Optimal resource utilization for enhancing household food security in Vihiga district, Kenya: Linear programming approach.

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Abstract
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Linear programming was applied to household data in Vihiga district to determine optimal resource levels and associated costs of meeting household food needs. Cluster sampling was used with divisions forming the main clusters in the district. Using systematic random sampling, 50 households were selected from each cluster resulting in a sample of 300. Results show that meeting domestic food needs, though attainable, must be accompanied by strict adherence to recommended agronomic practices. Rural folks are more vulnerable to escalating production cost than their urban counterparts.

Key Words: *Food security, optimal resource utilization, linear programming, Vihiga, Kenya.*

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AFFIRMATION STATEMENT

We hereby affirm that this work is our original research and has not been published or presented elsewhere for consideration.

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1 Introduction

Despite having the potential to meet domestic food demand, Kenya continued to face persistent food deficits over the last two decades. Over the last six years the annual demand for maize in the country rose from 29.5 million bags to 32.9 million bags (GOK, 2004). However, annual production ranged between 25 and 30 million bags in the same period thus necessitating importation of food to meet the deficit.

Vihiga, one of the poorest and densely populated districts in Kenya with an average household land size of less than 0.4 hectares is perpetually food deficit (GOK, 2004). This has been attributed to limited land, high poverty levels, limited off-farm income, and non-adoption of recommended farm technologies. Maize is the main staple food for residents of Vihiga district thus its insufficiency is synonymous with food insecurity. Over the last decade, the district maize demand outpaced local production worsening the already bad food deficit situation.

Food security describes a situation in which people do not live in hunger or fear of starvation. According to FAO (2003), food security exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Food security can therefore be assured by tackling both demand side and supply side constraints. Addressing demand side constraints encompasses measures that attempt to improve access to food by improving purchasing power of individuals through putting money in people's pockets. Addressing supply side constraints entails empowering individuals or households to access and utilize inputs optimally to maximize output while keeping the cost of production as low as possible.

As poverty levels rise, household food insecurity in the district worsens. Families with the financial resources to escape extreme poverty rarely suffer from chronic hunger; while poor families not only suffer the most from chronic hunger, but are also the segment of the population most at risk during food shortages and famines (FAO, 2003). Vihiga district has unfavorable poverty indicators as measured by food poverty, absolute poverty and hard-core poverty. About 57.6 percent of the population in Vihiga district lives below the absolute poverty line, which is set at US$ 34.39 and US$ 16.08 per month for urban and rural areas respectively (GOK, 2004). Similarly, more than half of the households in Vihiga, which is one of the worst hit districts in Kenya, fell below the absolute poverty line. Poverty has a twin impact on household food security.

It not only reduces the capacity of households to access farm inputs due to capital limitations thus hindering expanded food production, but also prevents households from accessing food due to their low or non-existent purchasing power. Poor welfare indicators and the failure of majority of farmers to meet targeted production in the district raise a number of questions. In their current financial status is it possible for households in Vihiga district to optimally produce maize to meet their food security requirements? If so, what levels of inputs should be used and what is the cost associated with such input combination? The paper examines the optimal input levels required to facilitate households in making rational production decisions that will at least enable them address their food needs from the supply side. The paper is subdivided into four sections. In section one, an introductory exposition of the problem is presented. In section two, materials and methods are presented with key considerations being the review of the theoretical framework and various methodologies used. In sections three and four, results and discussions followed by conclusions of the study are presented.

2 Materials and Methods

2.1 Theoretical considerations

2.1.1 Modeling Production Behavior

Producer's objective in a classical sense is to maximize output so as to reap more profits. Such behavior can be modeled using a profit function approach, production function approach, cost function approach, or through mathematical optimization and dynamic programming. In a subsistence economy like the one prevalent in Vihiga district, Kenya majority of households produce food entirely for domestic consumption. Such households are therefore driven by the desire to meet food security needs rather than the profit motive. Therefore modeling using the profit approach for a commodity that is not marketable may not be appropriate. Production functions and cost function approaches can be used to model producer behaviors in a set up with minimal marketed commodity. The cost function is one of the behavioral relationships that arise from producers' optimizing decisions. The cost function is the minimum variable cost of producing the given output. This function completely characterizes the producer behavior, as it includes both the technological constraint from the production function and the behavior of the producer (De Janvry, 1993). The cost function approach, without loss of generality, still results in the same optimal solution since it is the dual of the production function approach (Epstein, 1981, Varian, 1992, Jehle, 1998, Mas colell et al, 1995). However, while stochastic analysis of profit, production and cost functions determines the significance of some variables, it does not tell us how much of each variable input should be used to achieve optimal output. This calls for application of other analytical tools for solving the cost minimization problem. Such tools include mathematical optimization and dynamic programming. Linear programming is premised on three key assumptions namely: - proportionality and additivity assumptions, divisibility assumption and certainty assumption (Wayne, 1991). The implications of the proportionality and additivity assumptions is that the contribution to the objective function or the left hand side of constraints from each decision variable apart from being proportional to the value of the decision variable, should be independent of the values of other decision variables. The divisibility assumption requires that each decision variable be allowed to assume fractional values. The certainty assumption on the other hand requires that each parameter (objective function coefficient, right hand side and technological coefficient) be known with certainty. When any of these assumptions is violated a linear programming model breaks down. Alternative models that could be used when linear programming model fails include integer programming, goal programming and non-linear programming. However, since all decision variables satisfy the three assumptions linear programming was used to determine optimal input combinations that will at least enable households in Vihiga district to be self-sufficient in food supply.

2.1.2 Model Specification

In an effort to come up with policy alternatives for enhancing food security, the study used linear programming to model household production behavior. Six commonly used farm inputs were incorporated into the linear programming problem (LPP) model. Using agronomic recommendations and FAO food security requirements seven constraints were identified. During the LPP formulation the key decision variables identified were as follows: -

$\boldsymbol{X}$ = a vector of household annual input demand (man-hours, metric tons, US$), $\boldsymbol{X} = (X_1, X_2,.. X_6)$.
$\boldsymbol{W}$ = a vector of annual average input prices (Kshs), $\boldsymbol{W} = (W_1, W_2,..W_6)$.

The names of the six input variables are given in table 1 below: -

Table 1: Input variable description

Variable label	Variable name
X_1	Household annual labor demand (man-hours)
X_2	Household annual maize seed demand (metric tons)
X_3	Household annual land resource demand (hectares)

X_4	Household annual DAP fertilizer demand (metric tons)
X_5	Household annual CAN fertilizer demand (metric tons)
X_6	Household annual capital (loan) demand (US$)

The full LPP model for households living under absolute poverty is as follows: -

$Min\ Z = \boldsymbol{WX}$

Subject to:

1) $X_4/X_3 \geq 0.3125\ tons$/hectare (DAP application rate)
2) $X_5/X_3 \geq 0.1875\ tons$/hectare (CAN application rate)
3) $X_2/X_3 \geq 0.0625\ tons/hectare$ (maize seed application rate)
4) $X_3 \leq 0.6\ hectares$ (household land availability constraint)
5) $\omega X_3 \geq 0.54\ tons$ (household food security constraint), where ω is maize yield in tons per hectare.
6) $\mathbf{WX} \leq$ US$193.09 (Absolute household poverty constraint for rural group)

Or

7) $\boldsymbol{WX} \leq US\$412.68$ (Absolute household poverty constraint for urban group)
8) $\boldsymbol{X} \geq \boldsymbol{0}$(non-negativity constraint)

When constraints 1, 2, and 3 are rewritten the LPP model specification becomes: -

$Min\ Z = \boldsymbol{WX}$

Subject to:

1) $X_4 - 0.3125X_3 \geq 0$ (DAP application constraint)
2) $X_5 - 0.1875X_3 \geq 0$(CAN application constraint)
3) $X_2 - 0.0625X_3 \geq 0$(maize seed application constraint)
4) $X_3 \leq 0.6\ hectares$ (household land availability constraint)
5) $\omega X_3 \geq 0.54\ tons$ (household food security constraint)
6) $\mathbf{WX} \leq$ US$193.09 (Absolute household poverty constraint for rural group)

Or

7) $\boldsymbol{WX} \leq US\$412.68$ (Absolute household poverty constraint for urban group)
8) $\boldsymbol{X} \geq \boldsymbol{0}$(non-negativity constraint)

When the various coefficients are incorporated in the model, the final model to be estimated is given as:-

$Min\ Z = 0.103X_1+1.73X_2+0.51X_4+0.52X_5+ 0.0173X_6$

Subject to:

1) $X_4 -0.3125X_3 \geq 0$
2) $X_5 -0.1875X_3 \geq 0$
3) $X_2 -0.0625X_3 \geq 0$
4) $X_3 \leq 0.6$
5) $1.748X_3 \geq 0.54$
6) $0.103X_1+1.73X_2+0.51X_4+0.52X_5+ 0.0173X_6 \leq 193.09$

Or

7) $0.103X_1+1.73X_2+0.51X_4+0.52X_5+ 0.0173X_6 \leq 412.68$
8) $\mathbf{X} \geq \mathbf{0}$(non-negativity constraint)

2.2 Methodologies

The study targeted all farm households in Vihiga district. Cluster sampling was adopted on the basis of the six divisions. Using systematic random sampling procedure, 50 households were selected from each cluster generating a sample of 300 respondents. Both primary and secondary data was used. Types of data collected encompassed area allocated to maize in acres, yield in tons per acre, output in metric tons, farm input prices. Primary data was collected through a survey while secondary data was acquired through perusal of annual agricultural reports, economic surveys, statistical abstracts and development plans. Both interviews and questionnaires were used as instruments for data collection. To validate survey instruments, 10 questionnaires were pre-tested in one of the divisions, revised and forwarded to enumerators. Trained enumerators were used to administer the questionnaires. Focused group discussion was used to elicit information from key informants who included district agricultural officer, district development officer, heads of district non-governmental organizations, divisional agricultural extension officers, field extension workers and local administration. Observation was used to countercheck some of the findings. Descriptive statistics especially measures of central tendency were used to isolate the unique characteristics of an average household in Vihiga district using SPSS. Subsequently, the coefficients generated from descriptive statistics were used to formulate a linear programming problem. Lindo was used to solve the linear programming model.

3 Results and Discussion

Table 2 shows objective function and variable values as well as reduced costs for a production cost minimization problem for residents of Vihiga district, Kenya.

Table 2: Lindo Output for production cost minimization problem

	With current fertilizer prices		When fertilizer prices are doubled	
Variable	**Value**	**Reduced cost(US$)**	**Value**	**Reduced cost(US$)**
Objective function	US$ 112.35		US$ 191.35	
X_1	0	0.102	0	0.102
X_2	0.0193 tons	0	0.0193 tons	0
X_4	0.0966 tons	0	0.0966 tons	0
X_5	0.0579 tons	0	0.0579 tons	0
X_6	0	0.017	0	0.017
X_3	0.309 hectares	0	0.309 hectares	0

Source: Derived from authors' survey, 2006

Results (table 2) show that despite rampant poverty, it is possible for households in Vihiga district to optimally produce maize to meet their food security requirements. The optimal solution is to combine 0.019 tons of hybrid maize seed, 0.0966 tons of di-ammonium phosphate (DAP) fertilizer, and 0.0579 tons of calcium ammonium nitrate (CAN) fertilizer on land area equivalent to 0.309 hectares annually. The objective function value on the Lindo output shows that the cost of this input combination is US$112. Doubling the cost of fertilizer as happened in the aftermath of the post election violence in early 2008 not only raises the minimum cost of production to US $ 191.35 which is still affordable by both the rural and urban folks, but squeezes the amount of money remaining for both the rural and urban groups for addressing other household needs. However, the rural folks seem to be more vulnerable to increasing cost of production than their urban counterparts since they are left with only US$ 1.74 to address other family needs for the whole year as compared to the urban group who have US$221. From the reduced cost column (table 1), results show that any decision to hire an extra unit of labor will increase the cost of production by US$ 0.10 per man hour. Similarly, if a household were forced to borrow from financial institutions to support production activities such a decision will increase the cost of production by US$ 0.017 for every dollar borrowed.

Table 3 shows the Lindo output for slack/surplus values and dual prices.

Table 3: Lindo Output for Slack and Dual Prices

	With current fertilizer prices			When fertilizer prices are doubled		
	Slack/surplus		Dual prices(US$)	Slack/surplus		Dual prices(US$)
Row	Rural folks	Urban folks	Rural folks/ Urban folks	Rural folks	Urban folks	Rural folks/ Urban folks
2	0.00	0.00	-0.51	0.00	0.00	-1.013
3	0.00	0.00	-0.52	0.00	0.00	-1.039
4	0.00	0.00	-1.72	0.00	0.00	-1.727
5	0.291	0.291	0.00	0.291	0.291	0.00
6	0.00	0.00	-0.21	0.00	0.00	-0.354
7	80.73	300.31	0.00	1.741	221.33	0.00

Source: Derived from authors' survey, 2006

The slack or surplus column (table 3) shows that the fourth constraint (household land availability) has an excess of 0.291 hectares and sixth constraint (absolute household poverty) has an excess of US$80.7 for the rural folks. Thus land and poverty constraints for the rural folks are non-binding. Since the urban folks are more resource endowed than the rural folks they are able to achieve the optimal resource utilization with an excess income of US$ 300 which they can use to address other family needs. DAP, CAN, seed maize, and household food security constraints have no excess and are therefore binding constraints. Therefore despite living on less than a dollar a month and characterized by small pieces of land, households in Vihiga district, Kenya have the potential of producing enough food for domestic consumption. This can only be attained if they adhere strictly to the recommended agronomic practices which has been lacking amongst majority of the households in the district. Similarly, they could still be able to produce more by utilizing the surplus land resource available assuming they apply all the inputs at their optimal levels

4 Conclusions

Vihiga, one of the poorest and densely populated districts in Kenya is perpetually food deficit. Poor welfare indicators and failure of farmers to meet targeted production raise a number of questions. In an attempt to determine the feasibility of households to produce maize optimally to meet food security requirements, given their level of poverty, a linear programming model was applied to household survey data in Vihiga district.

It is concluded that its optimal to combine 0.019 tons maize seed, 0.097 tons of phosphate fertilizer, 0.058 tons nitrate fertilizer and 0.309 hectares of land annually to produce maize in sufficient quantities to meet food needs of households in Vihiga district. This optimal resource combination has an associated cost of US$112. However, achieving the optimal solution requires strict adherence by households to recommended agronomic practices in the areas of seeding and fertilizer application rates.

It is also concluded that rural folks are more vulnerable to escalating cost of production due to their lower resource endowments as compared to their urban counterparts. This, subsequently, squeezes their remaining resources for addressing other family needs.

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