The model has two main weaknesses, namely, the specification of target income and the maximum amount of income shortfall permitted. In order to overcome these weaknesses, one must have *a priori* information on the break-even point of the enterprises in consideration thus limiting its applicability.

The stochastic programming approach is another approach which involves the incorporation of a probability distribution in a linear programming model. In this case, decisions are made now with the uncertain outcomes resolved later. The optimal plan for a stochastic model does not place the decision maker in the best possible position for all or any states of nature, but rather establishes a robust position across the set of possible events (McCarl and Spreen, 1997). The main limitation of this model is that it is data intensive and is used for short term policy briefs.

Quadratic programming is yet another method which involves the use of non-linear forms of the mean absolute deviations. The model is limited by its non-linearity nature which complicates its estimation (McCarl, 1998).Due to limitations of the above models, MOTAD model developed by Hazell (1971) was chosen for this study. According to McCarl and Spreen (1997), MOTAD model is commonly used in agricultural economics due to several reasons, namely, the model is linear in nature, thus making its estimation process simple. In addition, it does not ignore variable covariance since the deviation equations add across all the variables, allowing negative deviation in one variable to cancel positive deviation in another. The model is also sensitive in the sense that results adhere to the efficient frontier which is crucial for decision making.

A condition for the use of MOTAD model is that one must have empirical values for the risk aversion parameter. The procedure involves parameterizing the risk aversion coefficients in small steps from 0 to 2, at each point computing a measure of the difference between the model solution and observed behavior (McCarl and Spreen, 1997; Aye and Oji, 2010). The general form of the ordinary profit maximization model in LP is expressed as:

Max Ax (1)

Subject to: $Mx \leq B$ (2)

$x \geq 0$ (3)

Where x is N by 1 column vector of activity levels, A is the matrix of objective function coefficients, M is the matrix of constraint technical coefficients and B is the vector of available resources.

The simple LP model (as shown in the above equations) is then transformed into MOTAD model by introducing risk through incorporation of means and absolute deviation from the mean. The MOTAD model entails a trade-off between expected returns and risk. Thus efficient actions are those that maximize expected returns for a given absolute deviation or minimize absolute deviation for a given level of expected return (Hazell, 1971). According to Bruce *et al*., (1997), the total absolute deviation of income from the mean income under the k^{th} state of nature (D_k) is given as:

$$D_k = |\left(\sum_j c_{kj}\, x_j\right) - \left(\sum_j \bar{c}_j\, x_j\right)| \quad (4)$$

Where c_{kj} is the per unit net return to x_j under the k^{th} state of nature, $\bar{c}_j$ is the mean, x_j is the j^{th} activity. The x_j can be factored out as:

$$D_k = |\sum_j \left(c_{kj} - \bar{c}_j\right) x_j| \quad (5)$$

Total absolute deviation (TAD) is the sum of D_k across the states of nature. Then introducing deviation variables d_k^+ and d_k^- to respectively depict positive and negative deviations, TAD can be expressed as:

$$TAD = \sum_k D_k = \sum_k \left(d_k^+ + d_k^-\right) \quad (6)$$

Where $\sum_j \left(c_{kj} - \bar{c}_j\right) x_j - d_k^+ + d_k^- = 0$; for all k (7)

Given that the sum of positive deviations about the mean are always equal to the sum of negative deviations, TAD is written in terms of the negative deviations from the mean as:

$$TAD = \sum_k D_k = \sum_k \left(d_k^+ + d_k^-\right) = 2\sum_k d_k^- \quad (8)$$

Subtracting the TAD from the mean net returns the MOTAD model's objective function is obtained which maximizes the mean net returns less the risk aversion coefficient times the TAD. The general MOTAD model is given as:

$$\max z = \sum_{j=1}^{n} \bar{c}_j\, x_j - 2\psi \sum_k \left(d_k^-\right); \quad (9)$$

Where ψ is the risk aversion coefficient;

For a normally distributed population of sample size *n*, the measure of risk is estimated from the standard error of the observations which is obtained by dividing the TAD by *n* and then multiplying it by a constraint:

$$\sigma = \left[\frac{\pi n}{2(n-1)}\right]^{0.5} \frac{TAD}{n} \quad (10)$$

The MOTAD model is then explicitly stated as follows:

$$\max z = \sum_{j=1}^{n} \bar{c}_j\, x_j - \psi\sigma \quad (11)$$

subject to

$$\sum_k \left(c_{kj} - \bar{c}_j\right) x_j - d_k^- \geq 0 \quad (12)$$

$$\sum_k d_k^- - TND = 0 \quad (13)$$

$$\left[\frac{\pi n}{2(n-1)}\right]^{0.5} \frac{TAD}{n} - \sigma = 0 \quad (14)$$

$Mx \leq B$ (LP constraints as indicated above) (15)

$x_j, TND, TAD, \psi, \sigma, d_k^- \geq 0$ (non- negativity constraint) (16)

Where z is the mean net income less risk aversion which is maximized, d_k^- is the absolute value of the negative deviations from the mean in the k^{th} state of nature, c_{kj} is the j^{th} enterprise gross margins in the k^{th} state of nature, ψ is the risk aversion coefficient, σ is the approximate standard error of revenue, $\bar{c}_j$ is the average gross margins for the j^{th} enterprise, $\sum_k \left(c_{kj} - \bar{c}_j\right) x_j$ is the total deviation of enterprise gross margins from average gross margin in the k^{th} state of nature and TND is the total negative deviations from the mean.

EMPIRICAL MODEL

The farm model considered five farming enterprises namely; maize, beans, avocado, Napier and timber trees. The farming resources examined include land holding, labor (both family and hired labor), capital (own and borrowed). The subsistence requirement constraints which is the amount of maize and beans required to feed the family was also considered. From the food balance sheet of 2005, 118 Kgs of maize and 26 Kgs of beans per person per year was used as the minimum food requirement. The study assumed that the farm resources were managed rationally under the prevailing technology and economic condition to maximize the farm returns.

The average profit margins obtained were used in the MOTAD model as technical coefficients of the objective function. Analysis of the MOTAD model was then done by parametrically running the model with regard to mean income and minimizing deviation to develop the mean-variance frontier (Hazell and Norton, 1986).

In this study, the empirical model was specified as:

$$\max z = \sum_{j=1}^{n} \bar{c}_j x_j - \psi\sigma \quad (17)$$

subject to

$\sum_{i=1}^{n} a_{ij}\, x_j \leq L$ Land constraint (18)

$\sum_{i=1}^{n} w_{ij}\, x_j \leq W$ Labor constraint (19)

$\sum_{i=1}^{n} k_{ij}\, x_j \leq K$ Capital constraint (20)

$\sum_{i=1}^{n} f_{ij}\, x_j \geq F$ Subsistence constraint (21)

$\Sigma_k(c_{kj} - \bar{c}_j)x_j + d_k^- \geq 0$ M0TAD constraint (22)

$\sigma, d_k, x_j \geq 0$ Non-negativity constraint (23)

Where z is the average net returns measured in Kshs per unit of land, $\bar{c}_j$ is the mean gross margin for enterprise j measured in Kshs/ hectare, ψ is the risk aversion coefficient, σ is the approximated standard error of income, $(c_{kj} - \bar{c}_j)$ is the deviation from the value expected for the j^{th} enterprise in k^{th} observation, d_k is the deviation of net returns from the mean, x_j is the quantity of output associated with enterprise j, a_{ij} is the amount of land devoted to farm activity j by farmer i, L is the total amount of land resource cultivated by the farmer, w_{ij} is the amount of labor required for farm activity *j* per hectare by farmer i, W is total amount of labor available to farmer, k_{ij} is the amount of physical capital required per hectare of activity j by farmer i, K is the total amount of capital that is owned by farmer i, f_{ij} is the amount of output per hectare of activity j required for household subsistence purposes by farmer i and F is the minimum amount of food required for the household.

Study area, sampling and data sources

The study was conducted in Mbooni West district of Makueni County targeting small scale farmers who practice agroforestry as part of their farming activities. The area is mountainous and is characterized by low and unreliable rainfall averaging between 750 and 1000mm p.a. Agriculture is the main source of livelihood although farmers engage in other income generating activities. The farming system predominant in the area is mixed farming. A typical farm in the area has food crops like white maize and beans as the main food staples while others include green peas, cassava, Irish and sweet potatoes and vegetables. Fruit trees grown in the area include avocado as the main fruit, mangoes, guavas and citrus fruits. Timber trees common in the area include eucalyptus and cypress. On livestock production, cattle, sheep, goat and chicken production are the most popular (Muricho, 2002).

The area is also characterized by land fragmentations and small land holdings. The soils in the study area are characterized by red clay and sandy soils which are sparingly distributed depending on the underlying parent rocks. The dominant vegetation in the area is bush land characterized by shrubs, Acacia *spp*. and semi-arid flora.

The information captured in the questionnaires was demographic data about the farmers, the inputs used in production and their costs, output and its value at different states of nature as well as alternative sources of off-farm income.

Multistage sampling technique was used to select 130 farmers required for the study. First the divisions, locations, sub-locations and villages from the study area were randomly selected. Then, systematic sampling was used to obtain the farmers respondents. Data were then collected through face-to-face interviews with farmers using pre-tested semi-structured questionnaires.

RESULTS AND DISCUSSION

Optimal solution of a simple deterministic linear programming model with and without subsistence requirements

From Table 1 below, the optimal solution for the deterministic ordinary linear programming model with subsistence constraint imposed requires 1.09 ha of land allocation to maize production, 1.35 ha to beans and 2.1 ha to timber trees, yield a net return of KSh 18,646/ha. On the other hand, without the subsistence constraint imposed, 2.33 ha of land is allocated to avocado and 4.04 ha to timber trees, with the combination producing a net return of KSh 34,256/ha. The average farm income as shown by the optimal net returns was high when no subsistence requirement constraints were imposed on the resource requirements. However, the model with the subsistence constraints coincided with the actual scenario on the ground where farmers allocated most of their resources to food production even though it may be less rewarding. This was done with the assumption that farmers were risk neutral.

Optimal values of the objective function under different risk aversion parameters

The optimal solution of risk neutral ($\psi = 0$) farmers coincided with that of a simple deterministic linear programming model with subsistence constraint. In this scenario, farmers' decision on the amount of each resource to devote in any particular production process depends on the expected yield from that particular enterprise. Assuming that farmers are risk neutral, a higher profit of KShs 18,646/ha is realized compared with KShs 17,958/ha for the risk averse farmers (Table 2).

As the risk aversion increases, the level of net returns decreases. This is because farmers tend to venture into farm activities which cushion them against the variability in net returns. From the results of the MOTAD model, it is clear that farmers in Mbooni West district use fruit crops (like avocado) as risk cushioning crops. This is shown by it relatively low variance in the variance-covariance matrix (Table 3). This is simply because fruit crops are used for both subsistence and cash purposes whereas some of their parts can be used to feed animals, hence their crucial role of risk cushioning.

From the variance-covariance matrix given below (Table 3), the variance of maize and beans which are the subsi-

Table 1. Optimal solution of a simple deterministic linear programming model (with and without subsistence requirements).

	With subsistence constraints	Without subsistence constraints
Net returns (Kshs/ha)	18,646.0	34,256.0
Optimal values of choice variables (hectares)		
Maize	1.09	-
Beans	1.35	-
Avocado	0.00	2.33
Napier	0.00	0.00
Timber trees	2.10	4.04

Source: own calculation.

Table 2. Optimal values of the objective function under different risk aversion parameters.

	Risk aversion coefficients $0 \le \psi \le 2$				
	$\Psi = 0$	$\Psi = 0.5$	$\Psi = 1$	$\Psi = 1.5$	$\Psi = 2$
Optimal profit (KShs/hectare)	18,646	17,958	17,697	17,436	17,175
Optimal planting area (hectares)					
Maize	1.09	1.09	1.07	1.07	1.07
Beans	1.35	1.35	1.32	1.30	1.30
Avocado	-	0.02	0.02	0.01	0.01
Napier	-	-	-	-	-
Timber trees	2.1	2.0	2.0	1.9	1.9
Optimal labor input (man days)	67.4	66.8	65.7	64.2	64.1
Optimal capital use (Kshs)	2280.7	2252.0	2238.4	2215.5	2215.3

Source: Own calculation.

Table 3. Enterprise variance–covariance matrix.

Enterprise/farming activity	Maize	Beans	Avocado	Napier	Timber trees
Maize	**150,599,351**				
Beans	21,724,203	**6.99142E+16**			
Avocado	6,794,119	1,294,922	**28,688,904**		
Napier	5,495,214	5,565,569	5,408,347	**19,012,158**	
Timber trees	182,552,549	25,846,059	99,008,804	133,951,116	**9,873,712,398**

*****The variances are in bold, the rest are covariances.
Source: Own calculation.

stence crops is relatively low compared to that of timber trees which is mainly grown for cash purposes. This implies that the net returns from annual food crops do not vary much compared to that of timber trees, and that is the reason as to why farmers give priority to the production of food crops.

This implies that any rational farmer would prefer to devote their production resources to the less variable crops (in this case maize and beans) whose output is more certain other than the highly variable and more promising but more risky activities like timber trees. As the variability of net return increase, expected returns to farm resources also increase. This supports the theory that highly risky enterprises have attached to them a commensurate high income.

The above observations imply that popular cropping pattern practiced by the small scale farmers may not be optimal and profit maximizing but it is rational since it is risk minimizing. Bearing in mind that small scale farmers are subsistence oriented, they cannot afford to forgo their low return food crop production to embrace the high return cash crops given that the income from cash crops (like timber trees) is not instant and is also subject to price and other market related risks.

From the results of deterministic ordinary linear programming model with and without subsistence requirement (Table 1), it is clear that farmers give priority to food production (maize and beans) over the production of other crops. A similar study by Nyikal and Kosura (2005) ascertained that farmers tend to prioritize food production by devoting more of their production resources to it compared to commercial crops. By so doing, they accrue lower profits with their subsistence requirements imposed than without subsistence requirement. In this scenario, optimal land allocation to avocado which is produced for both household consumption and sale increases from zero acreage with subsistence constraint to 2.33 ha without the subsistence constraint. This implies that avocado production is grown by the rational farmers in Mbooni West District as a cushioning activity, which would be more profitable to farmers if it was grown as a commercial crop.

From the results of the MOTAD model (Table 2), the introduction of quantified risk levels led to lowering of the farm income from different farm plans. Although an increase in risk aversion leads to reduced net returns which may not be profit maximizing, it is optimal in the sense that it is efficient in terms of resource-use. In addition, farmers tend to focus on the production of subsistence crops and in the process overlook higher value crops which are less subsistence and more market oriented and which would entail more specialized enterprise choices and high returns than were actually observed. This is an indication that, with current resource bundles and unchanged market prices, there is some untapped opportunity for increasing farm income. A study by Kuyia *et al*., (2010) indicated that farm plans are sensitive to the risk criteria. Further, the presence of high value enterprises in the risk efficient farm plans indicates that there is scope to raise farm income even under conditions of risk. Enterprise mix in the farm plans varies as influenced by the risks associated with the enterprises and feasibility of production as dictated by farm resource constraints.

CONCLUSION AND RECOMMENDATIONS

The simple deterministic linear programming model indicated that farmers accrue a higher net return from their farming activities assuming that no production risk and in a certain production environment. With the imposition of subsistence constraint, farmers realized lower net returns compared with the situation where no subsistence constraint. This was because their priority was to meet their family food requirements. In this case, more of the production resources were devoted to the production of food, which is the risk minimizing but not optimal strategy. However, the assumption of a risk-free environment does not exist in reality and hence the need to incorporate risk in the analysis.

The results of the MOTAD model showed that the farm enterprise mix was influenced by the risk associated with the enterprises and the feasibility of production as dictated by farm resource constraints. The magnitude of farmers' risk aversion also influenced the trade-off between food production and production of other crops. This implies that farmers are sensitive to the risks associated with various farm activities and therefore tend to minimize them through production of the relatively income stable enterprises such as food rather than cash crops. Although this tendency may not be profit maximizing, it reveals farmers' rationality in their production decisions.

The results of this study suggest that the resource allocation behavior of smallholder farmers towards food production reduces their efficiency in production. This is because more farm resources are devoted to the production of the low return food crops relative to the high return cash crops. However, in the case of Mbooni West District, this tendency reflects a rational but not optimal behavior given that farmers in the study area were not food self-sufficient.

Based on the findings of this study the following is recommended. First, policy strategies should be put in place to educate farmers on the importance of intensifying timber tree production, which is highly paying compared to the preferred food crops. In so doing, they will be able to accrue more income from the farms and therefore be able to buy food in addition to meeting other financial needs.

In order to make timber trees production to be an attractive venture to farmers, appropriate measures can be put in place to reduce price and other market related risks. This may require the establishment of more stable and predictable markets for the trees which can cushion the farmers against price and other market related risks. For instance, attractive input and output prices can be set by government. This in turn would increase input use thereby resulting in increased crop yields.

In addition, farmers should be trained on the importance of specialization as a way of improving their farm productivity and income. Given small land sizes and relatively abundant labor as seen from the analyses, land productivity needs to increase in order to increase labor productivity and farmer income. This can be achieved through specialization towards market-oriented production of high value enterprises such as timber trees.

Given that timber trees take relatively longer period of time (5-10 years) before yielding any returns to the farmers compared to maize and beans, strategies can be put in place to provide financial support to the framers as they await the trees to mature. This may include providing “soft” loans in terms of cash and other farm assets. By so doing, farmers will be able to meet their consumption requirements even before selling their crop hence a source of incentive to increase the production of the high return cash crops.

In addition, farmers should be encouraged to take in more off-farm and non-farm jobs, since this income provides a reliable option through which rural households can secure their livelihoods. There is also need to establish linkages between agroforestry farmers and organizations such as TIST that does carbon trading. This will help the farmers to benefit financially and also reduce accumulation of carbon dioxide hence conserving the natural environment. In general, any innovations made at the farmer level must be able to address and cushion the small scale farmers against all forms of production risk.

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