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# Estimation of Optimal Land Use Allocation Among Small Holder (A1) Farmer Households in Zimbabwe. A Case Study of Long Croft Farm, in Mazowe District

Douglas Mugabe[1], Nyasha Chipunza[1], Norman Mupaso[1], Vincent Tinashe Munyati[2] & Fungai Violet Makarudze[3]

[1] Department of Agricultural Economics and Development, Midlands State University, Gweru, Zimbabwe

[2] Department of Agricultural Economics, Education and Extension, Bindura University of Science Education, P Bag 1020 Bindura, Zimbabwe

[3] Department of Agriculture Economics and Extension, University Of Zimbabwe, P Bag MP167, Mt Pleasant Harare, Zimbabwe

Correspondence: Douglas Mugabe, Department of Agricultural Economics and Development, Midlands State University, Gweru, Zimbabwe. Tel: 26-377-322-8489. E-mail: mugabed@msu.ac.zw, mugdoug@gmail.com

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**Abstract**

This study aimed to develop an optimal land use plan for Long Croft farm (LCF) by assessing the available land resources. It evaluates the potential of the land resources for recommending optimum, sustainable and appropriate land utilisation in agriculture development. Possible ways in improving farming systems and more efficient utilization of the scarce available agricultural resources especially arable land were determined. The study used quantitative analytical approach in optimal land use allocation analysis. A total of thirty six structured questionnaires were used to gather data necessary for analysis. Every household at Long Croft farm was taken as a sampling unit and the area consisted of 36 A1 farmer households. The Linear programming model with an objective function that seeks to maximise net farm income subject to land, labour, capital and consumption constraints was run using Microsoft excel premium solver. The results of the study showed that A1 households are insecure with respect to their land holdings; they cannot use their land as collateral security which is affecting farmer access to credit. The households are also much constrained in land, labour, capital and consumption and as such their land allocation has been found to be not optimal. The LP (linear programming) model has depicted maize, soya beans and sugar beans for LCF when they are no factor markets. However introduction of factor markets (land and labour markets) and farmer performance groups depicted production of small grains and maize. The land reform programme promulgated by the government in 2000 should have focused on equitable right of use, optimising sustainable production, protection of natural resources/ environment against degradation and increase the effectiveness of economic growth of rural and urban population. Most of the fast track land reform developmental activities were done without proper resource surveying for optimum and sustainable resource utilization, especially land, hence great competition and losses of good agricultural uses to inefficient agricultural uses. Resource surveying, land evaluation and land use planning should be employed in Zimbabwe's agriculture to boast production.

**Keywords:** land, land use types, land use planning, optimal allocation

## 1. Introduction

Land use planning is a special allocation problem, where the planner (the farmer), by manipulating the proportions and locations of land uses, seeks to satisfy one or more goals. Land use planning is a potentially challenging search and optimization task, as the farmer must frequently take into account complex non-linear interactions between parcels of land allocated to particular land uses (Eldrandaly, 2009). He also added that, 'land use allocation must try to reconcile multiple conflicting interests as rationally and transparently as possible, which, among other things, involves evaluating land units not only with regard to their suitability for competing uses but also with regard to such factors as contiguity among units assigned to the same use, and the compactness of the single-use land masses so created'. Therefore, optimal land use allocation approaches involves designing the alternatives and searching for the best decision among an infinite or very large set of feasible alternatives to the farmer. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions.

Fast track land reform programme of 2000 resulted in agricultural institutional changes affecting the social and economic status of the country. Most of the land allocated to new farmers is underutilized. Resettled A1 farmers are not efficiently utilising their land resources, thus there is no PE optimal production due to environmental and socio-economic constraints limiting their capabilities. Resettled farmers are not yet adapted to the optimal path of land use. Rukuni and Eicher (2006) indicated that, Fast track land reform programme failed to guarantee the minimum tenure requirements to incentivize investment and sustainable land use practices among the new occupants resulting in farmers not optimally utilizing their land resources (reducing the investment incentives practically towards zero). Therefore farmers are constrained in optimally allocating their lands to achieve PE (Pareto Efficient) production leading to low net benefits realized. Resettled rural farmers are also characterised by less or no investment due to insecure land tenure systems, market imperfections and limited access to input and output market, credit, off farm employment and information.

Land use allocation problems can be solved with optimization modelling (linear programming), which involves, defining the potential land use types and searching the optimal distribution for these land uses that is efficient. The optimization model recommends the range of land use by sub-area at the end of the planning period. The modelling results directly answer the question of 'what to do?' One of the common and challenging dilemmas facing natural resource managers is how to allocate a fixed resource, especially land, amongst competing uses/users. In land use allocation the primary concern is often related to the notion of efficiency or 'whether a given land is used in its most socially valuable way' (Pierce, 1983). Not surprisingly, there are a variety of efficiency criteria. Pierce (1983) said 'perhaps the best known is the concept of Pareto Efficiency (PE)', in which an optimal state is reached once no-one can be made better off without making some one worse off. Then linear programming is recognized as an important tool for agricultural land use exploration (Hazel & Norton, 1986; De Wit et al., 1988; Van Keulen, 1990; Bouman et al., 1998). It can be used to explore land use allocations that optimize agricultural, economic or environmental objectives at the farm level (Rossing et al., 1997) and at the regional level (WRR, 1992; Rabbinge & Van Latesteijn, 1992; Van Ittersum et al., 1998; Bouman & Nieuwenhuyse, 1999; Raju & Kumar, 1999).

Majority of Zimbabwe's population depends on agriculture for their livelihood. There is great competing demand on land for food production. Arable land is scarce in Zimbabwe due to a greater population that depends on agriculture therefore land allocation problems become a pressing issue in maximising production. Resettled farmers should aim for optimal land use allocation that is (PE) Pareto Efficient to improve their performances and for efficiently allocation of resources to enhance agriculture development. A1 farmers are resource constrained so much in their production. They are facing environmental, economic and social constraints that are limiting their capacity to perform optimally in agriculture. Thus there is need for applying the economics of land production in their farming given such constraints to maximise their net benefits. A1 farmers should aim to allocate land to its best use that gives the highest returns per unit of dollar spent on production without much degradation of it. A1 farmers should know the crops that give the highest yield supported by their land resources (soil type and quality). The researcher designed the PE optimal utilization path under alternatives for resettled farmer, internal conditions, market and institutional conditions. Optimal allocation is defined by Fu et al. (2004) as the assignment of optimal use to a piece of land, of land resources that play an important role in human existence and development. If the land is not allocated properly it is vulnerable to degradation (Huda, 2004). For this analysis optimal land use is enterprise combination that would result in an increased Net Social Benefits (increase in farm Net income). For this definition the researcher takes farming as a business.

How is changing of crop enterprises and or land allocation of benefit to a farmer? The solution would depend on the choices/decisions the farmer puts about the types of crops and acreage to grow. The assumption is that farmers make choices so as to enhance their satisfaction or wellbeing. Bowman et al. (2013), in particular farmers will tend to go for activities that improve their income, reduce costs and physical risk, reduce labor requirements and are convenient and enjoyable. However a farmer is faced with a lot of constraints; production technologies, biophysical or geophysical, input market, capital, labor, social norms, credit, inter-temporal tradeoffs, policy, food and constraints to knowledge or skills (Stoorvogel et al., 2004). For this study only labor, land, capital and food constraints are taken into account. Biological and geophysical factors that influence farmer choices may include availability and distribution of rainfall, soil type, and pest and weed infestations (Leemans et al., 1994). The conditions on the input market can as well shape farmer decisions be it labor, capital or land market. Bowman et al. (2013) diversification of crop enterprises that a farmer venture into is a best tool to do with several risk including price, yield and risks in labor markets.

## 2. Research Methods

### *2.1 Data and Sampling Frame*

The study focused on a household as the unit of analysis. A combination of quantitative and qualitative research methodologies were used to gather data. The household was taken as the sampling unit. Long Croft farm consist of 36 resettled farmers (households), and all households were interviewed to obtain data on land use allocation. The participatory approach was utilized to collect the primary data in the Mazowe district. This was done using a structured questionnaire. Quantitative data was collected on variables like household characteristics, farmer perceptions and resource allocation to different activities and crop enterprises especially land allocation. Data on other factors that contribute to output was also collected including output data.

### *2.2 Analytical Framework: Linear Programming (LP) Optimisation Model*

In agriculture, where various crops are competing for a limited quantity of land and water resources, linear programming is one of the best tools for optimal allocation of land and water resources (Khepar & Chaturvedi, 1982; Kaushal et al., 1985; Panda et al., 1985; Vedula & Kumar, 1996; Paul et al., 2000). Most of the studies of optimization on land allocation adopt simplified or linear objective functions to maximize the net benefits while selecting an optimum cropping pattern.

This study estimated the optimal land allocation by A1 farmers in LCF. The paper also evaluated the effectiveness of changing land use systems (land allocation among crops) as a mechanism for increasing the net income for the resettled farmers. A (PMP) Positive Mathematical Programming model (Howitt, 1995) was applied for the 36 farmers using a net income/benefit maximizing objective function. The objective function is to maximise net income for the farm through changing agricultural land allocation among crops subject to land, capital, and labour and food security constraint.

*Assumptions:*

i. Land allocation by each farmer observed was assumed to be an outcome of PM (profit maximisation) behaviour.
ii. The allocation was also assumed to represent the intra-agricultural market equilibrium solution.
iii. Land use was optimised by allocating land Pareto efficiency (PE) in the pursuit to maximize social utility.
iv. The value of land use options was assumed to depend on national parameters and the flow of goods, services and factors of production.
v. Social utility is a function of maximum net income through the efficient use of land resources.

### *2.3 The Model*

The model searches for the PE agricultural land use allocation and calculate the increase in net income relative to PM solution. Data used encompassed land allocation among the seven crop enterprises; cotton, maize, soya beans, sugar beans, sunflower, groundnuts and small grains which in principle can be undergone by the 36 farmers at LCF.

Let $l_{ik}$ (in hectares) – be land allocated to enterprise i by farmer k

jK = 1............... 36

Accordingly $L_k \equiv (l_{1,k} \ldots\ldots\ldots\ldots\ldots l_{7,k})$ is a vector denoting land allocation by farmers

$L_k = \sum l_{ik}$ is the total agricultural land for LCF

Land allocation by each farmer observed was assumed to be an outcome of PM behaviour and such allocations also represent the intra-agricultural market equilibrium solution denoted by $L_k^{m,}$ that constitute a solution to the problem:

Max $_{(l_{1,k}.l_{7,k})}$: $\Pi_k(L_k) = \sum l_{ik}[P_iY_i - C_{ik}]$

Subject to: 1) Land constraint
2) Labour constraint
3) Capital constraint
4) Food constraint

Where;

$\Pi_k$ (\$/year) - Annual profit by farmer k

$\bar{L}_k$- Is the total agricultural land constraint for farmer k

$l_{ik}$ – Is amount of land allocated to crop i by farmer k

$Y_i$ – (tonnes/hectare-year) Denotes annual yield of crop i

$P_i$- (in \$/tonne) Output price for crop i

$C_{ik}$ – Production costs of crop i for farmer k

The term $C_{ik}$ (in \$/hectare-year) represents the per hectare average production cost which is expressed as a linear function of crop's land area $l_{ik}$. This function is used to indirectly reflect the impact of various factors that are unobserved considered by farmers while contemplating their land allocation among crops, including the spatial variability of the soil quality, marketing and agronomic risks, and managerial limitations. Contrary to CRS based model, this model will enable the optimal land allocation to be smoothly altered to exogenous shocks. The cost function $C_{ik}$ is a linear (\$/ha-year) which is base year average production costs.

*2.4 Application*

The PE solution was computed by searching the farmers' optimal agricultural land allocation among the 7 enterprises, $l_{ik}$. The solution maximises the net income function subject to land, labor, and capital and food security constraints.

Max net income: $\Pi_k(L_k)= \sum l_{ik}[P_iY_i - C_{ik}]$

s.t : Land, labor, capital and food constraints

I denoted $L_k^s$ the PE land allocation. It is assumed that farmers are willing to shift from the PM land allocation, $L_k^m$ to $L_k^s$ as long as they are maximising net income for the farm; moving from PM to PE optimal land allocation.

*2.5 Limitations of the Linear Programming Model*

1) The model assumes that land allocation observed by each farmer to be an outcome of profit maximization, yet most rural farmer household allocations are a result of their consumption.

2) The solution is assumed to represent intra-agricultural market equilibrium solution yet rural farm areas has no active factor markets.

## 3. Results

Having known the types of crop enterprises currently undergone by Long Croft farmers, this section will then seek to analyse the efficiency of choices (optimal) of allocating land resources to increase the net income at farm level. The question that motivates this analysis asks whether the A1 farmers are allocating their land resources optimally to increase their income. The LP (linear programming) model has been built on an Excel worksheet and run by premium solver. The LP model used was based on primary data that was computed to come up with one model for the farm. The specification of the model is to maximise net income subject to land, labour, capital and food security constraint. The food security constrained was assumed to be 1000 kgs of maize per year for each household given that an average household at Long Croft farm have seven (7) members. The evidence from previous done researches showed that an individual would consume between 120 kgs and 151 kgs of maize/cereal per year. Chiukira et al. (2010) indicated that the average maize consumption per capita was 120 kgs/year between 2004 and 2008. FAO/WFP (2010) report showed that the human cereal per capita consumption in Zimbabwe was 151kg/annum. The ZimStat (2013) report indicated that per capita maize consumption for 2011/12 was 135 kgs/annum. Therefore for a seven member family the maize consumption per year would be +/- 1000 kgs and as such the researcher assumed 36000 kgs of maize as a food constraint for the model. The linear programming model for this analysis was to:

Max net income: $\Pi_k(L_k)= \sum l_{ik}[P_iY_i - C_{ik}]$

i = enterprises = 1, 2 ...... 7

k = farmers = 1, 2 ......... 36

Subject to:

$\sum l_k \leq 211.25$ (arable land constraint);

$\sum L_{bik} \leq 10450$ labor days (labor constraint);

$\sum K_{ik} \leq \$71678.25$ (capital constraint);

$\sum Q^k_{maize} \geq 36000$kgs (food constraint);

$l_k \geq 0$; $L_{bik} \geq 0$; $K_{ik} \geq 0$; $Q^k \geq 0$ Non-negativity constraints.

I denoted $L_k^s$ the PE (Pareto Efficient) land allocation. I also assumed that farmers are rational in maximising profit therefore the current land allocation behaviour is assumed to be PM (Profit Maximising). Thus for the analysis farmers are willing to shift from the PM land allocation, $L_k^m$ to $L_k^s$ as long as they are maximising net income for the farm; moving from PM to PE optimal land allocation.

The results of the linear programming model are shown in Table 1 below where the original values are the PM values and final values are the PE behaviour. From the table below a positive slack after running the model indicates that land allocation for maize, soyabeans, groundnuts and sugar beans are not binding, that is, there are not exosting the constraints. Zero slack value for other allocations implies that the constraints are exosted.

Table 1. Results of Linear Programming model

Objective function: Maximise Net income

| Crop enterprise | Original area (PM) | Final area (PE) | Status (slack value) | Reduced gradient |
|---|---|---|---|---|
| Maize | 101 | 16.09 | Not binding (16.1) | 0 |
| Soyabeans | 44 | 161.24 | Not binding (161.2) | 0 |
| Cotton | 24.5 | 0 | Binding (0) | -117.47 |
| Groundnuts | 9.85 | 9.85 | Not binding (9.85) | -483.78 |
| Sugar beans | 6.3 | 12.77 | Not binding (33.9) | 0 |
| Sunflower | 5.55 | 0 | Binding (0) | -59.41 |
| Small grains | 11.55 | 0 | Binding (0) | -72.82 |
| Fallow | 8.5 | 0 | Binding (0) | -67.45 |
| Total area | 211.25 | 211.25 | Binding (0) | |
| Net income | \$29870.93 | \$41233.52 | | |

Source : Own calculations.

The original values of the assumed PM (profit maximising) behaviour indicate that not all the land is cultivated 8.5 hectares is left fallow. The land allocations under PM ($L_k^m$) show that groundnuts, sugar beans and sunflower are allocated less than 10 hectares each with soyabeans and maize taking most of the land. With PM behaviour ($L_k^m$ ) the farm is realising net benefits of \$29870.93. After running the model the PE (Pareto Efficient) behaviour indicated by $L_k^s$ land allocation indicated that there is an increase in net benefits for the farm of 38.04% with a value of \$41233.52. The optimal land allocation (PE) for the LCF newly resettled farmers depicts that 16.09 hectares of land should be put under maize, 161.25 hectares under soyabeans, 12.77 hectares under groundnuts and 9.85 hectares under sugar beans production. Other crop enterprises like cotton, sunflower and small grains should be allocated zero hectares each since they have shown to give less in terms of net income for the farm.

The reduced gradient entails us how much value would be lost when we force the production of certain crop. Maize, soya beans and sugar beans have a zero value meaning that since these are the three crops favoured by the model there would be no losses in net benefits (net income) if farmers increase area of each of these crops. If farmers force the production of groundnuts, a higher amount of \$483.78 would be lost from total net benefits per each unit hectare of groundnuts grown. Likewise forcing the production of cotton, sunflower and small grains result in losses per unit of land utilised by \$117.47, \$59.41 and \$72.82 respectively. Letting the land lie fallow would result in \$67.44 lost per each hectare uncropped.

Table 2 below illustrates the shadow values from the model.

Table 2. Lagrangean multipliers

| **Constraint** | **Status** | **Lagrange multiplier** |
|---|---|---|
| Total land | Binding (0) | 67.44 |
| Total capital | Not binding (11597.06) | 0 |
| Total labor | Binding (0) | 3.15 |
| Consumption | Binding (0) | -0.03 |

Source: Own calculations.

The Lagrange multiplier (shadow value) depicts the extra amount obtained when an additional unit of an input is employed. From Table 2 above an additional increase in total area by one hectare would result in an additional increase in net benefits obtained by an amount of $67.44. Likewise additional usage by one unit of labour results in an additional increase of $3.15 to net benefits. However an additional use of 1 unit of capital is resulting to zero additional benefits because capital was a non binding constraint in the model. Moreover an additional need of 1 kg of maize for food security reasons would result in a loss of $0.03 of net income obtained.

*3.1 Policy Scenarios: Allowing Trade (Labour and Land Markets)*

Land markets are the key to agricultural food security recovery and increase of the net income for the newly resettled farmers. Suppose the government offers tradable user rights 'permits' for leasing but not selling designated A1 farmland which allows them to trade within themselves. Or the government offers private title deeds for commercial farmland i.e. the government permits leasing and or buying/selling of zonal farmland. Therefore the PE land use allocation would be different with scenario of incomplete land markets. Likewise if labor is allowed to be traded among the farmers there would be also different outcome with a situation of incomplete labor market. Factor markets results in new land allocation which can result in higher net income gained by the farmers. Land market reform implies that poor performing farmers would lease their farmland to competitive producers who can produce more to obtain higher benefits, and good performing farmers would pay rent. The cost of land per hectare (rent) when a farmer leases his/her farmland was calculated using WTA (willingness to accept) and found to be $389.86 (see Table 3). The researcher then used 60% of this value for calculations which is $233.92 with the assumption that most of the rural farmers overprice the resources.

Table 3. Descriptive statistics of land value

| WTA for a hectare | Number of farmers | Minimum WTA ($) | Maximum WTA ($) | Mean WTA ($) | Standard deviation |
|---|---|---|---|---|---|
| Willingness to lease out | 36 | 200.00 | 800.00 | 389.8611 | 140.71494 |

Source: Own calculations.

The farmers were first put into four different performance groups according to their specialisations and farming opportunities before model optimisation. Such groups are as a result of farmer's ability to grow soyabeans, cotton or sugar beans. Group 1 farmers cannot grow these three crops. Group 2 are only able to grow soyabeans, group 3 are able to grow soyabeans and cotton only whilst group 3 can grow all the 3 crops. The models are to maximise net farm income subject to land, labour, and capital and consumption constraints for each farmer group.

Table 4 below shows the description of the different policy scenarios applied.

Table 4. Description of policy scenarios

| Description | Scenario1 (model 1) | Scenario2 (model 2) | Scenario3 (model 3) | Scenario4 (model 4) |
|---|---|---|---|---|
| Objective function | Max net income: $\Pi_k=\sum l_{jk}[P_iY_i-C_{ik}]$ | Max net income: $\Pi_k=\sum l_{jk}[P_iY_i-C_{ik}]$ | Max net income: $\Pi_k=\sum l_{jk}[P_iY_i-C_{ik}]$ | Max net income: $\Pi_k=\sum l_{jk}[P_iY_i-C_{ik}]$ |
| Labor market | Incomplete labor market | Complete labor market (labor is traded among groups) | Incomplete labor market | Complete labor market (labor is traded among groups) |
| Land market | Incomplete land market | Incomplete land market | Partially complete land markets (land leasing) | Partially complete land markets (land leasing) |

Source: Own suggestions.

### *3.2 Effect of Policy Scenarios on Net Income*

Table 5 below shows the net income obtained with different policy scenarios. Scenario 4 got the highest value of net farm income as compared to other scenarios. The partially complete land market and incomplete labor market scenario got the lowest net income.

Table 5. Total net income for different policy scenarios

| Policy scenario | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Net income obtained (US$) | $35 368.34 | $54 839.65 | $26 644.44 | $127 197.22 |

Source: Own calculations.

Above results clearly indicate that introduction of factor markets can result in higher farm net income.

It is clearly shown that optimisation resulted in higher net income obtained as compared to current PM scenario. However given model 1 (incomplete market scenario) the net income for the groups and for the scheme are less than with land and/or labor market scenarios (model 2, 3 and 4). Considering the net farm income model 4 gives the highest net income as compared to all other models. When farmers lease in/out their land as depicted by model 4 net income increased as compared to incomplete market scenario (model 1) with leasing out groups obtaining an increment in net income of 100.1%, 39.4%, 42.4% for groups 2, 3 and 4 respectively and net farm income for the whole farm increased by about 259.6%. Therefore with both land and markets all players, the producers (who lease in) and the land owners (who lease out) would benefit from greater clarity of division of roles and responsibilities.

### *3.3 Effect of Policy Scenarios on Land Allocations*

Table below illustrates changes in land allocations with each different model/policy scenario.

Table 6. Answer report for baseline and all scenario models land allocations

| GROUP | Crops grown | Model 1 (ha) | Model 2 (ha) | Model 3 (ha) | Model 4 (ha) |
|---|---|---|---|---|---|
| 1 | Maize | 2.38 | 2.38 | 29.68 | 14.28 |
| | Groundnuts | 1.326 | 0 | 0 | 0 |
| | Sunflower | 14.105 | 0 | 0 | 0 |
| | Small grains | 20.189 | 35.62 | 12.02 | 196.96 |
| 2 | Maize | 13.7 | 63.41 | 32.08 | 0 |
| | Groundnuts | 0 | 0 | 2.95 | 0 |
| | Soyabeans | 46.0 | 0 | 24.57 | 0 |
| | Sunflower | 7.84 | 4.09 | 3.74 | 0 |
| 3 | Maize | 5.9755 | 5.975 | 17.43 | 0 |
| | Groundnuts | 0 | 0 | 0.69 | 0 |
| | Cotton | 0 | 0 | 20 | 0 |
| | Soyabeans | 28.97 | 0 | 10.63 | 0 |
| | Sugar beans | 2.377 | 0 | 0 | 0 |
| | Sunflower | 17.385 | 50.52 | 5.32 | 0 |
| | Small grains | 0 | 0 | 2.65 | 0 |
| 4 | Maize | 32.97 | 4.27 | 23.28 | 0 |
| | Groundnuts | 0 | 0 | 2.2 | 0 |
| | Cotton | 0 | 0 | 5.56 | 0 |
| | Soyabeans | 12.521 | 0 | 11.15 | 0 |
| | Sugar beans | 0 | 44.98 | 3.4 | 0 |
| | Sunflower | 3.763 | 0 | 2.04 | 0 |

Source: Own calculations.

Model 1 indicates that each group would grow maize for food security reasons, and groundnuts and small grains would be grown by group 1 only but none of the groups venture into cotton production. Model 1 also depicted zero area for soyabeans in group 1 with other groups increasing their hectrage. The incomplete market model also indicates that group 3 is the only group that would grow sugar beans with 2.377hactares but sunflower is grown by all groups.

Under model 2, all groups would still grow maize for consumption purposes but on small scale as compared to PM allocations. Labor market scenario depicted zero hectares for groundnuts, cotton, soyabeans and fallow land for all the groups with 44.98hectares of sugar beans in group 3. Sunflower would only be grown by group 2 and 3 with 4.09 and 50.52 hectares respectively. 35.62 hectares of small grains would be grown by group 1.

Model 3 allows for land leasing within the farmers in the scheme but labor market is incomplete. The model resulted in zero fallow land in all groups but more land is put under maize as compared to scenario 2 and 3. Groundnuts are grown by all groups but cotton is only produced by group 2 and 4. Sugar beans would only be grown by group 4 farmers. Group 1 would put zero hectares of sunflower and 12.02 hectares of small grains.

In model 4 there in complete labor and partially complete land markets, which allows for land leasing among farmers. Scenario 4 resulted in farmers in groups 2, 3 and 4 leasing out all their land to group 1 farmers. This model depicted 196.96 hectares for small grains and 14.286 for maize. Farmers in groups 2, 3 and 4 became just land owners not producers. Therefore optimisation model with both land and labor markets would result in production of only maize and small grains.

### *3.4 Langrangean Multipliers for Policy Scenarios*

Table 7 illustrates the langrangean multipliers for all market scenarios. For all the models land is a binding constraint, thus an increase in land holding adds value to net income obtained at group level and as well at farm scheme level. Labor is binding in model 1 and 3 and not binding for the other two models. Therefore increasing labor for land and/or labor markets scenarios would not result into an increase in net income obtained. Capital is as well a binding constraint for model 1, 2, and 3 but not binding for scenario 4. Considering consumption, it is not binding for model 1, 2 and 3 but binding for model 4.

Table 7. Langrangean Multipliers for all models market scenarios

| Group | Constraint | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|---|
| 1 | Land | 0 | 573.688 | n/a | n/a |
| | Labor | -3.613 | n/a | 15.776 | n/a |
| | Capital | -1.806 | n/a | -1.413 | n/a |
| | Consumption | -0.044 | -0.221 | 0 | n/a |
| 2 | Land | -711.482 | 0 | n/a | n/a |
| | Labor | -0.904 | n/a | 7.403 | n/a |
| | Capital | 0.2498 | n/a | 0.582 | n/a |
| | Consumption | 0 | 0 | 0 | n/a |
| 3 | Land | -769.086 | 39.421 | n/a | n/a |
| | Labor | 0 | n/a | 6.38 | n/a |
| | Capital | 0 | n/a | 0 | n/a |
| | Consumption | -0.1152 | -0.122 | 0 | n/a |
| 4 | Land | -526.37 | 71.63 | n/a | n/a |
| | Labor | -1.5773 | n/a | 0 | n/a |
| | Capital | -0.5 | n/a | 0.796 | n/a |
| | Consumption | 0 | -0.0166 | 0 | n/a |
| Whole farm | Land | 379.224 | 29.554 | 406.06 | 244.25 |
| | Labor | 0.8428 | 0 | -11.824 | 0 |
| | Capital | 0.367 | 0.331 | -0.94 | 0 |
| | Consumption | 0 | 0 | 0 | -0.188 |

Source: Own calculations.

From Table 7 above it indicates that increasing land for the whole scheme with a unit hectare would result in \$379.224, \$29.554, \$406.06 and \$244.25 increment in whole scheme net income for models 1, 2, 3 and 4 respectively. But the Lagrangean multipliers for land are negative for group 2, 3 and 4 indicating losses in such groups with additional increase in land holding. An additional increase in labor by 1 unit can results in \$0.8428, \$0.00, -\$11.824 and \$0.00 gains for model 1, 2, 3 and 4 respectively. There is a positive gain for models 1 and 2 in net income given a unit increase in capital but with -\$0.94 for model 3 and \$0.00 for model 4. However increase in consumption is resulting in zero gains/losses in net farm income for model 1, 2 and 3 but with -\$0.188 loss given complete market scenario (model 4).

*3.5 Effect of Forcing the Production of Unfavoured Crops on Income*

Reduced gradients indicate the amount of income lost if we force production of a crop.

Table 8. Reduced gradients for all models

| Group | Crop | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|---|
| 1 | Maize & small grains | 0 | 0 | 0 | 0 |
| | Groundnuts | 0 | -1644.037 | 0 | -1338.78 |
| | Cotton | -769.086 | -603.24 | -795.92 | -634.11 |
| | Soyabeans | -769.086 | -603.24 | -795.92 | -634.11 |
| | Sugar beans | -769.086 | -603.24 | -795.92 | -634.11 |
| | Sunflower | 0 | -983.117 | 226.8911 | -799.930 |
| 2 | Maize | 0 | 0 | 0 | -96.68 |
| | Groundnuts | -318.33 | -509.417 | 0 | -846.06 |
| | Cotton | -57.603 | -29.55 | -795.92 | -634.11 |
| | Soyabeans | 0 | -20.82 | 0 | -542.02 |
| | Sugar beans | -57.603 | -29.55 | -795.92 | -634.11 |
| | Sunflower | 0 | 0 | 0 | -395.75 |
| | Small grains | -417.492 | -405.198 | -565.23 | -841.60 |
| 3 | Maize | 0 | 0 | 0 | -338.08 |
| | Groundnuts | -4349.334 | -4230.95 | 0 | -3603.46 |
| | Cotton | -22.824 | -41.97 | 0 | -516.91 |
| | Soyabeans | 0 | -7.03 | 0 | -465.85 |
| | Sugar beans | 0 | -68.98 | -795.92 | -634.11 |
| | Sunflower | 0 | 0 | 0 | -362.79 |
| | Small grains | -386.84 | -387.850 | 0 | -749.81 |
| 4 | Maize | 0 | 0 | 0 | -31.51 |
| | Groundnuts | -98.531 | -341.948 | 0 | -630.82 |
| | Cotton | -119.72 | -159.72 | 0 | -591.30 |
| | Soyabeans | 0 | 0 | 0 | -448.60 |
| | Sugar beans | -230.353 | -302.79 | 0 | -719.99 |
| | Sunflower | 0 | 228.654 | 0 | -531.69 |
| | Small grains | -507.239 | -740.37 | -226.36 | -1045.21 |

Source: Own calculations.

Results above indicates that if we force the production of maize in all groups nothing is going to be lost in the first 3 market scenarios but with model 4 group 2, 3 and 4 would lose \$96.68, \$338.08 and \$31.51 respectively.

With groundnuts production all the models except model 3 depicts losses if we force the production of this crop, but we a zero loss in group 1 for model1. Letting each group to produce cotton would result in losses except with scenario of land leasing for group 3 and 4. If group 1 is allowed to grow soyabeans it would lose \$769.086, \$603.242, \$795.92 and \$634.11 for scenarios 1, 2, 3 and 4 respectively. The reduced gradients are negative for sugar beans in all scenarios for each group except for model 1 in group 3 and scenario 3 for group 4.

## 4. Conclusion

### *4.1 Summary of Findings*

PE behaviour is the best combination of the enterprises that maximises the objective function subject to constraints. The PE is a collective goal/social planar problem that seeks to maximise utility for the whole farm or for all the households as a single unit and it therefore forces each individual to perform as expected. Linear programming model depicted 16.09 hectares for maize, 169.92 for soyabeans and 25.24 for sugar beans. The LP modelling resulted to a higher net social benefit value. With farmer performance groups introduced the market scenario (model 4) resulted in 196.96 hectares of land allocated to small grains and 14.29 hectares put under maize production. It has therefore been noted that factor markets will liberate land for commercial agricultural uses thus giving the land the maximum collateral value. Hence complete market scenario leads to greater net benefit that scenarios with incomplete land markets.

### *4.2 Policy Implications*

It has been noted that greater achievement in agriculture development to increase food security and increase net benefits for the farmers can be overcome by implementing factor markets reforms especially the land markets. The land marketing system should promote competitive domestic food and agricultural marketing systems. Let the good farmers produce and bad farmers lease out their farm land, with such a scenario greater farm incomes are realised by all players, the leasers and those who lease in.

### *4.3 Recommendations*

#### 4.3.1 Recommendations to Government

The government should introduce factor markets reforms i.e. allowing farmers to lease in/out their land so that good farmers would produce more and bad farmers are just land owners. With such a policy scenario all players would benefit much from greater clarity of division of roles and responsibilities.

The appropriate form of land reform and land policy is crucial for agriculture development. The continuation of the control of farm land by the state and undefined land rights plays important role in inhibiting land tenure security and thereby posing a serious structural constraints and challenge on the long term agriculture development for the A1 farmers. Not forgetting in mind that secure land rights help farmers to access credit therefore the Zimbabwean government must offer land rights to the newly resettled households.

Resource surveying, land evaluation and land use planning should be employed in Zimbabwe's agriculture to boast production.

#### 4.3.2 Recommendations to the Newly Resettled Farmers

Basing on the results of the study LCF should aim to put more land under soyabeans and sugar beans if they are to increase their net benefits and only few hectares for maize production just enough for food security given than factor market are incomplete.

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