Determination of optimum crop mix for crop cultivation in Kerala homesteads

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ABSTRACT
Homestead farming has been the backbone agricultural economy of Kerala but the productivity of the homesteads in Kerala has yet to reach an acceptable level. In this paper the possibility of increasing the contribution of this sector through proper crop planning is sought. The optimum model was developed by using linear programming (LP) technique. The constraints included in the analysis were total area, intercropped area, investment amount and population of each enterprise. The optimum model reveal the scope of 22.83 per cent enhancement in net return as compared to net return from the existing plan. Sensitivity analysis of the optimum model revealed that further enhancement of net return in The agro-ecological region could be achieved by increasing the cropping intensity in the underutilized intercropped area and changing the binding enterprises.

Key words: Homestead, Linear programming, Optimum Model, Sensitivity analysis.

INTRODUCTION
The home gardens of Kerala evolved because of the pressure of shrinking land resource base joined with a high population density, which necessitated a conscious attempt on the part of farmers to achieve their goals which could be economically viable and ecologically sustainable while contributing towards food security of the state. According to Nair and Kumar (2006) home gardening is a way of life and even now critical to local subsistence economy and food security.

However, the conventional home gardens were handled irrationally without any planning and with very low resource use efficiency. Though Kerala used to be an agrarian state; Agriculture has ceased to be the most important economic activity. The Situation Assessment Survey of Agricultural Households conducted at national level in NSSO 70th round (January-December 2013) revealed that Kerala had the least percentage share of agricultural households in the country i.e.; 27.3 per cent and nearly, 61 per cent of the agricultural households reported to have earned income from activities other than agricultural activities (PK et al., 2017).

In traditional agriculture, few inefficient allocations of resources were reported (Haque, 2006). Increasing farm inputs cost, volatile prices and resultant decline in profitability has been making agriculture a losing proposition. Increasing population and low per capita availability of lands have necessitated better management practices in home gardens. Evidences from various parts revealed that homestead farming and interventions in home gardens could play a considerable role in improving food security particularly for the resource poor rural households in developing countries.

In agriculture, like in any other business, the efficiency is accomplished by an optimum utilization of resources. Resources include land, labour, capital, etc. Optimum allocation of land and other resources involves decisions regarding what crops to produce, how much land to allot to each crop activity and what strategy and combination of inputs to each crop so that the farm return is maximum. In this perspective, it is necessary that the available scarce resources should be used economically and efficiently. The efficiency of farming depends on such combination of inputs that is most economical to secure a given output. The efficiency of given resources is said to be greater when higher the output for unit input and conversely greater the efficiency of resources when lower the input per unit of output. The maximization of efficiency is therefore, a criterion for maximizing the profit. Relating to this, according to Hassan et al. (2015) the only way to meet increasing demand of food, fibre and fuel for the ever increasing population is by increasing production per unit area which is possible by more scientific utilization of the resources and their optimal allocation to achieve maximum returns.

Mathematical programming/ optimization tools have been employed to model mixed farming, horticultural crops, and livestock alone, various breeds and varieties, and all sorts of combinations of different activities in homesteads.
Optimization is the act of achieving the best possible result under given circumstances. The goal of all such decisions is either to minimize effort or to maximize benefit. The effort or the benefit can be usually expressed as a function of certain design variables. Hence, optimization is the process of finding the conditions that give the maximum or the minimum value of a function.

In this context, the present study is an attempt to analyze the possibilities and prospects of increasing farm profitability by rational resource allocation through the application of Statistical modeling that enhances sustainable production of homesteads.

MATERIALS AND METHODS

The present study was conducted at Department of Agricultural Statistics, College of Agriculture, Vellayani. Trivandrum district was selected purposively for the present study and from the district south central laterite agro-ecological units (AEU 9) was purposively selected at the first stage and two Panchayaths (Anad and Vembayam) with maximum number of homesteads were purposively identified as the second stage units from the selected agro-ecological unit. At the third stage 20 homesteads having similar type of cropping systems and holding size between 0.1-0.3 ha were selected at random from the selected panchayaths. The data was collected during the period 2016-2017.

The benefit-cost analysis was worked out for average farm size of 0.21 ha by considering, different costs and returns incurred in cultivation of crop as well as rearing livestock and poultry. Cost of cultivation is taken into account in the case of annuals and biennials, whereas only maintenance cost is considered for perennials and per unit net return of each enterprise was determined.

Linear programming was applied to analyse the data generated through the survey, consisting of optimization of a linear objective function subjected to a number of linear equality and inequality constraints. In the present study the linear objective function was developed by considering the various activities/enterprises as variables and unit net return of these enterprises as the coefficients of the variables and the objective function was maximized by using the linear constraints developed by considering the unit net return of the enterprises/activities in the homesteads. A general form of maximization of an LP model can be developed in the following manner (Jaslam et al., 2017).

**Mathematical formulation of the model**

**Objective function:** The role of objective function in this study was to maximize the net income from the homesteads subjected to the specified constraints in the model. The objective function for $S_i$ is given as

$$
\text{Maximize } Z = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n
$$

where, $x_1, x_2, \ldots, x_n$ represents the homestead enterprises and $c_1, c_2, \ldots, c_n$ are unit net return associated to the enterprises.

**Constraints:** The constraints in the objective function are linear functions of the variables represented by the following form

$$
\sum_{j=1}^{n} a_{ij} x_j \leq r_i = o r \geq b_i
$$

where,

- $a_{ij}$ amount of $i^{th}$ resources required by $j^{th}$ activity
- $x_j$ unit of $j^{th}$ production activity
- $b_i$ quantity of $i^{th}$resources

$x_j, b_i \geq 0$

(Non negativity condition)

The constraints included in the study are

**Population constraints of each enterprise:** The constraints with respect to the population of different enterprises included in the model were decided so as to meet the multiple demand of the farm family by enterprise diversification, optimize the available resources and maximize the gross returns. Modal value, of farmer’s preference to the different enterprises was considered for developing the population constraint. This forms an identity matrix in the LHS (left hand side) and the RHS (right hand side) is a column matrix of order with model value each activity. In order to develop constrains for vegetables, all the vegetables were grouped into a single unit and a maximum of two units from which two units was considered in the inequality constraint of vegetables. All the enterprises were converted into linear constraints with RHS as populations (last column) in Table 2.

**Total area:** The model is developed for a holding size of 0.21 ha homestead (average homestead size in AEU 9) which includes area of house and permanent structures, net cropped area and uncultivated land.

**Intercropped area:** The interspace accessible was assessed after excluding the area occupied by the house and permanent structures and the area occupied by the basins of coconut and other tree components.

**Investment amount:** All the activities are financed internally and the farmer is not dependent upon external financing in the form of credit. The third quartile value of the investment/total expenditure was considered while developing the model rather going for higher value of the investment by the homestead farmers of each system.

Simplex iteration algorithm was used to solve the formulated LP models with the help of Optimization Modeling Software, LINGO 11.0.

**Sensitivity analysis:** The sensitivity analysis was carried out to determine the feasibility range of available resources.
in terms of R.H.S of the constraints and shadow price due to change in objective function coefficients in the optimal model of LP.

RESULTS AND DISCUSSION

The discussion of the results of the present investigation is carried through economic analysis of existing cropping pattern, development of optimal cropping pattern and sensitive analysis.

Cropping pattern and economic analysis of average homestead: The average size of homesteads was 0.21 ha in AEU9. The selected homesteads followed coconut based cropping system and comprised of thirty eight enterprises falling under the groups namely tubers, commercial crops, spices and condiments, stimulants, fruits, and vegetables.

Coconut was the major perennial crop observed with 28 adult bearing palms which constituted almost half of the net cultivated area (46.55%). Harvesting was done in every 3 month interval from which average yield of 19 nuts/palm was obtained. Jack (2 nos.), mango (3), gooseberry (1), banana (52), sapota (1), guava (1), pineapple (1) and papaya (6) were noticed all together occupying 13.70 per cent of the net cultivated area.

Table 1: Economic Analysis -Average farm of 2100 m$^2$ in AEU 9

| Enterprise | Population | Input Cost (₹) | Labour Cost (₹) | Other Expenses(₹) | Total Expenditure(₹) | Gross Return(₹) | Net Return(₹) | B:C Ratio |
|------------|------------|----------------|----------------|------------------|---------------------|----------------|--------------|-----------|
| Coconut    | 28 nos.    | 984.04         | 2450.86        | 56.07            | 3490.97             | 6424.75        | 2933.78      | 1.84      |
| Jack       | 2 nos.     | 0              | 446.43         | -                | 446.43              | 1585.35        | 1138.92      | 3.55      |
| Mango      | 3 nos.     | 47.76          | 682.44         | 98.13            | 828.33              | 2516.76        | 1688.43      | 3.04      |
| Gooseberry | 1 no.      | 9.35           | 100.97         | -                | 110.32              | 346.71         | 236.39       | 3.14      |
| Tamarind   | 1 no.      | -              | 190.19         | -                | 190.19              | 634.02         | 443.83       | 3.33      |
| Bread Fruit| 1 no.      | -              | 98.67          | 9.35             | 108.02              | 367.99         | 259.97       | 3.41      |
| Cashew     | 1 no.      | 13.36          | 184.58         | 18.69            | 216.63              | 405.61         | 188.98       | 1.87      |
| Areca nut  | 2 nos.     | 7.71           | 252.34         | 9.35             | 269.39              | 551.4          | 282.01       | 2.05      |
| Tapioca    | 91 nos.    | 1359.05        | 925.23         | 210.28           | 2494.56             | 5975.63        | 3481.06      | 2.4       |
| Banana     | 52 nos.    | 2940.08        | 5371           | 453.27           | 8764.35             | 17509.43       | 8745.08      | 2.0       |
| Pepper     | 4 nos.     | -              | 476.39         | -                | 476.39              | 1381.3         | 904.91       | 2.9       |
| Ginger     | 2 nos.     | 9.16           | 11.23          | -                | 20.39               | 38.9           | 18.51        | 1.91      |
| Turmeric   | 3 nos.     | 11.82          | -              | -                | 11.82               | 30.84          | 19.02        | 2.61      |
| Papaya     | 6 nos.     | 208.68         | 98.13          | 60.75            | 367.56              | 830.14         | 462.58       | 2.26      |
| Colocasia  | 6 nos.     | 74.81          | 22.45          | -                | 97.26               | 153.27         | 56.01        | 1.58      |
| Dioscorea  | 3 nos.     | 23.08          | 15.54          | -                | 38.62               | 65.42          | 26.8         | 1.69      |
| Amorphophallus 4 nos. | 30.14   | 88.79         | -              | 118.93            | 343.46              | 224.53         | 2.89      |
| Sapota     | 1 no.      | 11.83          | 172.9          | -                | 184.73              | 414.42         | 229.69       | 2.24      |
| Bilimbi    | 1 no.      | -              | 40.65          | -                | 40.65               | 95.7           | 55.05        | 2.35      |
| Guava      | 1 no.      | 6.64           | 142.52         | 14.02            | 163.18              | 414.95         | 251.77       | 2.54      |
| Pineapple  | 1 no.      | 7.02           | 11.68          | -                | 18.7                | 35.05          | 16.34        | 1.87      |
| Vegetables | 1 unit (40m$^2$) | 369.81      | 1549.16        | -                | 1918.97             | 3558.24        | 1639.27      | 1.85      |
| Total      | 6114.34    | 13332.15       | 929.91         | -                | 20376.39            | 43679.34       | 23302.9     | 2.14      |
Table 2: Optimum L P Homestead cropping model

| Enterprise       | Value  | Unit | Space (M²) | Expenditure (Rs) | Gross Return (Rs) | Net Return (Rs) | Constraints |
|------------------|--------|------|------------|------------------|------------------|----------------|-------------|
| Main Area        |        |      |            |                  |                  |                |             |
| Coconut          | 14 nos.| 15.2 | 212.77     | 124.68           | 1745.49          | 3212.38        | 1466.89     | 14 ≥ 30    |
| Jack             | 2 nos. | 6.15 | 12.31      | 223.22           | 446.43           | 792.68         | 1138.92     | ≤ 2        |
| Mango            | 3 nos. | 6.6  | 19.81      | 276.11           | 828.33           | 838.92         | 2516.76     | 1688.43    | ≤ 3        |
| Gooseberry       | 2 nos. | 7.07 | 14.13      | 110.32           | 220.63           | 346.71         | 693.42      | 472.79     | ≤ 2        |
| Tamarind         | 1 no.  | 36.3 | 36.3       | 190.19           | 190.19           | 634.02         | 643.83      | ≤ 1        |
| Bread Fruit      | 2 nos. | 19.63| 39.25      | 108.02           | 216.03           | 367.99         | 735.98      | 519.95     | ≤ 2        |
| Cashew           | 1 no   | 78.5 | 78.5       | 216.63           | 216.63           | 405.61         | 405.61      | 188.98     | ≥ 3        |
| House & Permanent| 1      | 394.86|          | -                | -                | -              | -           | 1          |
| Structures       |        |      |            |                  |                  |                |             |
| Interspaces      |        |      |            |                  |                  |                |             |
| Tapioca          | 100 nos.| 0.79 | 78.5       | 27.4128          | 2741.28          | 65.6623        | 3825.34     | ≤ 100      |
| Banana           | 47 nos. | 1.13 | 53.13      | 168.545          | 7921.63          | 336.7198       | 7904.2      | 35 ≥ 55    |
| Pepper           | 16 nos. | 0.38 | 6.15       | 119.099          | 1905.56          | 345.325        | 5525.2      | ≤ 16       |
| Ginger           | 7 nos.  | 0.32 | 2.25       | 10.1944          | 71.36            | 19.45093       | 136.16      | ≥ 5 ≤ 10   |
| Turmeric         | 10 nos. | 0.64 | 6.36       | 3.94081          | 39.41            | 10.28037       | 102.8       | 6 ≥ 10     |
| Papaya           | 20 nos. | 1.91 | 38.21      | 61.2598          | 1225.2           | 138.3567       | 1541.94     | ≤ 20       |
| Colocasia        | 10 nos. | 2.01 | 20.1       | 16.21            | 255.417          | 93.35          | 102 ≥ 12    |
| Dioscorea        | 6 nos.  | 1.45 | 8.71       | 12.8747          | 77.25            | 21.80685       | 130.84      | 53.59      | ≤ 5 ≥ 10   |
| Amorphophallus   | 15 nos. | 1.77 | 26.49      | 29.7313          | 445.97           | 85.86449       | 1287.97     | 842        | ≤ 15       |
| Sapota           | 3 nos.  | 7.07 | 21.2       | 184.727          | 554.18           | 414.42         | 1243.26     | 689.08     | 12 ≥ 3     |
| Bilimbi          | 2 nos.  | 2.83 | 5.67       | 40.65            | 81.3             | 95.7           | 191.4       | 110.1      | 12 ≥ 2     |
| Guava            | 2 nos.  | 8.04 | 16.08      | 163.182          | 326.36           | 414.9533       | 829.91      | 503.54     | = 2        |
| Pineapple        | 7 nos.  | 0.79 | 5.5        | 18.7022          | 130.92           | 35.04673       | 245.33      | 114.41     | ≥ 7 ≤ 13   |
| Vegetables       | 2 unit  | 80   | 80         | 1918.97          | 3837.94          | 3558.24        | 7116.48     | 3278.54    | 2          |
| Interspace total |        |      |            | 368.34           |                  |                |              | ≤ 1091.65  |
| Total main area  |        |      |            | 807.92           |                  |                |              | ≤ 2100.00  |
| Grand total      |        |      |            | 1176.25          | 23384.18         | 52007.9        | 28623.72    |            |

Fig 1: Optimization model for $S_1$ homesteads in AEU 9.
enhancement in net return as compared to net return from the existing plan (Fig.2), with B: C ratio of 2.22. Prime importance was given to the family requirement, taste, interest and market demand for the enterprises while selecting the diverse components by the framers.

For further increase of income from homesteads, the land area available as uncultivated and occupied by uneconomical enterprises must be utilized in economical manner but the LP showed that investment amount available was not enough to meet these expenses, hence farmers may give more emphasis on growing diverse crops by investing more to ensure food security.

The optimum model for average homesteads in AEU 8, comprising of 23 enterprises including house and permanent structures is presented in Fig.1 and Table 2.

**Sensitivity analyses of optimum model in AEU 9:** Sensitivity analysis was carried out on the model of AEU9 presented in Table 3 suggesting the range of value of net income for each enterprise, where the value of enterprise in the optimal LP solution will remain constant. The maximum range of objective coefficient/unit net return for the enterprises having non binding solution and minimum range for enterprises with binding solutions need to be investigated so as to ascertain reliability of model. The optimal LP model has fourteen numbers when the unit net returns from coconut palm was Rs.104.78/- The change in value in optimum model for coconut was recommended only if the unit net income attains above Rs.124.41/-. Similarly, the maximum suggested range for cashew was Rs.216.16/- and that of vegetables was Rs.1914.75/- and so on. The result proved that the value of enterprises remain unchanged for most of the perennial trees even if the net income gets reduced to half of the obtainable.

Sensitivity analysis of the model revealed that, there exist certain possibilities by which farmer can increase the farm income, provided his constraints are removed. The shadow prices presented in table 4 (unit worth of resources) indicated the increase or decrease in the gross returns of the model, for unit change in value of the constraint within the given range of minimum and maximum RHS. With respect to expenditure, third quartile of the investment amount (Rs.23384.2/-) was used for LP modeling and if the farmer is all set to put more money as investment, up to Rs.24789.95/-, for which he would receive Rs.0.9978/- on every additional rupee invested. Sensitivity analysis on the range of feasibility of available resources indicated that all the enterprise didn’t achieve the maximum feasibility range except for banana.

**Table 3: Sensitivity analysis on objective function coefficients Optimum Model**

| Name        | Final value | Objective Coefficient | Max.Range | Min. Range |
|-------------|-------------|-----------------------|-----------|------------|
| Coconut     | 14          | 104.78                | 124.41    |            |
| Jack        | 2           | 569.46                |           |            |
| Mango       | 3           | 562.81                |           | 227.5      |
| Gooseberry  | 2           | 236.39                |           | 110.07     |
| Tamarind    | 1           | 443.83                |           | 189.77     |
| Bread Fruit | 2           | 259.97                |           | 107.77     |
| Cashew      | 1           | 188.98                | 216.16    | -          |
| Areca nut   | 0           | 141                   | -         | 134.4      |
| Tapioca     | 100         | 38.25                 | -         | 27.35      |
| Banana      | 47          | 168.17                | 176.43    | 153.03     |
| Pepper      | 16          | 226.23                | -         | 118.84     |
| Ginger      | 7           | 9.26                  | 10.18     | -          |
| Turmeric    | 10          | 6.34                  | -         | 3.93       |
| Papaya      | 20          | 77.1                  | -         | 61.13      |
| Colocasia   | 10          | 9.34                  | 16.18     | -          |
| Dioscorea   | 6           | 8.93                  | 12.84     | -          |
| Amorphophallus | 15        | 56.13                 | -         | 29.66      |
| Sapota      | 3           | 229.69                | -         | 184.32     |
| Bilimbi     | 2           | 55.05                 | -         | 40.56      |
| Guava       | 2           | 251.77                | -         | 162.82     |
| Pineapple   | 7           | 16.34                 | 18.66     | -          |
| Vegetables  | 2           | 1639.27               | 1914.75   | -          |
| Home        | 1           | 0                     | -         | -          |

Fig 2: Net income from existing and optimum model – S, AEU 9

For further increase of income from homesteads, the land area available as uncultivated and occupied by uneconomical enterprises must be utilized in economical manner but the LP showed that investment amount available was not enough to meet these expenses, hence farmers may give more emphasis on growing diverse crops by investing more to ensure food security.
Table 4: Sensitivity analysis of available resources in AEU 9.

| Name          | Final Value | Constraint R.H. Side | Max R.H. Side | Min R.H. Side | Shadow Price |
|---------------|-------------|----------------------|---------------|---------------|--------------|
| Expenditure   | 23384.2     | 23384.2              | 24789.95      | 15519.96      | 0.9978       |
| Total Area    | 1176.26     | 2100                 | 2100          | 1176.255      | 0            |
| Interspace    | 368.34      | 1091.65              | 1091.65       | 368.34        | 0            |
| Home          | 1           | 1                    | 3.171495      | 0             | 0            |
| Coconut       | 14          | 30                   | 30            | 14            | 0            |
| Jack          | 2           | 2                    | 37.23158      | 0             | 346.736      |
| Mango         | 3           | 3                    | 31.48216      | 0             | 287.307      |
| Gooseberry    | 2           | 2                    | 73.28822      | 0             | 126.321      |
| Tamarind      | 1           | 1                    | 25.4822       | 0             | 254.065      |
| Bread Fruit   | 2           | 2                    | 47.36567      | 0             | 152.197      |
| Cashew        | 1           | 3                    | 3             | 1             | 0            |
| Arecanut      | 0           | 0                    | 58.38488      | 0             | 6.60497      |
| Tapioca       | 100         | 100                  | 386.8813      | 48.71835      | 10.901       |
| Banana        | 47          | 55                   | 55            | 47            | 0            |
| Pepper        | 16          | 16                   | 82.03175      | 4.19645       | 107.392      |
| Ginger        | 7           | 10                   | 10            | 7             | 0            |
| Turmeric      | 10          | 10                   | 1078.25       | 5             | 2.40742      |
| Papaya        | 20          | 20                   | 148.3749      | 0             | 15.9719      |
| Colocasia     | 10          | 12                   | 12            | 10            | 0            |
| Dioscorea     | 6           | 10                   | 10            | 6             | 0            |
| Amorphophallus| 15          | 15                   | 279.5096      | 0             | 26.4673      |
| Sapota        | 3           | 3                    | 45.57206      | 1             | 45.3719      |
| Bilimbi       | 2           | 2                    | 195.4617      | 1             | 14.4894      |
| Guava         | 2           | 2                    | 50.1929       | 0             | 88.9481      |
| Pineapple     | 7           | 13                   | 13            | 7             | 0            |
| Vegetables    | 2           | 2                    | 2             | 2             | 0            |

**CONCLUSION**

The present study developed statistical models for the existing cropping systems in homesteads and the developed optimum model for average homestead had non-binding solution for coconut, cashew, ginger, dioscorea, pineapple and banana. Compared to the existing model this provides 22.83% percent increase in net return. LP model suggests that farm income could be further enhanced by increasing cropping intensity and by removing the most uneconomical and less important enterprises in the existing plan with due importance to food security.

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