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FARM MODELLING OF BIO ENERGY AND FOOD CROPS CULTIVATION WITHIN GHANAIAN FARMING SYSTEMS: A LINEAR AND QUADRATIC PROGRAMMING APPROACH

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ABSTRACT

We designed a Linear and Quadratic Programming Farm Model using Premium Solver to quantify trade-offs, risks andCO2 emissions in farming systems between food and bio energy crops. LP results showed that consumption of food staples, notably maize and cassava, declined by 33% from Farm Plan 1 (FP1) in order to achieve the Total Gross Margin (TMG) in Farm Plan 2 (FP2). FP2, which introduced Jatropha, created demand for hired labour compared to FP1. QP analysis showed that increasing farm income from GH₵60320.88 to GH₵67023.21 increases the risk by 28%. Switching from a higher risk option in Farm Plan 4 (FP4) to a lower risk option in Farm Plan 3 (FP3) reduces expected farm income by 25%. Trading off profit for a reduction in risk can initially be done at relatively low cost in terms of profit foregone. GHG emissions can be reduced by 3% but with implications for food production.

Keywords: Linear Programming, Quadratic Programming, Risks, Total Gross Margin, Trade-offs

1. INTRODUCTION

Throughout the world policies are being developed to encourage the use and production of energy from biomass including energy from plant materials. The main energy crop in Ghana is Jatropha curcas (Physic nut). The plant has many uses such as for production of biodiesel from the seed (we cover this in detail in chapter two). Its by-products (seed cake and glycerine) are used as fertilizers, soaps, medicines and pesticides. However, oil content and quality is variable. Jatropha has also been associated with social and environmental concerns such as health related issues, lower food production (‘food for fuel’), high production costs, GHG emissions as a result of fertilizer and energy use and conflicts relating to land issues.

In Ghana, there is increasingly limited access to land and this is causing changes in the spatial distribution of crops. Reliance on crude oil as a source of energy coupled with the oil crisis of the early 1970s generated a high interest in biofuels as a possible replacement for fossil liquid fuels (Janda et al., 2011). According to the authors, increased consciousness of climate change has also contributed to increased demand for biofuels as an alternative source of energy. While high oil prices might have contributed to the introduction of biofuels in the 1970s and 2000s, more recent growth in demand has partially been driven by low food prices and a desire to find alternative markets for agricultural produce (Janda et al., 2011). Gallagher (2008) cautioned that

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there was a risk that certain biofuels could lead to a net increase in GHG emissions, through displacement of existing agricultural production, they also raise environmental issues relating to hydrology, biodiversity and nutrient cycling (Fargione et al., 2008). Nonetheless, many authors have presented biofuels in a positive light. For example, Sawyer (2008) summed up the benefits of biofuels as follows. For developing countries, there are promises of generation of employment and income generation (Sawyer, 2008). De Fraiture et al. (2008), argue for example that producing biofuels to substitute for oil imports should also help reduce high costs associated with oil imports.

The government of Ghana's economic policies include those that are aimed at direct foreign investment and job creation (GSS, 2009). As a result, multinational companies from Europe and Brazil are setting up Jatropha plantations in Ghana for the purpose of producing biodiesel. We therefore designed a Linear and Quadratic Programming Farm Model using Premium Solver to quantify trade-offs, risks and CO2 emissions in farming systems between food and bio energy crops

2. MATERIALS AND METHODS

The scope of our research covered the period 2012-2015 with a field survey undertaken to collect farm data from farmers in the Bredi community in the Nkoranza district of the Brong Ahafo region of Ghana using a carefully designed questionnaire (see section 2.3). Data analysis was carried out at the University of Nottingham at the Department of Agricultural and Environmental Sciences under the supervision of two academic supervisors. Two Jatropha producing companies were selected for data collection. Kimminick Estates Ltd is located in the Yeji district of Ashanti region with its plantations located in the Nkoranza and Yeji districts while Jatropha Africa, located in the Northern region with its plantations in Buipe.

Primary data were collected from farmers and Jatropha companies (Table 6) while secondary data was sourced from FAOSTAT, the Ministry of Food and Agriculture and Kumar et al. (2012).Farm output data defined as the yield multiplied by the selling price of a particular farm produce of each farmer in the survey area (Table 4) and farm input use (Table 5).

Table 2 Farm size of cultivated crops by farmers (ha)

Name	Maize	Cassava	Yam	Groundnut	Cowpea	Total
Samuel Adaie	6.8	0.4	0.4			**7.6**
Victoria Adei	1.6		0.4	0.4		**2.4**
Gladys Adjei	1.2		0.4			**1.6**
Nana Mansa	10.8	0.4	0.4			**11.6**
Kofi Sarpong	1.2	0.4	0.4			**2.0**
Adu Boahene	4.0		0.4		0.4	**4.8**

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Nana Kwasi Sarpong	2.0					**2.0**
Ama Dasi	2.8		0.4	0.4		**3.6**
Kwaku Ofori	4.8		0.4	0.4		**5.6**
Nana John	3.6	0.4	1.2		0.8	**6.0**
Mary Daanda	0.8					**0.8**
Doogo Kuraa	3.2	0.6	0.4		1.6	**5.8**
Millicent Adjoa	2.8	0.4	0.4			**3.6**
Akwasi Owusu	2.0	0.2				**2.2**

Table 3 Estimated yield per hectare by crop (Mt/ha)

Name	Maize	Cassava	Yam	Cowpea	Groundnut	Total
Samuel Adaie	5.0	2.3	10.0			**17.3**
Victoria Adei	0.8		0.0		0.1	**0.9**
Gladys Adjei	0.6		0.0			**0.6**
Nana Mansa	1.7	0.0	10.0			**11.7**
Kofi Sarpong	0.7	0.0	0.0			**0.7**
Adu Boahene	4.2		0.0	0.0		**4.2**
Nana Kwasi Sarpong	1.0					**1.0**
Ama Dasi	3.6		0.0		0.2	**3.8**
Kwaku Ofori	1.9		0.0		0.0	**1.9**
Nana John	1.0	2.5	0.0	0.0		**3.5**
Mary Daanda	0.4					**0.4**
Doogo Kuraa	1.2	0.0	0.0	0.4		**1.6**
Millicent Adjoa	2.8	0.0	2.0			**4.8**
Akwasi Owusu	1.0	0.0				**1.0**
Akosua Ataa	1.4		0.0		0.2	**1.6**
Kwasi Ankama	0.8		0.0			**0.8**
Margaret Ohenewaa	1.4	5.0		1.2		**7.6**

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Kofi Ababio	0.5	0.0		0.0		**0.5**
Mornonkuri Erenbong	1.2		0.0	0.0		**1.2**
Richard Kuniakwan	1.4					**1.4**
Mean	**1.6**	**3.3**	**7.3**	**0.8**	**0.2**	**13.2**
SD	**1.3**	**1.5**	**4.6**	**0.5**	**0.1**	**8.0**

Table 5 Input use by farmers (kg/ha)

Name	NPK	SA	UREA	Herbicide	Pesticide	Fertilizer total	Pesticides total
Samuel Adaie			58.82	0.44		**58.82**	**0.44**
Victoria Adei			93.75	5.63		**93.75**	**5.63**
Gladys Adjei				5.00	0.08		**5.08**
Nana Mansa				0.56	0.01		**0.56**
Kofi Sarpong				5.00			**5.00**
Adu Boahene	12.50	25.00			0.02	**37.50**	**0.02**
Nana Kwasi Sarpong	125.00	50.00		0.75	0.50	**175.00**	**1.25**
Ama Dasi		107.14		1.25		**107.14**	**1.25**
Kwaku Ofori				0.21			**0.21**
Nana John		41.67	125.00	4.17	0.03	**166.67**	**4.19**
Mary Daanda			125.00	4.38		**125.00**	**4.38**
Doogo Kuraa			78.13	7.50	1.25	**78.13**	**8.75**
Millicent Adjoa	142.90	142.90		0.36		**285.79**	**0.36**
Akwasi Owusu	50.00			3.00		**50.00**	**3.00**
Akosua Ataa	187.50			0.63		**187.50**	**0.63**
Kwasi Ankama	41.67			2.50		**41.67**	**2.50**
Margaret Ohenewaa	83.33	83.33	125.00	0.83	0.83	**291.67**	**1.67**
Kofi Ababio		41.67	41.67			**83.33**	**0.00**
Mornonkuri					0.71		**0.71**

Erenbong							
Richard Kuniakwan							**0.00**
Mean	91.84	70.24	92.48	2.64	0.43	127.28	2.28
SD	62.57	42.62	34.39	2.34	0.47	83.91	2.45

Table 6 Yield and fertilizer application in Jatropha production in Ghana

Type	Unit	Jatropha Africa	Kimminick Ltd
Total acreage	Ha	100	1400
Yield per/ha	Mt/ha	2	2.19
Total number of plants	Ha	2500	2500
N20	Kg/ha	0	18.75
P2O5	Kg/ha	0	18.75
K2O	Kg/ha	0	18.75
SA	Kg/ha	0	26.25
Sunphosate(glyphosates)	Kg/ha	7.5	3
Cymethioate	Kg/ha	0	1
Powdered fungicide	Kg/ha	0	0.3

Secondary data sourced were from the Ministry of Food and Agriculture, FAOSTAT and (Kumar et al., 2012). We used time series crop yield data collected from the Ministry of Food and Agriculture and time series crop prices data from the FAOSTAT website to construct these data. We also constructed Jatropha time series data (Table 10) using time series data from www.biozio.com. The construct data (Tables 7-10) were used as data sets to capture variability in our QP model. Covariance was constructed using output data of crops and intercrops across different scenarios. Data for oil extraction and esterification was not available from Jatropha producing companies as such data by Kumar et al. (2012) was used. The Amount of machinery calculations were based on Nemecek and Kagi, 2007 while fuel consumption data of farm machinery in the surveyed were assumed. Fuel combustion emission was also taken from Nemecek and Kagi (2007). The values were used to calculate emissions from diesel use by farm machinery in the LCA. These data were generated based on assumptions and calculations using secondary sources.

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Table 7 Time series yield data from 2003-2012 (Mt/ha)

Year	Maize	Cowpea	Groundnut	Yam	Cassava
2003	1.51	0.82	1.13	10.91	11.84
2004	1.46	0.77	0.99	11.84	11.73
2005	1.55	0.74	1.09	11.42	13.93
2006	1.33	0.99	1.17	11.63	10.83
2007	1.31	0.84	0.95	11.59	11.58
2008	1.59	1.11	1.35	12.58	12.48
2009	1.59	0.88	0.93	13.55	12.86
2010	1.72	1	1.37	13.73	14.15
2011	1.54	0.94	1.23	13.39	14.63
2012	1.71	1.12	1.31	13.78	15.33
Mean	1.5	0.9	1.2	12.4	12.9
SD	0.1	0.1	0.2	1.1	1.5

Obtained from the Ministry of Food and Agriculture, Ghana (SRID**)**

Table 8 Time series price data from 2003-2012 (GH₵/tonne)

Year	Maize	Cowpea	Groundnut	Yam	Cassava
2003	149.7	125.31	417.7	185.4	63.2
2004	211.9	138.99	463.3	216.4	80.5
2005	332.5	202.53	675.1	266.3	115.1
2006	233.3	230.46	768.2	274	115.7
2007	271.1	227.46	758.2	327.9	111.6
2008	468.7	263.19	877.3	405	163.1
2009	538.7	295.38	984.6	480.4	201.2
2010	487.7	320.19	1067.3	580.6	241.6
2011	649	664.83	2216.1	646.9	267.2

2012	371.4	274.26	914.2	375.88	151.02
Mean	**371.40**	**274.26**	**914.20**	**375.88**	**151.02**
SD	**161.00**	**150.91**	**503.03**	**154.03**	**67.61**

Table 9 Time series output data from 2003-2012 (GH₵)

Year	Maize	Cowpea	Groundnut	Yam	Cassava
2003	226.05	102.75	472.00	2022.71	748.29
2004	309.37	107.02	458.67	2562.18	944.27
2005	515.38	149.87	735.86	3041.15	1603.34
2006	310.29	228.16	898.79	3186.62	1253.03
2007	355.14	191.07	720.29	3800.36	1292.33
2008	745.23	292.14	1184.36	5094.90	2035.49
2009	856.53	259.93	915.68	6509.42	2587.43
2010	838.84	320.19	1462.20	7971.64	3418.64
2011	999.46	624.94	2725.80	8661.99	3909.14
2012	635.09	307.17	1197.60	5179.60	1976.88
Mean	**579.14**	**258.32**	**1077.13**	**4803.06**	**1976.88**
SD	**274.01**	**151.31**	**661.88**	**2298.41**	**1048.61**

Calculated using time series yield and price data respectively.

Table 10 Time series data for Jatropha based on calculations from 2003-2012

Year	Mt/ha	Kg/ha	Price/tonne (GH₵)	Output
2003.00	0.25	250.00	28.80	7.20
2004.00	0.90	900.00	195.60	176.04
2005.00	1.95	1950.00	327.00	637.65
2006.00	5.00	5000.00	392.40	1962.00
2007.00	6.50	6500.00	425.10	2763.15
2008.00	6.80	6800.00	686.70	4669.56

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2009.00	7.50	7500.00	915.60	6867.00
2010.00	7.90	7900.00	850.20	6716.58
2011.00	8.30	8300.00	1111.80	9227.94
2012.00	8.70	8700.00	1274.80	11090.76
Mean	**5.38**	**5380.00**	**620.80**	**4411.79**
SD	**3.20**	**3196.54**	**411.06**	**3937.23**

Calculations based on data from Biozio (2014)

In Ghana, the life span of agricultural machinery such as tractors, combine harvesters, planters, cultivators, trailers and spreaders used in rural areas is much higher than in Europe. We assumed a life span of 25 years for tractors while ploughs and harrows are assumed to have a life span of 20 years. We also assumed that between 1.5 and 2 hours are needed for harvesting and tillage operations respectively. The research used an adjustment procedure to compensate for the limitation identified during the research: The term agricultural machinery is defined as machines designed for and used in agricultural production (Nemecek et al., 2007). The use of agricultural machinery contributes to environmental impact, it is therefore necessary to estimate the amount of machinery used for various agricultural processes to determine their correct impact on the environment. According to the authors, the amount of machinery can be calculated based on the following formula. The weights of machinery were taken from Nemecek et al. (2007).

AM (kg/WU) = Weight (kg)*Operation time (h/WU)/ Lifetime (h)

Air emissions from fuel combustion were also calculated using the emission factors from Nemecek et al. (2007). The emission factor of each substance multiplied by the amount of fuel consumed to carry out an operation was used to estimate the emission due to fuel combustion. The formula for emissions due to fuel combustion can therefore be represented mathematically as (E) = A*Q,

Where A = Emission factor of each substance

Q (kg/ha) = the amount of fuel consumed to carry out each farm operation

The specific density of diesel is taken to be 0.84kg/L. The amount of diesel needed to plough a hectare was not available. We assumed to be 22.5L/ha while 16L/ha are assumed for harrowing and harvesting.

The most common fertilizers used in the survey area were NKP (compound fertilizers); Ammonium sulphates (SA) and Urea. Available Nitrogen in compost was estimated using the formula from Rosen and Biermann (2005) as follows

Available N= (Organic N*KM) + Ammonium-N

Organic N= Total N - Ammonium-N

Where KM is the fraction of Organic N released in the first year after application.

Historical crop yield and price data from the Ministry of Food and Agriculture and FAOSTAT respectively were used in this study. While yield data of the food crops were obtained from the Ministry of Agriculture from 2000-2012, price data for the same period was obtained from

FAOSTAT (country specific data) were also obtained covering the same period. The yield and price data were then used to compute covariance and total output. Total output per crop is used instead of gross margins because the Model accounts for variable costs. Time series prices of the studied crops were multiplied by the times series yield per crop to derive total output for each crop. The covariance was obtained using the relevant function in Excel, we then used the data to construct variance and covariance (table 5.1) for QP analysis. Unlike LP, QP calculates the expected income associated with variability as shown by our results in 3.1. It is worth noting that whereas LP generate 'three distinct reports' made up of limits, answer report and sensitivity report respectively, QP only generate results of crop mix at optimal solution and its expected income and variability. The data was then entered into the Risk Solver Platform add on to Excel. Historical data for Jatropha was obtained from (www.biozio.com) and then used to construct data as shown in Table 10 for our QP modelling

2.5 Methodologies

To capture trade-offs between Jatropha production, food production and environmental impacts, the study used Solver premium software to carry out the LP analysis. The components of an LP are the objective function, constraints, and technical co-efficient and cropping activities. A diagrammatic flow of the general structure of the LP is represented in Figure 1 below.

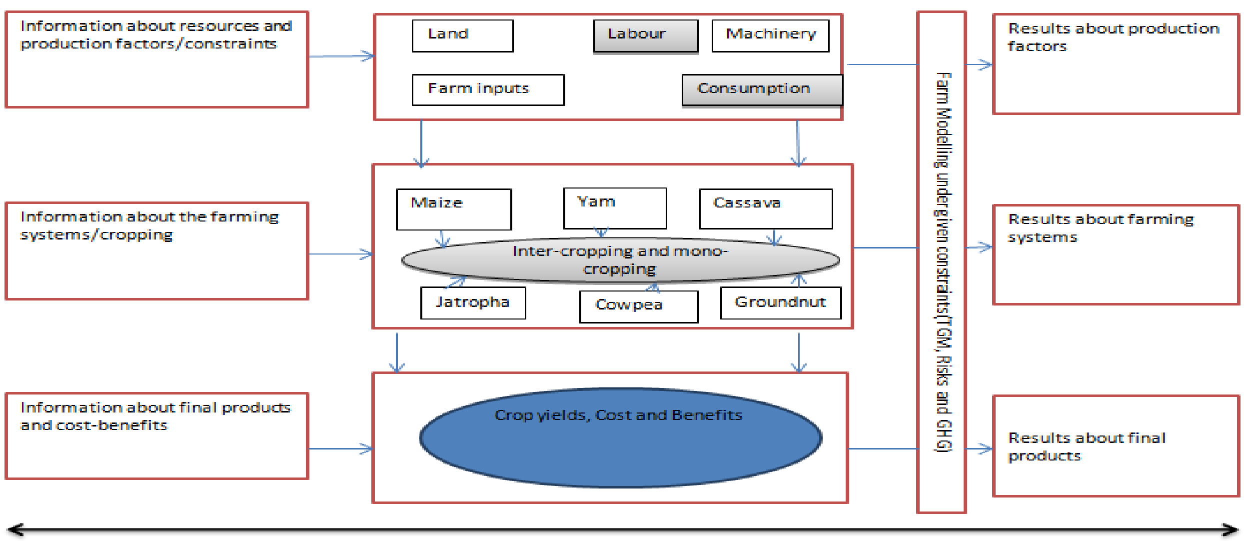

Figure 1General Farm Model structure

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We used the Model to analyse for GHG emissions, profit and risk. The model is a linear programming optimisation model that represents the various cropping options within a single year framework, based on crop combinations commonly grown in the surveyed area. The main components of the model are: activities for crops, work rates for the various crop operations, levels of fertilizer, compost and pesticide application, yield data for grain for each crop, hired labour and machinery costs and farm input costs. Output from crops is the grain only at prevailing market price (the product of yield by the selling price): the model maximises the gross margins between total output and variable costs of seeds, fertilizers and pesticides, hired labour and machinery costs. In our model the variable inputs are accounted for separately. The major constraints in the model are land, crop rotations, a consumption constraint, cash constraint and availability of hired machinery, hired and own labour (family labour) for crop operations. The model can optimise for either maximised farm gross margin or minimised emissions. QP is capable of generating three distinct reports (Limits, answer and sensitivity reports) showing combination of cropping activities at optimal solution.

The objective was to build a model that captures trade-offs between food crop production on one hand and Jatropha production on the other hand within the farming systems and patterns in Ghana. The model structure allows trade-offs between food crops and Jatropha production for biofuel and the financial performance to be quantified with a focus on Jatropha production as a biofuel. We used the LCA to assess environmental impacts of GHG of food crops and Jatropha and integrated these results into the LP model to minimise their impacts. .

Our QP is an extension of LP. It can be defined as the measurement of expected income associated with variability. The expected income criterion assumes that a farmer’s preferences among alternative farm plans are based on expected income E[Y] and the associated income variance V[Y]. Covariances as in Table 11, are fundamental for efficient diversification among farm enterprises as a means of hedging against risk (Hazell and Norton, 1986). Combinations of activities that have negatively covariate gross margins will have a more stable aggregate return than the return from more specialized strategies. In addition, a crop that is risky in terms of its own variance (see Table 11) of returns may still prove attractive if its returns are negatively covariate with other enterprises in the farm plan

Table 11 Variance and Covariance of different crops and scenarios

	Maize	Cowpea	Groundnut	Yam	Cassava	Jatropha	Intercrop Jatropha and Maize	Intercrop Jatropha and Cowpea	Maize+S1	Maize+S2	Maize+S3	Maize+S4	Maize+S5
Maize	67575												
Cowpea	30480	20606											
Groundnut	130289	89161	394276										
Yam	534552	272066	1169914	4754436									
Cassava	244983	125632	553148	2132818	989632								
Jatropha	768695	416739	1686182	6666852	2824013	13951611							
Intercrop Jatropha and Maize	93165	51082	209069	772592	335072	1791386	13615378						
Intercrop Jatropha and Cowpea	98341	54653	222171	830409	355783	1901104	258098	13830999					
Maize+S1	95348	43007	183837	754253	345671	1084628	131455	138758	134537				
Maize+S2	82915	37399	159864	655895	300594	943188	114313	120664	116992	101736			
Maize+S3	78765	35527	151864	623074	285552	895990	108593	114626	111138	96645	91809		
Maize+S4	34409	15520	66343	272194	124745	391419	47439	50075	48551	42220	40107	17521	
Maize+S5	116080	52358	223810	918253	420832	1320464	160038	168929	163789	142431	135303	59108	199403

To obtain the efficient E/V set, it is required to minimize V for each possible level of expected income E, while retaining feasibility with respect to the available resource constraints. The sum of $\sum c_j X_j$ is expected total gross margin E, which is set equal to a parameter λ. By varying λ over its feasible range through parametric procedures, a sequence of solutions is obtained of increasing total gross margin and variance until the maximum possible total gross margin under the resource constraints has been attained. This maximum value corresponds to the standard linear programming problem of maximising expected total gross margin subject to constraints. Solutions are obtained for critical turning points in the solution

3.RESULTS

The objectives were to maximize Total Gross Margin (TGM) from the mix of crops and to minimise emissions of greenhouse gases (GWP100a kgCO2eq). Calorie content values of maize, cassava, yam, groundnut and cowpea are 860 Kcal/kg, 1600 Kcal/kg, 1160 Kcal/kg,5670 Kcal/kg and 3180 Kcal/kg respectively as calculated from the United States Department of Agriculture Agricultural Research Service National Nutrient Database for Standard Reference. We set consumption at 70% of the calorie requirement (Kcal/kg) in proportions of 418 kg, 55 kg, 31 kg, 767 kg and 151 kg for maize, cowpea, groundnut, cassava and yam respectively. We assume that 30% of calories are met by animal sources.

Farm Plan 1 referred to as FP1 while Farm Plan 2 is also referred as FP2. In FP1 there is a farm family size of four and a consumption requirement of one year. The farmer receives an input subsidy and the interest rate on loans is 15%. Prices of farm inputs are subsidized at a rate of GH₵0.72/kg, GH₵0.76/kg, GH₵0.76/kg, GH₵0.72/kg, GH₵7.00/kg and GH₵7.00/kg for NPK, SA, Urea, compost, herbicides, and pesticides respectively. Land is set at a maximum of 12ha. In FP2, Jatropha is introduced into the model with the same consumption requirements, input prices and interest rates are the same as in FP1.

We define reduced cost as a reduction in the objective function resulting from increasing by one hectare, a crop not included in the optimal solution. We define shadow price as the rate of change in maximizing TGM whenever we increase one unit in the right-hand side constraint. A positive shadow price signifies that maximum TGM will increase with a one unit increase in the right hand side constraint. Allowable increase and allowable decrease explains the magnitude of changes allowed by the right-hand side quantity without changing the value of the shadow price.
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Crop choices, sales and consumption in FP1

The optimal crop mix is Maize+S5, cowpea, groundnut, yam and cassava (S5 is referred to as scenario 1 as in section 5.26). We met the objective solution of maximising TGM by growing 2.3ha each of Maize+S5, cowpea and yam respectively, with this the consumption requirement is satisfied. The total calorie requirement for one year is 2,271,758. The optimal solution allowed sales of 5685.8 kg of maize, 7606 kg of cowpea and 16917 kg of yam. Under FP1, more yam and cowpea are sold while more maize and cassava are consumed (Table 3.1).

Table 3.1Crop choices, sales and consumption FP1

Activity	Area cultivated (ha)	Sales (kg)	Consumption (kg)	Total production (kg)	% sold	% consumed
Maize+S5	2.3	5685.8	814.9	6500.7	18.8	44.8
Cowpea	2.3	7606.4	55.1	7661.5	25.2	3.0
Groundnut	0.8	0.0	151.0	151.0	0.0	8.3
Yam	2.3	16917.3	30.9	16948.2	56.0	1.7
Cassava	1.0	0.0	766.5	766.5	0.0	42.2
Total	8.7	30209.6	1818.4	32028.0	100.0	100.0
Mean	1.7	6041.9	363.7	6405.6		

3.2 Labour and machinery use in FP1

The objective function was met with 22 days of family labour (Figure 3.2) and 9.3 days of 'own knapsack' for spaying purposes. Hired labour and machinery amounted to 31 days and 54 days respectively.

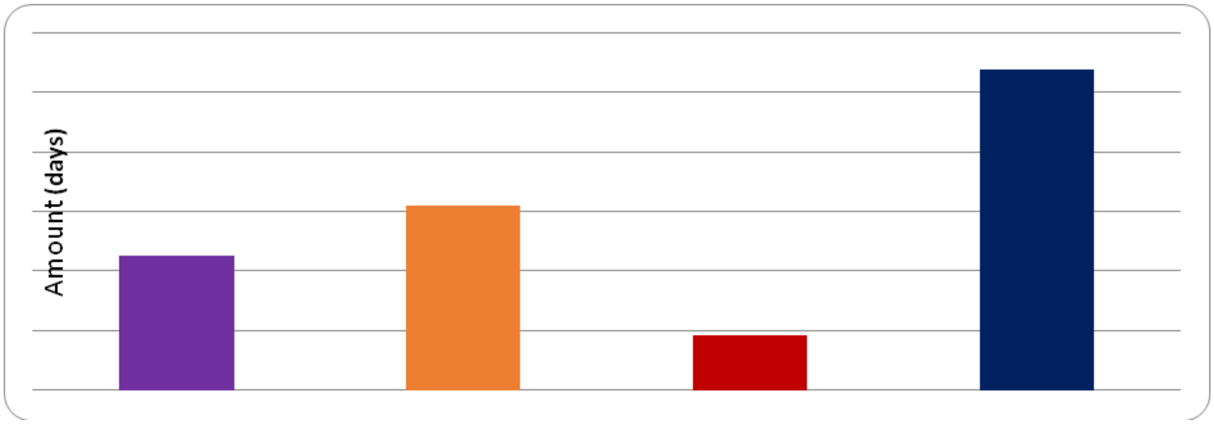

Figure 3.2Labour and machinery use

3.3 Variable input use in FP1

To meet the nutrient requirements of crop production, a greater proportion of the fertilizers applied were Urea and SA. Application of Urea is 50% of the total, while 15% was NPK. Relatively little compost was used. Of the pesticides, the main use was herbicides (3.3).

Table 3.3 Variable input use under FP1

Type	Amount (kg)	% use
NPK	125.4	14.6
SA	290.2	33.7
Urea	435.3	50.5
Compost	10.4	1.2
Herbicides	15.4	86.5
Pesticides	2.3	12.9
Total (Fert)	861.3	100.0
Total (Pesticides)	17.8	100

3.4 Capital use and Total Gross Margin (TGM)

Financial requirements showed that GH₵500.00 of own capital was used while GH₵3740 of borrowed capital at an interest rate of 15% was also used. The Total Gross Margin (TGM) under FP1 is GH₵89,814**.**

3.5 Reduced cost and Total Gross Margin

We examined the extent to which reduced cost affected TGM (Table 3.5). As noted, reduced cost gives an indication of the effect on the objective function of including suboptimal cropping options. Forcing in one hectare of maize led to a reduced cost of GH₵3362.8. The objective function would thereby be reduced by nearly 4%.The reduced cost of one hectare of Jatropha is GH₵6519.

The optimal solution restricted intercropping; however, forcing in one hectare of maize and Jatropha intercrop would change the optimal solution.

Table 3.5Reduced costs (GH₵)

Activity	Reduced cost	% difference
Grow maize	3362.8	3.7
Grow Jatropha	6519.2	7.3
Intercrop Jatropha and Maize	4520.9	5.0
Intercrop Jatropha and Cowpea	5691.4	6.3
Grow Maize+S1*	1368.2	1.5
Grow Maize+S2*	8268.2	9.2
Grow Maize+S3*	2256.5	2.5
Grow Maize+S4*	2440.9	2.7
Sell Cassava	7.4	0.0
Sell Groundnut	12.3	0.0
Hired labour	11.5	0.0
Hired knapsack	0.6	0.0

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TGM (GH₵) in FP1	89814	100.0

3.7 Crop choices, sales and consumption in FP2

The optimal solution changed with the introduction of Jatropha (Table 3.7) with 11ha of land used for cropping compared with 8.7ha in FP1. The optimal solution allowed for the cultivation of cowpea, groundnut, yam and cassava, maize. Our results showed that land size in some cultivated crops reduced significantly. Unlike FP1, the optimal solution in FP2 allowed for intercropping to take place with the introduction of Jatropha.

Table 3.7Crop choices, sales and consumption in FP2

Activity	Area cultivated (ha)	Sales (kg)	Consumption (kg)	Total production (kg)	% sold	% consumed
Maize+S5	1.0	4049.5	814.9	4816.0	20.7	44.8
Cowpea	1.0	3106.7	55.1	3161.8	15.9	3.0
Groundnut	0.8	0.0	151.0	7172.3	0.0	8.3
Cassava	1.0	0.0	766.5	0.0	0.0	42.2
Yam	1.0	6963.4	30.9	6963.4	35.6	1.7
Jatropha	1.8	5454.2	0.0	7471.7	27.9	0.0
Intercrop Jatropha and maize	3.6					
Rotation of a Cover crop	1.0					
Total	11.2	19573.9	1818.4	29585.3	100.0	100.0
Mean	1.4	3262.3	303.1	4930.9		

3.8 Labour and machinery use in FP2

Labour and machinery use in FP2 have also changed compared with FP1 (Figure 3.8).The optimal solution allowed hiring of 91 days of labour compared to 31 days in FP1. Machinery use

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showed that 4 days of own knapsack was used while 52 days of hired machinery was also used compared with 9 days and 54 days respectively in FP1.

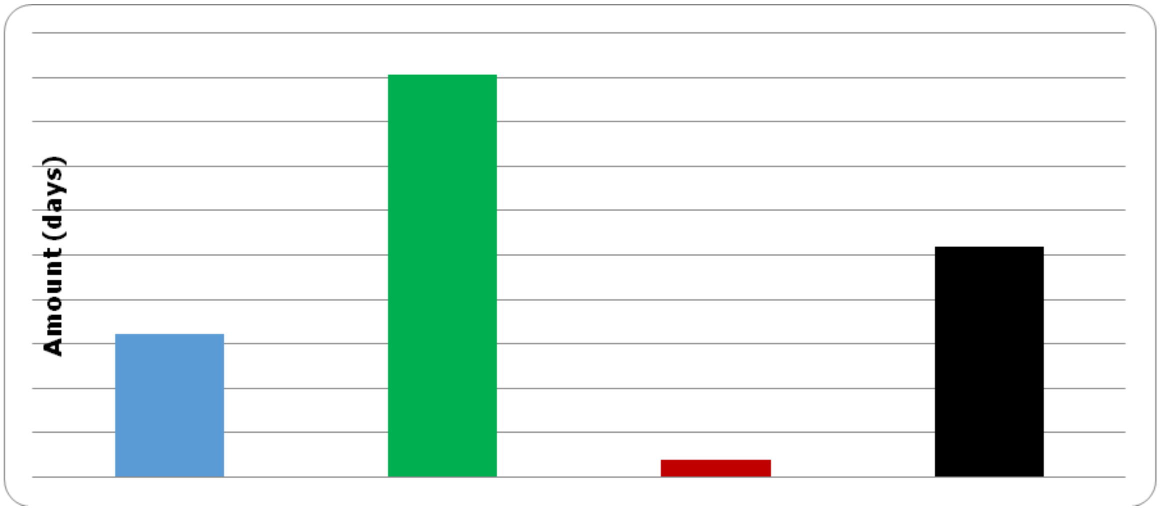

Figure 3.8 Labour and machinery use

3.9 Variable input use in FP2

The optimal solution showed that a greater proportion of fertilizer applied was NPK and the least applied was compost. We found that NPK requirement increased significantly in FP2 compared with FP1. There is an increase of nearly 700% of NPK in FP2. However, there was a 59% reduction in the use of Urea and compost compared with FP1.

Table 3.9 Comparison of input uses between FP1 and FP2

Type of Inputs	FP1 (kg)	FP2 (kg)	% change from FP1
NPK	125.4	960.8	666
SA	290.2	574.3	98
UREA	435.3	179.6	-59
Compost	10.4	4.3	-59
Herbicides	15.4	14.5	-6
Pesticides	2.3	1.0	-59
Total fert (kg)	861.3	1719.0	
Total pesticides(kg)	17.8	15.5	

3.10 Effect of interest rate on loans and variable input pricing on Total Gross Margin

Interest rates and input pricing influence TGM. Our analysis showed that at a 0% interest rate, TGM stands at GH₵95,375 but when the interest rate increased by 15%, TGM falls to GH₵89,814, while at a 20% interest rate TGM reduced to GH₵89,253. The TGM of GH₵95,375 is attained with subsidisation of agricultural inputs but declines to GH₵89,139 with a 10% increase in the price of these inputs. When the prices of inputs increase by 20% TGM falls to GH₵89,024.

3.11 Risk and Trade-offs analysis

The objective here is to minimise risk, as measured by TGM variability, associated with a given Total Gross Margin. Risk was minimised for set levels of TGM (i.e. using an equality constraint), starting with a 0% reduction from profit maximisation to a 70% reduction. In this section we present results for the crop mix at each of these levels and quantify the trade-offs between profit, risk, production, labour and machinery use and variable input use. Two approaches are compared: FP3 (producing with Jatropha) and FP4 (without Jatropha).

3.12 Crop mix and area under cultivation in FP3

Our results on crop mix and area under cultivation in FP3 are presented in Table 3.12; 33% of land is dedicated to the cultivation of Jatropha and maize intercrop while 17% of land is dedicated to the cultivation of Jatropha as a sole crop. The results also showed that whilst 11% of yam, maize and cowpea are grown, only 0.3% of groundnut and 4% of cassava are included in the optimal solution. As set TGM and associated variability decline, cowpea and maize area declined by 62% while yam declined by 78%. However, the cultivation of Jatropha as a sole crop rises by nearly 30% while maize intercrop rises by 59%. The cultivation of Jatropha and Jatropha and maize intercropping are completely given up as TGM falls to 70%.

Table 3.12 Crop mix and area under cultivation in FP3

Crop mix	Level of TGM variability and optimal solution for FP3							
	0%	10%	20%	30%	40%	50%	60%	70%
Cowpea (ha)	1.6	0.59	1.0	2.0	2.9	3.9	4.9	4.1
Groundnut (ha)	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.0
Yam (ha)	1.6	0.34	0.0	0.0	0.0	0.0	0.0	0.0
Cassava (ha)	0.6	0.59	0.6	0.6	0.6	0.6	0.6	0.6
Jatropha(ha)	2.3	2.78	2.6	2.0	1.4	0.8	0.1	0.0

Intercrop Jatropha and cowpea(ha)	4.6	5.56	5.2	3.9	2.7	1.5	0.3	0.0
Maize+S4 (ha)	1.6	0.59	1.0	2.0	2.9	3.9	4.9	0.0
Rotate cover crop (ha)	1.6	0.59	0.6	0.6	0.6	0.6	0.6	0.6
Total	13.9	**11.1**	11.0	11.1	11.2	11.3	11.4	5.3

3.14 Labour and machinery use

At maximum TGM, 42 days of family labour were used compared to 88 days of hired labour. Use of own machinery was 25 days compared to 65 days of hired machinery. As TGM falls to 10%, there is less use of family and hired labour, by 7% and 17% respectively. Family labour use remains steady at 38 days as TGM falls to between 10%-30% but falling to between 28 days-37 days as TGM falls to between 40%-70%. Thus, between 2%-20% of family labour is given up. Hired machinery and own machinery uses showed a rise of between 2%-20% and 25%-90% respectively as TGM falls to between 10%-60%; however, as TGM falls to 70% there is a reduction of 17% of own machinery use and 18% of hired machinery.

Table 3.14Labour and machinery use in FP3

Labour mix	**Level of TGM variability and optimal solution for labour use in FP3**							
	0%	10%	20%	30%	40%	50%	60%	70%
Family labour (days)	41.82	38.89	38.72	37.83	36.95	36.06	35.17	28.01
Family labour replace hired (days)	118.18	121.11	121.28	122.17	123.05	123.94	124.83	131.99
Hired labour (days)	87.78	72.17	71.16	65.83	60.50	55.18	49.85	6.89
Own machinery (days)	24.78	2.36	3.94	7.84	11.73	15.63	19.52	16.22
Hired machinery (days)	64.50	51.73	52.57	56.74	60.92	65.09	69.26	56.55

3.15 Variable input uses

Fertilizer and pesticide application are presented in Table 3.15. Our study showed that as TGM falls by 10%, there is a sharp increase in the application of NPK and SA compared to Urea. Whilst 140 kg of NPK was applied, up to 606 kg at profit maximisation and 720 kg SA (up from

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353 kg) Urea use dropped from 98 kg to 37 kg. NPK and SA use increase initially and then drop with TGM.

Table 3.15 Variable input uses in FP3 (kg)

Input mix	Level of TGM variability and optimal solution for input use in FP3							
	0%	10%	20%	30%	40%	50%	60%	70%
NPK	606	1401	1310	1023	735	447	160	73
SA	354	720	687	575	463	351	239	169
UREA	98	37	62	122	183	244	305	253
Total	**1059**	**2157**	**2060**	**1721**	**1382**	**1043**	**704**	**496**
Herbicides	19	14	14	16	17	19	20	16
Pesticides	6	1	1	2	3	4	5	4
Total	**25**	**15**	**15**	**18**	**20**	**23**	**25**	**20**

3.16 Total production, sales and consumption of farm produce

At maximum TGM, total production of food crops and Jatropha stood at 14787kg but declined to 12646kg (14.5%) as TGM falls to 10%. There was a further decline in production to 11675kg (8%) as TGM falls to 20%. Interestingly, as TGM falls between 30%-60%, total production increases marginally to between 11980kg-12894kg, representing a marginal increase of 2.4%-2.6%. There is a sharp decline in total production as TGM falls to 70%.

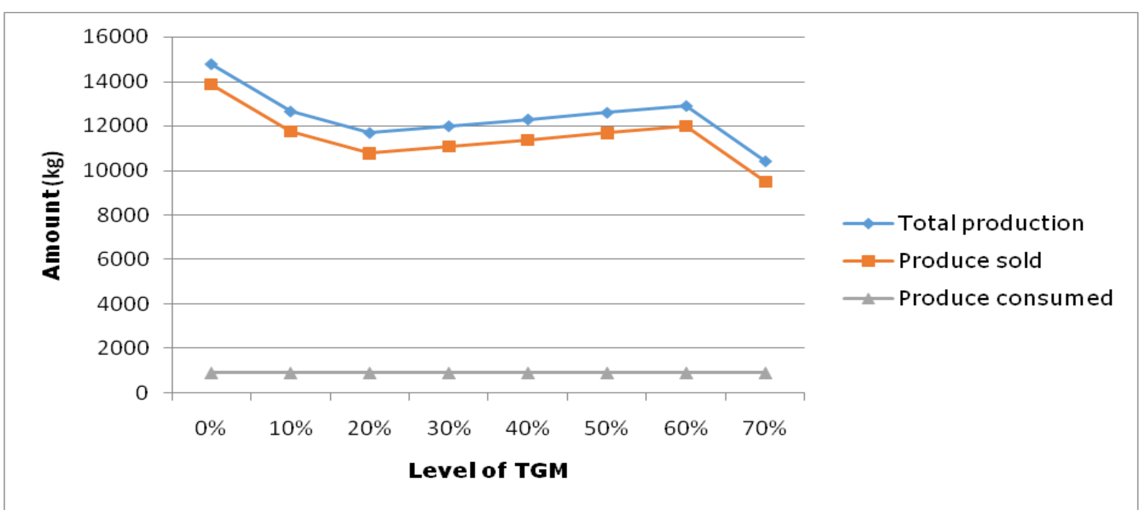

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Figure 3.16Total production, sale and consumption in FP3 (kg)

3.17 Crop mix and area under cultivation in FP4

The optimal solution allowed for the cultivation of Maize+S4 and Maize+S5 respectively. The solution also allowed for the cultivation of cowpea, yam, groundnut and cassava. We observed that 3.4 ha of cowpea and yam can be grown compared with 1.6 ha in FP4. We also observed that nearly 1 ha of groundnut can be grown compared to no groundnut in FP3. As TGM fell by 10%, the solution allowed for the cultivation of 4 ha of cowpea and 2.5 ha of yam (0.6 ha and 0.3 ha) and a further 3.7 ha of Maize+S4 (1 ha in FP3. We note however that whereas intercropping and rotation can take place in FP3, the optimal solution in FP4 restricts intercropping and rotation.

Table 3.17 Crop mix and area under cultivation in FP4

Crop mix	Level of TGM variability and optimal solution in FP4							
	0%	10%	20%	30%	40%	50%	60%	70%
Grow Cowpea (ha)	3.34	4.21	4.45	4.62	4.79	4.95	5.08	4.06
Grow Groundnut (ha)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Grow Yam (ha)	3.34	2.48	2.06	1.57	1.08	0.60	0.13	0.02
Grow Cassava (ha)	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
Grow Maize+S4 (ha)	2.81	3.65	4.45	4.62	4.79	4.95	5.08	4.06
Grow Maize+S5 (ha)	0.54	0.56	0.00	0.00	0.00	0.00	0.00	0.00
Total	**10.66**	**11.62**	**11.78**	**11.73**	**11.68**	**11.63**	**11.52**	**9.46**
Mean	**1.78**	**1.92**	**1.93**	**1.91**	**1.88**	**1.86**	**1.82**	**1.46**

3.18 Labour and machinery use

We observed a decrease in the use of hired labour compared to the optimal solution in FP3 and an increase in the use of hired machinery. There is also an increase in family labour replacing hired labour compared to FP3. Whereas at maximum TGM the optimal solution allowed for the

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use of 17 days of hired labour in FP3, the optimal solution in FP4 allowed for the use of 88 days of hired labour**.**

Table 3.18 Labour and machinery use in FP4

Labour mix	Level of TGM variability and optimal solution for labour in FP4							
	0%	10%	20%	30%	40%	50%	60%	70%
Family labour (days)	31	34	35	35	35	35	35	28
Family labour replace hired (days)	129	126	125	125	125	125	125	132
Hired labour (days)	18	41	45	46	47	47	48	7
Own machinery (days)	13	17	18	18	19	20	20	16
Hired machinery (days)	69	75	75	74	72	71	70	57

3.19 Variable input use

The optimal solution allowed for the use of compost compared to no use of compost in FP3. There is a significant decrease in the application of NPK and SA compared to NKP and SA applications in FP3. The profit maximising solution allowed for the application of 79 kg compared to 606 kg in FP3. We also observed that an amount of 183 kg of SA was applied compared to 35 4kg in FP3.

Table 3.19Variable input uses in FP4

Input mix	Level of TGM variability and optimal solution for input use in FP4							
	0%	10%	20%	30%	40%	50%	60%	70%
NPK	79	96	80	83	86	89	91	73
SA	184	222	185	192	199	206	212	169
UREA	276	333	278	289	299	310	317	253
Compost	2	3	0	0	0	0	0	0
Herbicides	20	22	22	22	21	21	21	16

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Pesticides	3	4	4	5	5	5	5	4

3.20 Total production, sales and consumption

Total production is higher compared to FP3. At maximum TGM, total production is 20633 kg compared to 14787 kg, representing a difference of 42%. Compared to FP1, total production when TGM falls to 10% is 21105 kg compared to 12646 kg representing a difference of 67%. The level of production when TGM falls to between 20%-60% in FP4 is 11675 kg-12894 kg compared to 13335 kg- 19505 kg in FP3 representing a 3%-50% difference. At maximum TGM, total produce sold is 19724 kg compared to 13878 kg in FP3. As TGM falls by 10%, 20196kg of produce is sold compared to 11736 kg in FP3, a 72% increase in produce sold.

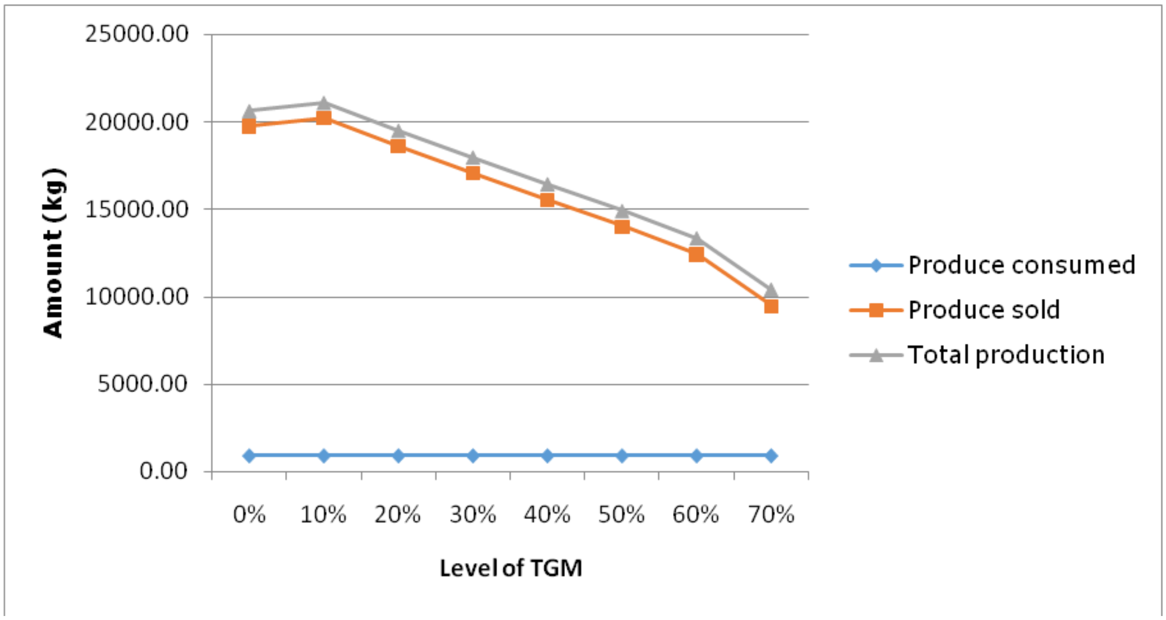

Figure 3.20 Total production, sales and consumption in FP4 (kg)

3.21 Risks levels and TGM between Farm plans

We observed a significant difference in the level of risk associated with the two Farm plans. Risk level is highest in FP4 compared to FP3. Our study showed that at maximum TGM, risk as measured by variability rises to 78,831,303 in FP4 compared to 56,337,970 in FP3, 40% higher in FP4.

Maximising TGM, as we would expect, increases the level of risk. Maximum variability always occurs at maximum profit. Trading off profit for a reduction in risk can initially be done at relatively low cost in terms of profit foregone. The EV frontier becomes steeper, indicating that more and more profit has to be traded away, as you try to get further risk reductions (Figure 3.21).

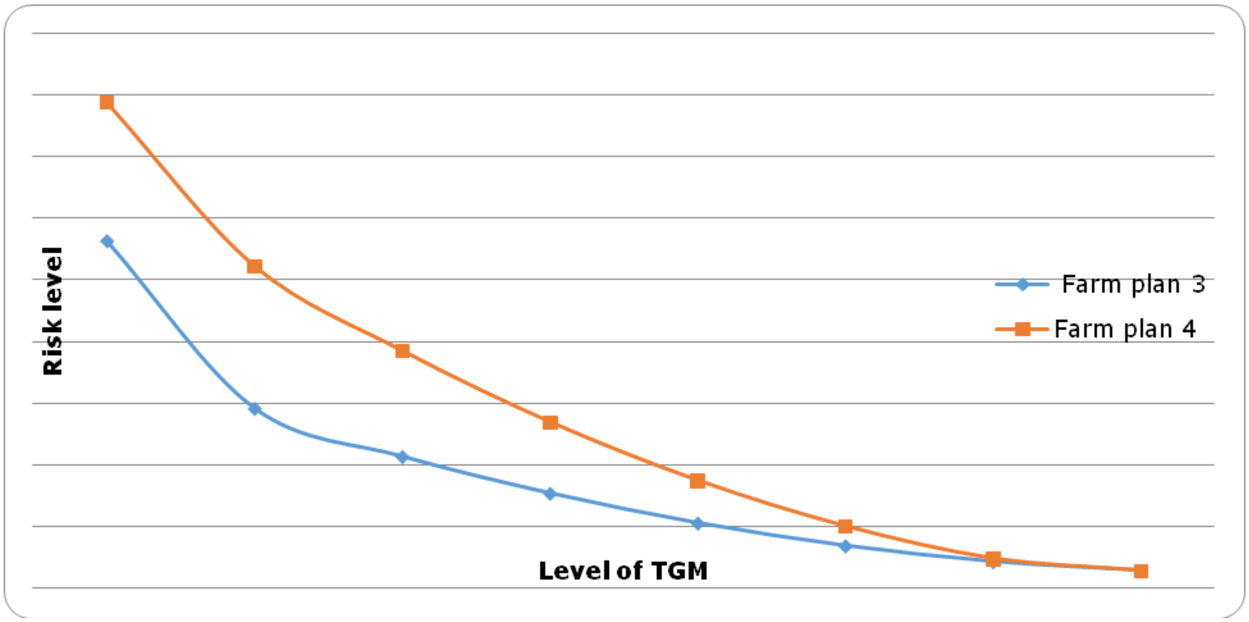

Figure 3.2 1Risks levels between Farm plan31 and FP4

3.22 Modelling CO2 emissions in an LP

We used the results obtained from LCA to model CO2 emissions in a farm environment. The LCA results showed that the activities of food crops and Jatropha produce environmental impacts and our objective here is to specifically minimise CO2 emissions. Calorie content values of maize, cassava, yam, groundnut and cowpea are 860 Kcal/kg, 1600 Kcal/kg, 1160 Kcal/kg,5670 Kcal/kg and 3180 Kcal/kg respectively as calculated from the United States Department of Agriculture Agricultural Research Service National Nutrient Database for Standard Reference. We set the consumption requirement in proportions of 815 kg, 55 kg, 31 kg, 767 kg and 151 kg for maize, cowpea, groundnut, cassava and yam respectively. We assume a farm family size of four and a consumption requirement of one year. The farmer receives an input subsidy and the interest rate on loans is 15%. Prices of farm inputs are subsidized at a rate of GH₵0.72/kg, GH₵0.76/kg, GH₵0.76/kg, GH₵0.72/kg, GH₵7.00/kg and GH₵7.00/kg for NPK, SA, Urea, compost, herbicides, and pesticides respectively. Available land is set at 12ha. The crop activities are maize, cowpea, yam, Jatropha and groundnut. We also modelled emissions from rotations of maize and cover crop, cowpea and maize, cover crop and cassava, cover crop and yam, intercropping Jatropha and maize and intercropping Jatropha and cowpea.

3.23 Crop choices, sales and consumption in CO2 emissions

Results showed that under a minimisation objective, the optimal solution allowed a crop mix of maize, cowpea, groundnut, yam and cassava (table 3.23), with 1ha each of maize, cowpea and cassava and 0.8ha of groundnut. Out of the 12ha of land available, the optimal solution limited production to 4.8ha representing 45% decline in area cultivated compared to FP1 of 8.7ha.

Table 3.23 Crop choices, sales and consumption in CO2 emissions

Activity	Area cultivated (ha)	Sales (kg)	Consumption (kg)	Total production (kg)	% sold	% consumed
Maize	1.0	516.3	814.9	1331.2	22.1	44.8
Cowpea	1.0	0.0	55.1	55.1	0.0	3.0
Groundnut	0.8	0.0	151.0	151.0	0.0	8.3
Cassava	1.0	0.0	766.5	766.5	0.0	42.2
Yam	0.0	0.0	30.9	30.9	0.0	1.7
Rotation with Cover crop	1.0				0.0	0.0
Total	4.8	516.3	1818.4	2334.7	22.1	100.0

24 Labour and machinery use in CO2 emissions

The optimal solution showed that by reducing GHGs, only 8.8 days of family labour was permitted to be used. Meeting the objective function required the use of 22 days of hired machinery while the use of own machinery was restricted to a maximum of 4 days. There is a decline in total days of labour compared to the optimization Model in section 3.8.

Table 3.24 Labour and Machinery use in CO2 emissions

Type	Amount (days)
Family labour	8.8
Own machinery (knapsack)	3.8
Hired machinery	22

3.25 Variable input use in CO2 emissions

Meeting the objective function required a total amount of 34.5 kg of NPK and 79.8 kg of SA to be used up. The optimal solution restricted use of Urea to a total amount of 119.8 kg. Herbicide and pesticide use however showed that a total amount of 5.4 kg and 1.0 kg of herbicides and pesticides were used. NPK use decreased significantly from 125kg in FP1, to only 35 kg.

Table 6 25 Variable input use in CO2 emissions (kg)

Type of Inputs	Amount (kg)	% use
NPK	34.5	15
SA	79.8	34
UREA	119.8	51
Herbicides	5.4	85
Pesticides	1.0	15
Total fert (kg)	234.1	100.0
Mean fert (kg)	78.0	
Total pesticides(kg)	6.3	100.0
Mean pesticides (kg)	3.2	

3.26 Cropping activities and CO2 emissions

The effect of forcing in one hectare of crop on CO2 emissions are presented in Table 3.26. Our study showed that forcing in Scenario 1 would increase CO2 by 8% while forcing in Jatropha would increase by 28%. Forcing in an intercrop of either Jatropha and maize or Jatropha and cowpea would also increase CO2, by 34% and 30% respectively.

Table 3.26 Effect of growing one hectare on CO2 emissions

Activity	Unit	GWP 100a (kg CO2eq)	% increase
Grow Jatropha	ha	223142.9	27.8
Intercrop Jatropha and maize	ha	273291.2	34.0

Intercrop Jatropha and cowpea	ha	237615.3	29.6
Grow Maize+S1	ha	61658.7	7.7
Grow Maize+S2	ha	1911.9	0.2
Grow Maize+S3	ha	1900.7	0.2
Grow Maize+S4	ha	1833.5	0.2
Grow Maize+S5	ha	1978.6	0.2
Total	ha	**803332.8**	100.0

4. DISCUSSION

This study has shown that by varying the costs of variable inputs and interest on loans payable by small scale farmers, we can influence TGM, risk and trade-offs. FP1 (Farm Plan 1) shows that when we introduce an input subsidy and maintain interest rate at 15% we maximised TGM by producing 2.3ha of maize and 1.0ha of cassava respectively. The crop mix is 31% maize, cowpea and yam while groundnut and cassava form only 5% and 1.2% respectively of the crop mix in FP1.

Although total production declined quite substantially, from 32,028kg in FP1 to 15,938kg in FP2 (FP2), total consumption of food staples declined by only 11%. Fertilizer and pesticide use are also much higher in FP2 (Farm Plan 2) compared to FP1. Adoyele and Oso (2014) found that cowpea yield significantly increased with an application of NPK of 45kg ha-1. 0.45Mt/ha with application as against 0.38Mt/ha without). Buah et al, 2009, found that maize yields increased in Northern Ghana by nearly 38% with an application of 90kg ha-1, compared to zero application by farmers. To meet the demands of increased fertilizer and pesticide use in FP2 we noted that borrowing increased (albeit by a relatively small amount, from GH₵3,739 to GH₵4,859).Farmers repay these loans by either committing a portion of their produce before harvest or a commitment to sell to the lender all of the harvested produce. A crop failure is therefore very difficult for farmers as they have to accept the low prices offered by the lender – lower than prevailing market prices. .

Demand for NPK and SA fertilizers also increased substantially, from 125kg yr-1 and 290kg yr-1 respectively to 960kg yr-1 and 574kg yr-1. The potential for increased demand for variable inputs is that local businesses that trade in agricultural products would take advantage of the expected increase in demand for fertilizers to expand. The resultant effect is that the local economy becomes more vibrant through a ‘multiplier effect’. However, the opportunity cost in

FP2, as we would expect, is a decline in production of food staples due to the decline in production of Cowpea and Yam and increased farm expenditure.

Land for the cultivation of maize, cowpea, groundnut and yam is substantially less in FP2: from 2.3ha in total in FP1 to 1ha in FP2. Maize produced declined from 6500.7kg yr-1 to 4864kg yr-1 while the total cowpea and yam produced declined from 7662kg yr-1 to 3162kg yr-1 and 16948kg yr-1 to 6994kg yr-1 respectively. The decline in maize produced represents a shortfall of 25% while in cowpea and yam the shortfalls are 58% respectively. At a local market level, these reductions may affect prices.

Whilst the optimal solutions in FP1 did not include intercropping, the solution in FP2 – with Jatropha – did. Jatropha was intercropped with Cowpea. We anticipate benefits due to a change in land use: plant residue improves soils structure and also creates a positive micro-climate (DaMatta, 2004) but it also revealed a shift in the demand for family labour. For instance the use of family labour increased from 22 days in FP1 to 32 days in FP2 while demand for hired labour has increased from 31 days in FP1 to 90 days in FP2. The uncertainty of casual labour availability and costs become complicated depending on the season and flow of migrant labour from up North and vice versa. This point is underscored by Ngeleza et al (2011).

The introduction of Jatropha will probably raise the expectation of casual labourers who will demand a higher wage per hectare at critical periods of the production cycle. Our study revealed that hiring extra labour is more efficient compared to previous Farm plans; however, we assumed that wages were fixed.

Overall, FP2 is more attractive compared to FP1. Total Gross Margin in FP2 is estimated at GH₵92,495 compared to GH₵89,814 in FP1. This represents GH₵2,681. As noted, reduced costs and shadow prices are important as they indicate how changes in the mix of enterprises or in the constraints affect TGM of a farm. Our analysis found that cropping activity with the highest reduced cost was S2 (GH₵8,268) while the cropping activity with the least reduced cost was S1 (GH₵1,368). Land is the most binding resource, with the highest shadow price (GH₵9,888). Analysis of risks associated with TGM showed that growing Jatropha is preferred to growing just food crops but in the Ghanaian context, in addition to TGM, there are other decisions influencing what farmers take into consideration. Some farmers attach importance to a crop based on its social value; others would choose a crop based on compatibility to farming systems while others choose on the basis of knowledge of the crop that is intended to be grown.

A significant conclusion from the risk analysis is that growing Jatropha presents a lower risk compared to growing food crops (see Figure 6.7). The analysis showed that at Max TGM of GH₵67,023, the associated risks between FP3 and FP4 are 56,337,970 and 78,831,303 respectively. The percentage change in risk is 38% in FP4 compared to FP3. At this point, there is a relatively decrease in farm area from 13ha in FP3 to 10.7ha in FP4. As TGM and risk decline in both plans so does total farm area until both attain a convergence point at which TGM and risk remains the same (TGM at GH₵26,809).

Fixed prices for Jatropha seeds could boost its production and also remove the risks and uncertainty associated with its production. It is worth pointing out however, that the QP results assume that all things being equal, farmers would behave in same manner in relation to risks and TGM but as many authors have warned (e.g. Fafchamps, 1992), large scale farmers are very different from small scale farmers because the former are better able to sustain risk compared to small scale farmers.

5.CONCLUSION

We conclude that the aim and objectives have been achieved based on the results and findings of our research. Jatropha has been presented as having both economic and environmental benefits (Janda et al., 2011, Kumar and Sharma, 2008).

The analysis showed that the relationship between interest rate and TGM is strong. This therefore means that the policy that helps farmers to get access to credit would have a positive impact on farmers' income. It is worth pointing out however, that the QP results assume that all things being equal, farmers would behave in same manner in relation to risks and TGM but as many authors have warned (e.g. Fafchamps, 1992), large scale farmers are very different from small scale farmers because the former are better able to sustain risk compared to small scale farmers. Data on Jatropha extraction and esterification into biodiesel in Ghana was also limited. We recognise therefore, that our findings might be compromised as a result. As such further research in farm data collection can be identified

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