Journal of Agriculture, Environmental Resources and Management

Journal of Agriculture, Environmental Resources and Management
ISSN2245-1800(paper) ISSN 2245-2943(online)
5(6)1-800; **DEC**.2023; pp1022-1037

www.saerem.com

Farm Plans Optimization for Cassava Based Farmers in Enugu State, Nigeria: An Application of Linear Programming (Lp) and Target Minimization of Total Absolute Deviation (T-Motad)

[1]Onu, D. O., [2]Somonyan, J. B. and [3]Igwe, K.C.

[1.2..3]Department of Agricultural Economics, College of Agricultural Economics, Rural Sociology and Extension, Michael Okpara University of Agriculture, Umudike, P.M.B 7267 Umuahia Abia State, Nigeria

Corresponding Author's Email: onu.donatus@mouau.edu.ng

ABSTRACT

The study developed an alternative farm plan involving risk constraint for smallholder cassava based farmers in Enugu State, Nigeria. Both primary and secondary data were used for the study. A structured questionnaire was used to obtain stratified randomly selected 240 farmers in the study area. Data were analyzed using descriptive statistics, farm budgeting technique, LP and T-MOTAD models. Seventeen major crop enterprises were identified as the existing crop plans. The optimum plan and risk efficient plan I prescribed five enterprises and 2.53 hectares. Specifically, the most important enterprises in the two plans were: Ca/Ym (0.51ha), Ca/Ok (0.43ha), Ca/Mz/Me (0.69ha), Ca/Mz/Ym (0.52ha) and Ca/Mz/Gn (0.38ha). The T-MOTAD model prescribed 0.55ha for Ca/Mz, 0.35ha for Ca/Ym, 0.27ha for Ca/Ok, 0.84ha for Ca/Mz/Me, 0.66ha for Ca/Mz/Ym and 0.45ha for Ca/Mz/Gn in risk efficient plan II. In risk efficient plan III, 0.42ha, 0.48ha, 0.41ha, 0.23ha, 0.64ha, 0.70ha and 0.49ha for Ca/Mz, Ca/Ym, Ca/Gn, Ca/Ok, Ca/Mz/Me, Ca/Mz/Ym and Ca/Mz/Gn respectively were prescribed for the farmers. Ca/Mz/Me/Co, Ca/Mz/Me/Co, Ca/Mz/Ym/Ok, and Ca/Mz/Ym/Pu in the optimum plan, risk efficient plans I, II and III respectively had the highest marginal opportunity cost values of ₦57,579.52, ₦57,278.84, ₦113,512.96 and ₦89,486.71 respectively. Gross margin increased from ₦244,225.17/ha in the existing plan to ₦303,132.28/ha in optimum plan, and to ₦291,238.52/ha, ₦298,345.47/ha and ₦280,687.99/ha in risk efficient plans I, II and III respectively. Labour and capital were the limiting resources in the study area. The study showed that the cassava farmers' existing level of returns were not optimal. It is recommended that the farmers should adopt the prescribed farm plans to improve their farm income and minimize risk.

Keywords: Resource allocation, Efficient, Cassava based Enterprises, yield variability; normative plan,

INTRODUCTION: Agriculture has continued to contribute immensely to the wellbeing of Nigerians as well as the economy of the country as it provides food, raw materials for agro-based industries as well as income to the farmers (Sani, Hanruna and Sirajo, 2013). Smallholder farmers who are key actors in economy of many countries of the world are characterized with limited level of resources and are faSced with the challenge of competing choices for allocating farm resources between different farm enterprises. The farmers' ultimate aim is to attain production objectives by making efficient utilization of the limited available resources at their disposal and combining farm enterprises optimally as affirmed by (Adewunmi, Tanko, Ibrahim and Yisa, (2021), Igwe, Nwaru, Igwe and Asumugha (2015)) Cropping plan decisions are the basic land-use decisions in farming systems and consist of at least, the choice of crops to be grown, their acreage and their resource allocation within a particular farmland (Bharwani, Besa, Fischer and Devisscher, 2015) These decisions mostly take place at the farm level and are usually part of the global technical management of farm production (Bharwani *et al,* 2015). A typical farm anywhere in the world is often encountered with the challenge as to what enterprise to undertake, the level it should be taken up and the optimal combination of enterprises to adopt. According to Egbodion and Ada-Okungbowa (2012), combination of farm enterprises in agricultural production economics is a needful relationship which involves allocating limited resources among two or more enterprises.

Foster and Rauser (1991) opined that smallholder farmers have two alternative decision criteria in farm planning. The first one is to allocate resources in a way to maximize farm profit, while the second one is to allocate resources in such a way that utility will be maximized by striking a balance between increasing expected income and minimizing variability to reflect risk behaviour. Risk according to Adubi (1992) is a pervasive phenomenon in any economic activity which is particularly important in traditional agriculture where it affects production decisions and adoption of technology among others. Many factors including weather, diseases, insect infestations, general economic conditions, the development and adoption of technological innovations, public and private institutional policies interact to create a unique decision making environment for the agricultural producer. Smallholder farmer's production decisions are generally made under this environment of risks and uncertainties.

Mathematical programming as an optimization tool has been used to study the problems of resource allocation among farmers. It provides prudent solutions to whole farm planning problems (Reddy, Ram, Sastry and Devi, 2004) These mathematical programming tools such as the quadratic programming (QP) along with linear programming/minimization of total absolute deviation (LP/MOTAD) models as seen in the works of Udo, Onyenweaku, Igwe and Salimonu (2015a) Udo, Kesit and Igwe (2015b) Adewunmi *et al*, (2021)and Okpanachi, Tanko and Ibrahim (2021) are the most recent and popular methods in the agricultural economics literature on risk-return analysis particularly in Nigeria. However, most of these research efforts aimed to inquire into the possibilities of maximizing farm production and income under the conditions of risk and uncertainty in Nigeria such as those of Adubi (1992), Umoh and Adeyeye (2000), Olarinde (2004), Umoh (2008), Salimonu *et al*. (2008), Udo *et al*. (2015a) and Udo *et al*. (2015b) has focused only on the arable cropping enterprises. No effort has been made to consider cassava based food crop enterprise in the risk programming models. In this study, the focus was on incorporating risk into farm planning model to derive integrated optimum cassava based enterprise combinations that will offer more realistic solutions and increase farm income for the smallholder cassava based farmers in Enugu State, Nigeria. Maximizing farm enterprise returns under limited resources and risk conditions by prescribing an efficient enterprise system is appropriate in improving the growth prospects of farm families particularly in terms of increased farm incomes and food security (Adewunmi *et al.,* 2021). Risk efficient farm enterprise plans will provide a valuable guide to existing and intending cassava based farmers and will be a huge step towards efficient resource allocation, increased production and income generation which will in the long run enhance food security and improve the farmers' standard of living It is against this backdrop that this study sought to determine the optimum production plan for cassava-based crop farmers under risk conditions using risk programming models in Enugu State, Nigeria.

MATERIALS AND METHODS: The Study Area.: The study was conducted in Enugu State, Nigeria. Enugu State is one of the 36 states in Nigeria, located at the southeast geopolitical zone of the country. It lies between latitudes 70 061N and 70 05N of the Equator and longitudes 6° 53/E and 70 55/E of the Greenwich meridian (Enugu State Agricultural Development Project [ENADEP], 2018). Enugu State shares boundaries in the East with Ebonyi State, in the North with Benue and Kogi States, in the south with Abia State and in the West with Anambra State. The state occupies an area of about 8,022.95 km2 with a population of about 3,257,298 (ENADEP, 2018). The state has seventeen Local Government Areas (LGAs). According to Enugu State Agricultural Development Project ENADEP (2012),

Sampling Procedure: A multi-stage sampling procedure was employed for this study. All smallholder cassava based food crop farmers in Enugu State constituted the population of study. The farmers were identified and selected with the assistance of the village heads and the resident extension agents. A total of 240 cassava based farmers were sampled for the study.

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Method of Data Collection : This study made use of both primary and secondary data. The primary data were obtained through the use of structured questionnaire for the selected cassava based farmers. Information on resources employed – land, (hectares of crops farmed by the farmers in a production season) capital, labour (labour use in terms of number of people and hours), material inputs, cropping patterns, yield, revenue earned from sale of farm products, amount and interest on loans were also collected. In addition, depreciated value of capital implement such as cutlasses, hoes basins, wheel barrow were obtained. Secondary data were sourced from the state Agricultural Development Programmes, the Nigeria Bureau of Statistics (NBS), the Central Bank (CBN) and other publications relevant for the study. The secondary data from the State's ADP provided the information on monthly yields and returns of selected cassava based crops from 2016 to 2021 to determine yield variability to be considered as risk constraint in the study area. The Consumer Price Index (CPI) from 2016 to 2021 were obtained from the CBN Statistical Bulletin. This was used to remove or address the influence of inflation in the output values of the selected crops used for this study.

In computing the average costs and returns per hectare for the various crop enterprises, the open market prices were used to value the inputs and outputs. Two ADP extension agents, with one well-trained enumerator were hired to assist the researcher in data collection using designed questionnaire. The cassava based food crop farmers were identified and selected with the assistance of the village heads and the resident extension agents..

Analytical Techniques : Data analysis involved the use of farm budgeting model, linear programming and target-minimization of total absolute deviation (T-MOTAD) models. A farm budgeting model was used to estimate the costs and returns associated with the various cassava based enterprises undertaken by the smallholder farmers. The gross margins (GM) as well as the corresponding net farm incomes (NFI) were computed. The farm budgeting model following Ibeun, Ojo, Mohammed, and Adewunmi (2018) and Adewumi *et al.* (2021) was used and is specified in equation 1 and 2

$$\text{GM} = \sum_{i=1}^{n} P_{yi}Y_i - \sum_{j=1}^{m} P_{xj}X_j \qquad \ldots(1)$$

$$\text{NFI} = \sum_{i=1}^{n} P_{yi}Y_i - \sum_{j=1}^{m} P_{xj}X_j - \sum_{k=1}^{o} F_k \qquad \ldots(2)$$

Where;
GM = Gross Margin,
NFI = Net farm income,
Y_i = Output per unit enterprise (where i = 1, 2, 3… n products),
P_{yi} = Unit price of the product,
X_j = Quantity of the variable inputs per unit enterprise (where j =, 1, 2, 3… m variable inputs),
P_{xj} = Price per unit of variable inputs, and
F_k = Cost of fixed inputs per unit enterprise (where k =, 1, 2, 3…, o fixed inputs).

Linear programming (LP) model was used to derive optimum cassava based enterprise combination plan for the smallholder farmers in the study area. The LP model adopted from Igwe *et al.* (2013), Jirgi *et al.* (2018) and Adewunmi *et al.*, (2021) and modified for this study is specified in equation 3. The objective function of the Linear programming model was to maximize the gross margin of the smallholder cassava based food crop farmers for each enterprise undertaken which is total farm revenue less the total variable costs of production, that is gross income minus costs of planting materials, agrochemicals, labour, and transportation.

Generally, the linear programming model is given as follows:

$$\text{Maximize } Z_i = \sum_{j=1}^{n} P_i X_j \ (j = 1, 2\ldots.n) \qquad \ldots (3)$$

Subject to:

$$\sum_{j=1}^{m} A_{ii} X_j \leq b_i t \ (i = 1,2,\ldots,m \qquad \ldots(4)$$

and
$X_j \geq 0$ for all j_s
Where:
Z_i = Net Farm Income
X_j = Activity or enterprise undertaken (decision variable),
P_j = Output coefficient or net price (gross margin/unit) of each enterprise activity maximized,
= Input-output coefficients, that is, quantity of ith resource required to produce a unit output of jth activity.
βit = Level of available resources for enterprises in tth period,
The model for determining the optimum farm plans can also be expressed explicitly by the equation:
Maximize $Z = P_1X_1 + P_2X_2 + P_3X_3 + \dots + P_8X_8$ …(5)
Subject to:
$A_{11}X_1 + A_{12}X_2 + A_{13}X_3 + \dots + A_{18}X_8 \leq L_S\,(Land)$
$A_{21}X_1 + A_{22}X_2 + A_{23}X_3 + \dots + A_{28}X_8 \leq H_t\,(Labour)$
$A_{31}X_1 + A_{32}X_2 + A_{33}X_3 + \dots + A_{38}X_8 \leq C_t\,(Capital)$
$A_{41}X_1 + A_{42}X_2 + A_{43}X_3 + \dots + A_{48}X_8 \leq S_t$ (planting materials)
$A_{51}X_1 + A_{52}X_2 + A_{53}X_3 + \dots + A_{58}X_8 \leq F_t\,(Fertilizer)$
$A_{61}X_1 + A_{62}X_2 + A_{63}X_3 + \dots + A_{68}X_8 \leq A_t\,(Agrochemical)$

and $X_1 \geq 0, X_2 \geq 0, X_3 \geq 0, \dots, X8 \geq 0$
Z - Gross Margin (₦/ha),

$X_1, X_2, X_3, X_4, X_5, X_6\ X_7, X_8$ - different crop activities or enterprises undertaken (decision variables), $P_1, P_2, P_3, \dots P_8$ - Output coefficients per hectare of the different crop activities maximized, Aij - Input- Output coefficient (quantity of i^{th} resource (land, labour, capital, planting materials, fertilizer, and agrochemical) required to produce a unit output of j^{th} crop activity,
Ls - Level of available land in hectare for crop activities with s restriction,
H_t - Level of available labour in man-day for crop activities in t^{th} period,
C_t - Level of available working capital in Naira for crop activities in t^{th} period,
S_t - Level of available seed in kilograms for crop activities in t^{th} period,
F_t - Level of available fertilizer in kilograms for crop activities in t^{th} period,
A_t - Level of available agrochemical in litres for crop activities in t^{th} period.

Target minimization of total absolute deviation (T-MOTAD) model was also used to analyse the data. To incorporate risk into the LP model, the modified T-MOTAD model adopted following Tauer (1983), Udo et al. (2015b) and Adewunmi *et al.*, (2021) was used. The optimum gross margins obtained from LP models for limited resources condition was used as the target return (Tr) in this model. The objective function was specified as

$$Max\ E(Z) = \sum P_j X_j \quad \dots(6)$$

Subject to:
$\sum A_{ij}X_j \leq \beta_i$ (Technical resources requirement for cassava based activities), …(7)
$\sum L_{ij}X_j \geq \delta i$ (Farm family cassava based food requirement), … (8)
$\sum CrjXj \geq Tr$ (Absolute deviations from Tr), …(9)
$\sum P_rY_r = \lambda$ (Risk:–ve deviations (₦)) …(10)
and $X_j \geq 0$ ...(11)
Where;
(Z) = Expected return per hectare of the plan (₦),
P_j = Output coefficients (gross margin) per hectare of cassava based enterprise (₦),
X_j = cassava based enterprise j undertaken (decision variables),
A_{ij} = Technical resource i requirement of cassava based enterprise j,
β_i = Level of available technical resource i,
L_{ij} = Minimum farm family cassava based food product i requirement of cassava based enterprise j,
δi = Level of cassava based food product i consumed,

C_{rj} = Level of total absolute deviations from target returns of cassava enterprise j for state of nature r in Naira,
T_r = Target level of return in Naira,
Y_r = Level of negative deviation below T_r for state of nature r in Naira,
P_r = Probability that state of nature r will occur, and
λ = A constant parameterised from M to 0.

RESULTS AND DISCUSSION: CASSAVA-BASED FOOD CROP ENTERPRISE COMBINATIONS UNDERTAKEN BY THE FARMERS IN SOUTHEAST NIGERIA AND THEIR COST AND RETURNS

Table 1 shows the summary of the various cassava-based food crop enterprise combinations undertaken by the farmers in Enugu State, Nigeria.

Table 1 Cassava-based food crop enterprise operated by farmers in Southeast Nigeria

S/N	Enterprise	Description	Variable Identifier	Freq.	%
1	Ca/Mz	Cassava/Maize	(X_1)	12	5.0
2	Ca/Ym	Cassava/yam	(X_2)	30	12.5
3	Ca/Me	Cassava/Melon	(X_3)	6	2.5
4	Ca/Pu	Cassava/Pumpkin	(X_4)	18	7.5
5	Ca/Gn	Cassava/Groundnut	(X_5)	6	2.5
6	Ca/Co	Cassava/Cocoyam	(X_6)	24	10.0
7	Ca/Ok	Cassava/Okra	(X_7)	6	2.5
8	Ca/Mz/Me	Cassava/Maize/Melon	(X_8)	60	25.0
9	Ca/Mz/Ym	Cassava/Maize/Yam	(X_9)	6	2.5
10	Ca/Mz/Co	Cassava/ Maize/Cocoyam	(X_{10})	6	2.5
11	Ca/Mz/Ok	Cassava/Maize/Okra	(X_{11})	18	7.5
12	Ca/Mz/Pu	Cassava/Maize/Pumpkin	(X_{12})	18	7.5
13	Ca/Mz/Gn	Cassava/Maize/Groundnut	(X_{13})	6	2.5
14	Ca/Ym/Ok/Pu	Cassava/yam/Okra/Pumpkin	(X_{14})	6	2.5
15	Ca/Mz/Me/Co	Cassava/Maize/Melon/Cocoyam	(X_{15})	6	2.5
16	Ca/Mz/Ym/Pu	Cassava/Maize/Yam/Pumpkin	(X_{16})	6	2.5
17	Ca/Mz/Ym/Ok	Cassava/Maize/Yam/Okra	(X_{17})	6	2.5
		Total	**80**	**240**	**100.0**

Source: Field survey data, 2023

A specific classification of the cassava-based enterprises, their respective identification codes and descriptions operated by smallholder cassava based farmers in Enugu State, Nigeria are presents in Table 1. The result showed that a total of seventeen (17) cassava based food crop enterprises were identified, in which all the combinations were mixed cropping system. These mixtures include: cassava/maize, cassava/yam, cassava/melon, cassava/pumpkin, cassava/groundnut, Cassava/Cocoyam, Cassava/Okra, Cassava/Maize/Melon, Cassava/Maize/Yam, Cassava/Maize/Cocoyam, Cassava/Maize/Okra, Cassava/Maize/Pumpkin, Cassava/Maize/Groundnut, Cassava/Yam/Okra/Pumpkin, Cassava/Maize/Melon/Cocoyam, Cassava/Maize/Yam/Pumpkin and Cassava/Maize/Yam/Okra. The identified seventeen (17) enterprise combinations were common systems of cassava-based food crop production combinations in the study area. These enterprises are similar to those of Adewunmi *et al*., (2018) who reported thirteen different cassava crop mixtures in Kwara state to include cassava/maize, cassava/melon, cassava/yam, cassava/sorghum, cassava/groundnut, cassava/soybean, cassava/yam/maize, cassava/maize/cowpea, cassava/sorghum/groundnut, cassava/maize/groundnut, cassava/yam/melon, cassava/soybean/maize, cassava/maize/melon and cassava/maize/okra. This crop mix is also a form of diversification indicative of risk management strategy adopted by the smallholder cassava based farmers to avoid total crop failure and to mitigate risk. This assertion is in agreement with those of Olarinde, Manyong and Okoruwa (2008) who in their study on

"Analysing Optimum and Alternative Farm Plans for Risk Averse Grain Crop Farmers in Kaduna State, Northern Nigeria" asserted that enterprise combination was a form of risk mitigating strategy against crop failure. Some of the crops can tolerate poor soils and still do well whereas others cannot. Sometime a risk averse farmer is willing to accept a lower average return for lesser uncertainty depending on his level of risk aversion. This is supported by the submission of Salimonu and Falusi (2008) who reported lower mean return can be regarded as a risk premium for avoiding a more risky plan and shifting to a plan with a reduced probability of risk. This also implies that improved strategies or technologies developed for farmers should not be evaluated solely in terms of average or expected returns, but risk should also be considered.

The crops cultivated in the state comprised tubers, cereals, legumes and vegetables (major four groups of staple crops) which is similar to those cultivated in Akwa Ibom State, Nogeria as reported by Udo *et al*., (2015a). The result further showed that cassava production is mostly done in combination with maize and melon as reported by 25.0% of the sampled respondents. This is followed by 12.5% of cassava-based food crop farmers who combined cassava farming with yam production, 10.0% of cassava-based food crop farmers who combined cassava farming with cocoyam production, and 7.5% of cassava-based food crop farmers who combined cassava farming with pumpkin or maize and okra or with maize and pumpkin production.

Costs and Return Analysis of Smallholder Cassava Based Enterprises : The variable and fixed costs of production, revenue, gross margin and net farm income per unit enterprise were computed. The values estimated were on a per-hectare basis and the gross values of each crop output per hectare were calculated based on prevailing market prices in the study area. The variable and fixed costs of production, revenue, gross margin, net farm income, and gross ratio per unit enterprise were computed. The variable cost items included the cost expended on planting materials, labour, fertilizer, agrochemicals, marketing expenses, processing, and storage, while the fixed cost items were those of land rent, depreciation on farm tools and machinery, and interest on borrowed capital. The result of the costs and returns analysis of each cassava-based enterprise undertaken by farmers in Enugu State is presented in Table 2

The total production costs for cassava-based combinations including Ca/Mz, Ca/Ym, Ca/Me, Ca/Pu, Ca/Gn, Ca/Co, Ca/Ok, Ca/Mz/Me, Ca/Mz/Ym, Ca/Mz/Co, Ca/Mz/Ok, Ca/Mz/Pu, Ca/Mz/Gn, CaYm/Ok/Pu, Ca/Mz/Me/Co, Ca/Mz/Ym/Pu, and Ca/Mz/Ym/Ok are ₦100998.41, ₦97213.414, ₦114731.44, ₦98688.716, ₦84707.978, ₦79154.312, ₦88447.36, ₦105441.22, ₦85121.153, ₦91002.677, ₦92303.82, ₦100639.68, ₦95805.74, ₦103656.2, ₦87384.21, ₦88167.59 and ₦83680.75. A further look at the costs of production shows that cassava-based crop enterprises involving cassava and melon (Ca/Me) are slightly more cost-intensive than any other cassava-based mixed crop enterprises in Enugu State whereas, cassava/Maize/Yam/okra (Ca/Mz/Ym/Ok) had the least total cost of production in the study area.

Based on the estimated gross margins, net farm incomes, and gross ratios, the result in Table 2 shows that all the crop enterprises undertaken by the smallholder farmers were profitable, given that the computed gross ratios were less than one. Cassava/Okra (Ca/Ok) enterprise is the most profitable with a net farm income of ₦309,020.10, which is closely followed by Cassava/yam/Okra/Pumpkin (Ca/Ym/Ok/Pu) enterprise with a net farm income of ₦302,286.61. On the other hand, Cassava/Groundnut (Ca/Gn) enterprise was the least profitable cassava-based enterprise with a net farm income of ₦145,945.40, closely followed by Cassava/Maize/Groundnut (Ca/Mz/Gn) enterprise with a net farm income of ₦179,782.31.

The computed gross ratios revealed that Cassava/Okra (Ca/Ok) and Cassava/Maize/Yam/okra (Ca/Mz/Ym/Ok) were the most profitable cassava-based enterprise, while Cassava/Groundnut (Ca/Gn) was the least profitable cassava-based enterprise in Enugu State. Cassava-based mixed crop enterprises involving yam in the combinations were slightly more profitable than cassava based crop enterprise combinations without yam. This could be due to the high value of yam output in the study area and also due to its traditional significance. Thus, this shows that cassava in combination with yam only or with yam and other crops has the potential for judicious exploitation of land in the study area. This result supports the findings of Igwe *et al*., (2015) who reported that yam is of a great value and culturally significant in Southeast, Nigeria

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Table 2: Costs and returns analysis of cropping patterns of cassava-based farming farmers in Enugu State

S/N	Enterprises	Average value (₦/hectare)						
		Total Fixed Cost	Total Variable Cost	Total Cost	Total Revenue	Gross Margin	Net-Farm Income	Gross Ratio
1	Cassava/Maize (Ca/Mz)	36,654.57	64,343.84	100,998.41	390,688.97	326,345.13	289,690.56	0.26
2	Cassava/yam (Ca/Ym)	35,588.21	61,625.2	97,213.41	389,741.9	328,116.7	292,528.49	0.25
3	Cassava/Melon (Ca/Me)	40,404.77	74,326.67	114,731.44	334,410.29	260,083.62	219,678.85	0.34
4	Cassava/Pumpkin (Ca/Pu)	34,774.14	63,914.58	98,688.72	335,952.76	272,038.18	237,264.04	0.29
5	Cassava/Groundnut (Ca/Gn)	30,806.11	53,901.87	84,707.98	230,653.38	176,751.51	145,945.40	0.37
6	Cassava/Cocoyam (Ca/Co)	30,533.01	48,621.3	79,154.31	263,616.51	214,995.21	184,462.20	0.30
7	Cassava/Okra (Ca/Ok)	33,818.90	54,628.46	88,447.36	397,467.46	342,839.00	309,020.10	0.22
8	Cassava/Maize/Melon (Ca/Mz/Me)	35,157.16	70,284.06	105,441.22	379,471.55	309,187.49	274,030.33	0.28
9	Cassava/Maize/Yam (Ca/Mz/Ym)	30,325.17	54,795.98	85,121.153	365,110.31	310,314.33	279,989.16	0.23
10	Cassava/ Maize/Cocoyam (Ca/Mz/Co)	36,591.72	54,410.96	91,002.677	292,985.09	238,574.13	201,982.41	0.31
11	Cassava/Maize/Okra (Ca/Mz/Ok)	34,362.38	57,941.44	92,303.82	277,004.22	219,062.78	184,700.40	0.33
12	Cassava/Maize/Pumpkin (Ca/Mz/Pu)	35,572.32	65,067.36	100,639.68	331,830.19	266,762.83	231,190.51	0.30
13	Cassava/Maize/Groundnut (Ca/Mz/Gn)	37,074.99	58,730.75	95,805.74	275,588.05	216,857.3	179,782.31	0.35
14	Cassava/yam/Okra/Pumpkin (Ca/Ym/Ok/Pu)	39,626.52	64,029.68	103,656.2	405,942.81	341,913.13	302,286.61	0.26
15	Cassava/Maize/Melon/Cocoyam (Ca/Mz/Me/Co)	31,894.65	55,489.56	87,384.21	306,762.18	251,272.62	219,377.97	0.28
16	Cassava/Maize/Yam/Pumpkin (Ca/Mz/Ym/Pu)	34,704.89	53,462.7	88,167.59	367,366.13	313,903.43	279,198.54	0.24
17	Cassava/Maize/Yam/okra (Ca/Mz/Ym/Ok)	32,433.22	51,247.53	83,680.75	382,219.85	330,972.32	298,539.10	0.22

Source: Field survey data, 2023

CASSAVA-BASED CROPPING PATTERN IN EXISTING, OPTIMUM AND RISK EFFICIENT PLANS IN ENUGU STATE, NIGERIA

The results of existing, optimum and risk efficient cassava based enterprise plans using the LP model and T-MOTAD models for cassava based crop enterprises in Enugu State are presented in Tables 3.

Table 3: Results of basic linear programming and T-MOTAD models of existing, optimum and risk efficient cassava-based enterprise plans for Enugu State

S/N	Cassava-based Enterprises	Farmers existing Plan	LP solution	T-MOTAD Solution		
			Optimum Plan	Risk efficient Plan I	Risk efficient Plan II	Risk efficient Plan III
1	Ca/Mz	0.75(7.49)	-	-	0.55(17.6)	0.42(12.5)
2	Ca/Ym	0.69(6.89)	0.51(20.2)	0.51(20.2)	0.35(11.2)	0.48(14.2)
3	Ca/Me	0.62(6.19)	-	-	-	-
4	Ca/Pu	0.38(3.80)	-	-	-	-
5	Ca/Gn	0.72(7.19)	-	-	-	0.41(12.2)
6	Ca/Co	0.4(4.00)	-	-	-	-
7	Ca/Ok	0.54(5.39)	0.43(17)	0.43(17)	0.27(8.7)	0.23(6.8)
8	Ca/Mz/Me	0.87(8.69)	0.69(27.3)	0.69(27.3)	0.84(26.9)	0.64(19.0)
9	Ca/Mz/Ym	0.73(7.29)	0.52(20.6)	0.52(20.6)	0.66(21.2)	0.70(20.8)
10	Ca/Mz/Co	0.43(4.3)	-	-	-	-
11	Ca/Mz/Ok	0.65(6.49)	-	-	-	-
12	Ca/Mz/Pu	0.39(3.90)	-	-	-	-
13	Ca/Mz/Gn	0.43(4.30)	0.38(15)	0.38(15)	0.45(14.4)	0.49(14.5)
14	CaY/Ok/P	0.48(4.80)	-	-	-	-
15	Ca/Mz/Me/Co	0.65(6.49)	-	-	-	-
16	Ca/Mz/Ym/Pu	0.7(6.99)	-	-	-	-
17	Ca/Mz/Ym/Ok	0.58(5.79)	-	-	-	-
	Total cropped area (ha)	**10.01**	2.53	2.53	3.12	3.37

Source: Field survey data, 2023 **Figures in parenthesis are the percentage cropped area**

Results in Table 3 showed that only five of the seventeen enterprises were included in the optimum plan and risk efficient plan I. The optimum plan prescribed the same enterprises and hectarage in the risk efficient plan I. The recommended allocation pattern depicts the most important enterprises in the two plans as: Ca/Ym (0.51ha), Ca/Ok (0.43ha), Ca/Mz/Me (0.69ha), Ca/Mz/Ym (0.52ha). And Ca/Mz/Gn (0.38ha). These also represent the enterprises that are in better competitive position to yield more returns for the profit maximizing and risk minimizing farmers in Enugu State as the case may be. This result is in agreement with that of Olasunkanm *et al.*, (2012) who noted that cassava/maize/melon enterprise was an optimum cassava based enterprise mix in Ogun State, Nigeria. Table 3 further showed that the T-MOTAD model prescribed six, and seven enterprises in plans II and III, respectively for the farmers. Again, just as in the optimum plan and risk efficient plan I, Ca/Ym, Ca/Ok, Ca/Mz/Me, Ca/Mz/Ym. And Ca/Mz/Gn enterprises were also prescribed in efficient plan II with the addition of one more enterprise (Ca/Mz). These same enterprises were also recommended in risk efficient plan III with the addition of two more enterprises Ca/Mz and Ca/Gn. Specifically, 0.55ha for Ca/Mz, 0.35ha for Ca/Ym, 0.27ha for Ca/Ok, 0.84ha of Ca/Mz/Me, 0.66ha for Ca/Mz/Ym and 0.45ha for Ca/Mz/Gn were prescribed in risk efficient plan II. However, in risk efficient plan III, 0.42ha , 0.48ha, 0.41ha, 0.23ha, 0.64ha, 0.70ha and 0.49ha for Ca/Mz, Ca/Ym, Ca/Gn, Ca/Ok, Ca/Mz/Me, Ca/Mz/Ym and Ca/Mz/Gn respectively were prescribed for the farmers. It is seen in Table 4.9 that more enterprises entered the risk efficient plans I and III implying a mitigation strategy towards reducing the possible risk among the enterprises. This finding agrees with those of Salimonu *et al.*, (2008) and (Olarinde, *et al.*, 2008) who noted in their separate studies that recommending more enterprises in risk efficient farm plans was diversification strategies to mitigate possible risks among crop enterprises.

MARGINAL OPPORTUNITY COST (MOC) OR SHADOW PRICES OF EXCLUDED ACTIVITIES OF OPTIMUM AND RISK EFFICIENT FARM ENTERPRISE PLANS

In LP and T-MOTAD problems, marginal opportunity costs also known as shadow prices for activities are the income penalties that would be experienced by a farmer who forcefully introduces/undertakes any such activity that has been excluded by the maximization or optimum/risk efficient solution (Olayemi and Onyenweaku, 1999). In essence, it indicates the amount by which net returns would be reduced if an excluded activity was undertaken or forced into the production plan by the smallholder farmers. The higher the value of the marginal opportunity cost of an excluded activity the lower its chances of being included in the optimum plan and vice versa. The marginal opportunity costs also known as shadow prices of the excluded farm enterprises in the various obtained plans are presented in Tables 4

Table 4: Marginal Opportunity Cost of excluded cassava-based enterprises for farmers in Enugu State

S/N	Cassava-based Enterprises	LP Solution	T-MOTAD Solution		
		Optimum Plan	Risk efficient Plan I	Risk efficient Plan II	Risk efficient Plan III
1	Ca/Mz	42,917.12	43,108.71	-	-
2	Ca/Me	48,069.77	48,494.23	48,926.25	39,581.77
3	Ca/Pu	45,981.40	45,107.23	79,618.81	33,417.47
4	Ca/Gn	30,986.28	30,725.35	57,458.82	-
5	Ca/Co	26,579.57	26,694.96	46,699.29	60,479.41
6	Ca/Mz/Co	52,191.84	52,462.96	60,655.38	49,024.86
7	Ca/Mz/Ok	30,886.35	30,732.18	41,320.00	53,381.62
8	Ca/Mz/Pu	52,662.99	52,904.01	93,599.40	61,323.74
9	Ca/Ym/Ok/Pu	39,156.30	39,258.00	67,174.80	88,647.10
10	Ca/Mz/Me/Co	57,579.52	57,278.84	74,873.03	63,039.65
11	Ca/Mz/Ym/Pu	37,078.16	36,979.94	50,125.41	89,486.71
12	Ca/Mz/Ym/Ok	54,083.17	53,887.92	113,512.96	65,325.84

Source: Field survey data, 2023

Results in Table 4 shows that the Optimum plan and risk efficient plan I all recorded twelve non – basic activities or excluded enterprises whereas the risk efficient plan II and III recorded eleven and ten excluded activities respectively. The results further showed that Ca/Co in the optimum and risk efficient plan I; Ca/Mz/Ok in risk efficient plan II and Ca/Pu in risk efficient plan III had the least MOC values in their respective derived plans. This implies that these enterprises are in a better competitive position to fit into their various derived plans when compared to the other non-basic activities. On the contrary however, Ca/Mz/Me/Co, Ca/Mz/Me/Co, Ca/Mz/Ym/Ok, and Ca/Mz/Ym/Pu in the optimum plan, risk efficient plans I, II and III respectively had the highest MOC values ₦57,579.52, ₦57,278.84, ₦113,512.96 and ₦89,486.71 respectively in all their respective derived plans. The income penalties outlined here indicated the loss in profit that would have been incurred if any of the excluded activities was forced into the programme**.** This findings lend credence to the findings of Udoh *et al*., (2015b) who identified Cassava/Maize/Melon/Cocoyam as an enterprise with highest marginal opportunity cost in their study on ‘optimizing farm plans for arable crop farmers in selected agricultural zones of Akwa ibom State, Nigeria: an application of linear programming and T-MOTAD models.

NET FARM INCOME IN EXISTING, OPTIMUM AND RISK EFFICIENT CASSAVA-BASED PLANS

The mean net farm income obtained in Naira per hectare in the existing plan, optimum plans I and II and the risk efficient plans I, II and II for cassava based food crop enterprises in the study area are presented in in Table 5

Table 5 Gross margin in existing, optimum and risk efficient plans for cassava-based food crop

Farmers existing Plan (₦)	LP Solution	T-MOTAD Solution		
	Optimum Plan(₦)	Risk efficient Plan I (₦)	Risk efficient Plan II (₦)	Risk efficient Plan III (₦)
244,225.17	303,132.28	291,238.52	298,345.47	280,687.99
Average Increase in Net Return in the Optimum and Risk Efficient Plans over the Existing Plan (₦)				
-	58,907.11	47,013.35	54,120.30	36,462.82
Percentage Increment in Net Return in the Optimum and Risk Efficient Plans over the Existing Plan (%)				
-	24.12	19.25	22.16	14.93

Source: Filed survey data, 2023

The estimated net farm income in the existing farm plan was ₦244,225.17/ha. However, the mean net farm income of ₦303,132.28/ha obtained in the optimum plan was higher. This depicts that there is an average increase of ₦58,907.11/ha, representing 24.12% proportionate change in the optimum plan over the existing plan. This increment satisfies the increased income objective of the farmers. The implication of this increment in the optimum plan is that, an average cassava farmer in the study area has the potential to increase and maximize net returns. This result is similar to those obtained from the study carried out by Jirgi *et al.* (2018), Adewunmi *et al*., (2018) and Udoh *et al.*, (2015b) who noted that gross margins obtained in optimized farm plans offers a higher and better value than the gross margins obtainable in the farmers' existing farm plans.

More so, as presented in Table 5, the average net farm income obtained from the T- MOTAD solution for risk efficient plans were ₦291,238.52/ha in plan I, ₦298,345.47/ha in plan II and ₦280,687.99/ha in plan III representing 19.25%, 22.16% and 14.93% increase over the existing plan. The average net farm income obtained in the risk efficient plans especially in risk efficient plan III are slightly lower than those obtained in the optimum plan across all the derived plans. The difference in these net returns (net farm income) could be regarded as the risk premium payable by the smallholder farmers for foregoing more risky optimum farm plan and adopting farm plans with minimized risk. This is in consonance with the assertion of Salimonu and Falusi (2008) who asserted that lower mean return was as a risk premium for avoiding a more risky plan and shifting to a plan with a reduced probability of risk. It is worthy of note that the average net returns (net farm income) of the farmers increased across the optimum and risk efficient plans. It however increased proportionately highest in optimum plan and least in risk efficient plan III. The implication of these increments in the optimum and risk efficient plans is that, an average smallholder cassava farmer in the study area has the potential to increase and maximize net profit under risk.

The result shows that the returns in the risk minimized plans I, II and III were higher than the returns in the farmer's existing plan thus satisfying the increased income or limited out of pocket cash expenses objective (Salimonu *et al*., 2008). It also implies that farmers can increase their level of profit with less level of risk.

The result also showed that the optimum plan recorded the highest returns among all the plans. The average farmer would be operating at a high-risk level if he adopts the profit maximization plan (optimum plan) since no consideration for yield variability inherent in crop farming was included in the linear programming model used to formulate the plan (Salimonu *et al*., 2008)... However, these high risks levels can be averted if the average farmer shifts to enterprise mixes with less variability in returns to farm resources. These are risk efficient plans I, II and III with minimized risk.

MARGINAL VALUE PRODUCT (MVP) OF RESOURCES UNDER CASSAVA-BASED ENTERPRISES

Any resource that is abundant, that is not used up by the programme, is not a limiting resource and therefore, has a zero shadow price as it does not constrain the attainment of a programme's objective and vice versa (Olayemi and Onyenweaku, 1999). The status therefore of the available resources in the optimized plans that constrained the attainment of the objective programme for is presented in Table 6.

Table 6: Marginal value product (MVP) of resources under cassava-based enterprises in Enugu State, Nigeria

Resources	LP Solution			T-MOTAD Solution								
	Optimum Plan			Risk efficient Plan I			Risk efficient Plan II			Risk efficient Plan III		
	US	S/S	SP(₦)	US	S/S	SP(₦)	US	S/S	SP(₦)	US	S/S	SP(₦)
A. Land	NFU	4.88	0	NFU	4.87	0	NFU	5.13	0	NFU	5.24	0
B. Human Labour												
1. Land preparation	FU	0	1200.37	FU	0	1200.37	FU	0	1204.21	FU	0	1089.18
2. Planting	FU	0	1200.11	FU	0	1200.11	FU	0	1090.16	FU	0	1011.32
3. Weeding	FU	0	1200.86	FU	0	1200.86	FU	0	1189.67	FU	0	1200.07
4. Fertilizer application	FU	0	1200.56	FU	0	1200.56	FU	0	1211.51	FU	0	1263.54
5. Pesticides application	FU	0	1001.40	FU	0	1001.40	FU	0	1061.66	FU	0	986.12
6. Harvesting	FU	0	1200.28	FU	0	1200.28	FU	0	1120.34	FU	0	1217.09
C. Capital												
1. Owned capital	FU	0	11.50	FU	0	11.50	FU	0	10.94	FU	0	12.63
2. Borrowed capital	FU	0	13.25	FU	0	13.25	FU	0	9.55	FU	0	10.17
D. Planting Material												
1. Cassava	NFU	463.82	0	NFU	463.83	0	NFU	376.18	0	NFU	411.67	0
2. Maize	NFU	211.93	0	NFU	211.94	0	NFU	250.23	0	NFU	189.47	0
3. Melon	NFU	200.56	0	NFU	200.57	0	NFU	239.16	0	NFU	420.13	0
4. Groundnut	NFU	350.32	0	NFU	350.31	0	NFU	429.81	0	NFU	330.88	0
5. Yam	NFU	748.79	0	NFU	748.78	0	NFU	489.33	0	NFU	587.30	0
6. Pumpkin	NFU	399.27	0	NFU	399.26	0	NFU	361.20	0	NFU	410.31	0
7. Cocoyam	NFU	205.91	0	NFU	205.92	0	NFU	204.39	0	NFU	118.92	0
8. Okra	NFU	120.47	0	NFU	120.45	0	NFU	218.27	0	FU	0	420.39
E. Fertilizer (Kg)	NFU	7.558	0	NFU	7.556	0	NFU	8.861	0	NFU	9.163	0
F. Agrochemicals	NFU	0.683	0	NFU	0.681	0	NFU	0.919	0	NFU	0.798	0

Source: Field survey data, 2023

US = Use status; S/S = Slack/Surplus resource; SP = Shadow price; FU = Fully utilized; NFU = Not fully utilized.

The factors limiting the achievement of the profit maximization and risk minimization objectives in Enugu State as obtained from the LP and T-MOTAD outputs are presented in Table 6. The result showed that labour and capital were used up by the programme. Labour had shadow price of above ₦1,000 across all the derived plans. Borrowed capital had shadow prices ₦11.50, ₦11.50, ₦10.94 and ₦12.63 for the optimum plan, risk efficient plans I, II and III respectively whereas owned capital had shadow prices of ₦13.25, ₦13.25, ₦9.55 and ₦10.17 for the optimum plan, risk efficient plans I, II and III respectively whereas. This finding corroborates those of Igwe and Onyenweaku (2013) and Udo *et al.*, (2015b) who in their respective studies identified labour and capital as factors limiting gross margins of arable crop farmers in Abia and Akwa Ibom States respectively. Ibrahim *et al*., (2020) also identified labour and capital as limiting factors to the maximization of maize based famers' gross margin in Niger State, Nigeria. It also corroborates the report of Jacob (2019) and Adewunmi *et al*., (2021) that labour and capital were limiting the gross margin maximization objective of livestock farmers in Niger State.

This implies that none of the other basic resources constrained the attainment of the objective function aside labour of all categories and capital (owned and borrowed). Farmers in Enugu State therefore would most likely achieve more in their drive to maximize gross return and minimize risks if more labour and capital were available and channeled to land preparation, planting, weeding, fertilizer application pesticides application and harvesting (labour)) and owned and borrowed capital.

On the other hand, result also showed that land (farm size), fertilizer, agrochemical and planting materials except okra seed in risk efficient plan (III) were identified to be surplus as they were not completely utilized in the programme. These resources equally had zero MVPs and imply that they were in excess of the actual requirements to maximize the net returns of the smallholder cassava based farmers, therefore, they should not be in further use for the production of the activities. This is also consistent with Olayemi and Onyenweaku (1999) who asserted that resources not used up were not limiting in fulfilling the attainment of programme's goal and vice versa. This finding is similar to those of Sathyanarayan *et al.* (2010), Baruwa (2013) and Bamiro *et al*. (2015) and Adewunmi *et al*., (2021) who reported that human labour and feed were factors limiting the profit maximization objective of livestock farmers in their respective study areas. . It also corroborates the report of Jacob (2019) that labour and capital were limiting the gross margin maximization objective of livestock farmers in Niger State but at variance with those of Udo et al., (2015b) who reported that human labour was not a limiting factor to gross margin maximizing objective of arable crop farmers in Akwa Ibom State, Nigeria.

CONCLUSION AND RECOMMENDATIONS : The study prescribed farms plans that would adequately provide the cassava based crop farmers in the Enugu State with improved income under risky environment. The result had shown that farm resources in the study area were not optimally allocated. The analysis showed that the net returns of profit maximizing farm plans with attendant high variability, varied across the normative plans. The alternative and risk efficient farm plans which have the objectives of satisfying family subsistence, generating income equal to or higher than farmers income threshold with minimum variability also varied.. The farmer's existing plans, the profit maximizing and risk efficient farm plans have important implications for strategies to improve food crop production in the study area. All the normative farm plans that were undertaken provided alternative farm plans for the arable crop farmers in the study area. The farm plans that were generated are efficient and they indicated optimum enterprise combinations, optimum farm income and optimum resource use. The study had demonstrated the importance of incorporating risk when modeling farm plans for smallholder crop farmers in tropical agriculture. It further showed that farm income will be overestimated if risk is not included in subsistence farm models. It can be concluded that appropriate combination of enterprises in cassava based crop farming not only helps to increase net farm income but also utilize all available resources efficiently. The farmers are therefore advised to adopt any of the recommended enterprise combinations or plans that best suits their plan. This would help them to achieve increased farm incomes, reduced cost of production, risk minimization and food security. In essence, the optimum plans should be incorporated in to extension education content of the Abia State ADP.

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