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A DECISION SUPPORT SYSTEM FOR IDENTIFYING AN OPTIMAL CROPPING PATTERN IN NOYYAL RIVER BASIN, TAMILNADU

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ABSTRACT

The objective of the present study was to obtain an optimal cropping pattern for the Noyyal river basin in Tamil Nadu, India to maximize the net income, using linear programming technique. The objective of maximizing the net income was achieved considering the ground and surface water availability, crop water requirement, land preparation cost, cost of fertilizer, cost of man power, expected returns and availability of labour. The cost data has been worked out using the rates prevailing in the basin area during the year, 2008. The three constraints considered in the optimization model were land availability, water availability and labour availability. The linear programming model has been developed with these three constraints and other appropriate constraints using the software MATLAB. The model was developed to allocate the water resources and to identify the appropriate cropping pattern over the entire cultivable area of the basin. It is found from the optimization model that maximum profit can be obtained from the basin when no restriction was imposed on the area of cultivation However, the results are not feasible since only few crops are to be cultivated in the entire region which will result in marketing problems. Hence, constraints were introduced by ecifying minimum area required for cultivation of each crop based on the per capita requirement and the population of the basin. The results of this study indicate that it is possible to increase the net profit by about 12.5% by suitably modifying the cropping pattern.

Keywords: Conjunctive Use, Runoff, Groundwater, Optimal Cropping Pattern.

INTRODUCTION

Water Resources management involves many complexities related to hydrologic, sociologic and environmental constraints. Interdependence of the constraints further complicates the water resources utilization. A systematic approach is needed to plan, how the water resources can be used and how developmental activities will affect water use patterns. Integrated use of surface and groundwater management is commonly known as conjunctive use. Implementation of conjunctive use of surface water and groundwater resources will satisfy the ever increasing demand for water. Conjunctive use of water resources is defined as the coordinated and planned operation of both surface and groundwater resources to meet water requirements in a manner whereby water is conserved (David K. Todd 1980). Conjunctive use policies can be developed based on programming techniques for proper allocation of water resources.

This paper deals with an optimization model that uses the conjunctive water for obtaining optimal cropping pattern for a basin. The area identified for the study is Noyyal river basin which is located in the western part of Tamilnadu, where there is an increasing demand for water as a result of increasing population, industrial and agricultural growth.

LITERATURE REVIEW

Laxmi Narayan Sethi et al.(2006) developed a dynamic linear programming model and a Chance constrained linear programming model for obtaining a optimal cropping pattern to maximise the annual net returns. The authors showed that the optimal cropping pattern remains constant in both the Dynamic linear programming model and Chance Constrained linear programming model at 10% risk level and also it was found that 40% deviation from the existing cropping pattern was found optimal to satisfy the food requirement of the basin. Madan Mohan Jha and Ranvir Singh (2008) developed a goal programming model to maximize the net economic returns considering the economic efficiency, nutritional requirement of the area and total irrigated cropped area. The developed model is a mathematical tool for generating and evaluating alternative irrigation development plans based on conjunctive use of surface and groundwater. Mohan and Jothiprakash (2000) formulated a fuzzy linear programming model to derive optimal crop plans with the aim of conjunctive utilization of surface and groundwater. The model has evolved an optimal cropping pattern with a degree of satisfaction of 0.78 with high groundwater utilization and more crop area under rice. Vedula et al. (2005)developed a mathematical model to arrive at an optimal conjunctive use policy for the irrigation of multiple crops in a reservoir-canal-aquifer system. The objective was to maximize the sum of yield of crops over a year considering three sets of constraints: mass balance at reservoir, soil moisture balance and groundwater flow. Radhey Shyam et al. (1994)devised an optimal operation policy of water allocation to different canals in a canal system, using linear programming. The objective was to maximize the net returns. The Variables considered were area to be allocated under different crops, water to be allocated from the main canal, required running hours of the branch and distributaries. Deepak Khare et al. (2006) developed an economic optimization model to explore the possibility of conjunctive use of surface and groundwater using linear programming with various hydrological and management constraints. The objective was to arrive at an optimal cropping pattern for optimal use of water resources for maximization of net benefits. Srinivasulu and Satyanarayana (2005) developed a linear programming model for allocation of land and water resources to different crops in saline groundwater areas to maximise the net returns. The model predicted that even in the case of change in irrigation water supply, it is not economical to change the cropping pattern. Mohamed and Azaiez (2001) developed a mathematical model to obtain optimal cropping pattern under water deficit condition in dry regions. An operating policy was identified for both the total land area and the irrigation water allocated to a particular crop. The model was developed based on land, water and non-negativity constraints.

Study Area

The area selected for the study is the Noyyal River basin. The Noyyal River, a tributary to Cauvery river, rises from the Vellingiri hills in the westernghats in Tamilnadu. The river joins the river Cauvery at Kodumudi in Karur district. The total length of the river basin is 175 km and the average width is around 25 km. The total areal extent of the basin is about 3500 sq. km. The basin falls within Coimbatore, Erode and Karur districts of Tamilnadu. The western periphery of the basin is the western ghats which has an average altitude of 2200 meters (7220 feet) above mean sea level .The average elevation of the terrain of the basin in the western part near the foot of the hills is about 450 meters and it slopes towards east. The average gradient of the basin is about 2.5 meters per kilo meter(1 in 400). The soil type in Noyyal basin varies from shallow red non calcareous soils to very deep grey calcareous ones. The rainfall in the Noyyal basin is influenced by north-east monsoon and also by pre-monsoon showers and south-west monsoon. There are 18 raingauge stations in and around the basin. The average annual rainfall in the basin is 714 mm. The study area is shown in Fig.1.

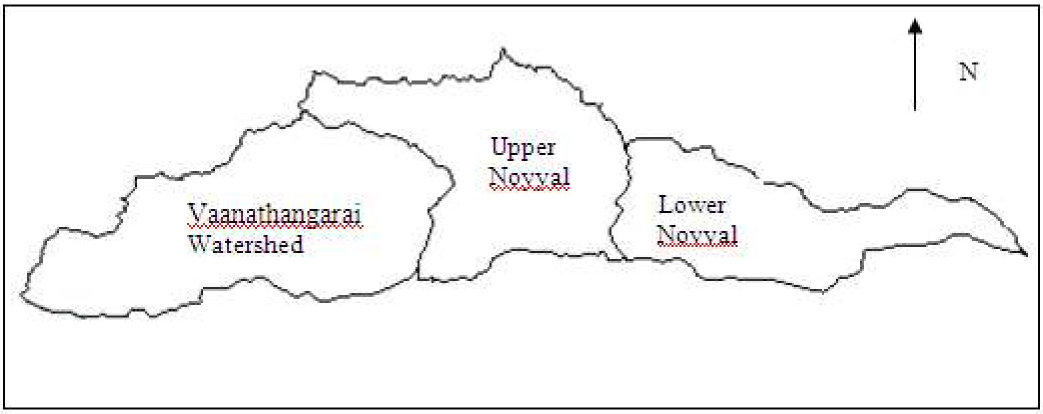

Fig.1 Noyyal River Basin

METHODOLGY

Linear Programming is a special case of a Mathematical Programming. It is a mathematical program which tries to identify an extreme (i.e., minimum or maximum) point of a function, which furthermore satisfies a set of constraints. From the application point of view, linear programming is an optimisation tool, which allows the rationalization of many managerial and technological decisions required for socio-economic applications. An optimisation model for identifying a suitable cropping pattern has been developed with the objective of maximizing the net agricultural benefits from a basin. The constraints considered were availability of water, labour and agricultural land. The available water has been estimated using the GIS based models developed for the estimation of surface and groundwater quantities based on rainfall, slope, specific yield of the aquifer and change in ground water level before and after monsoon period. These estimated values were given as inputs in the optimization model. The schematic representation of the proposed model is shown in Fig.2.

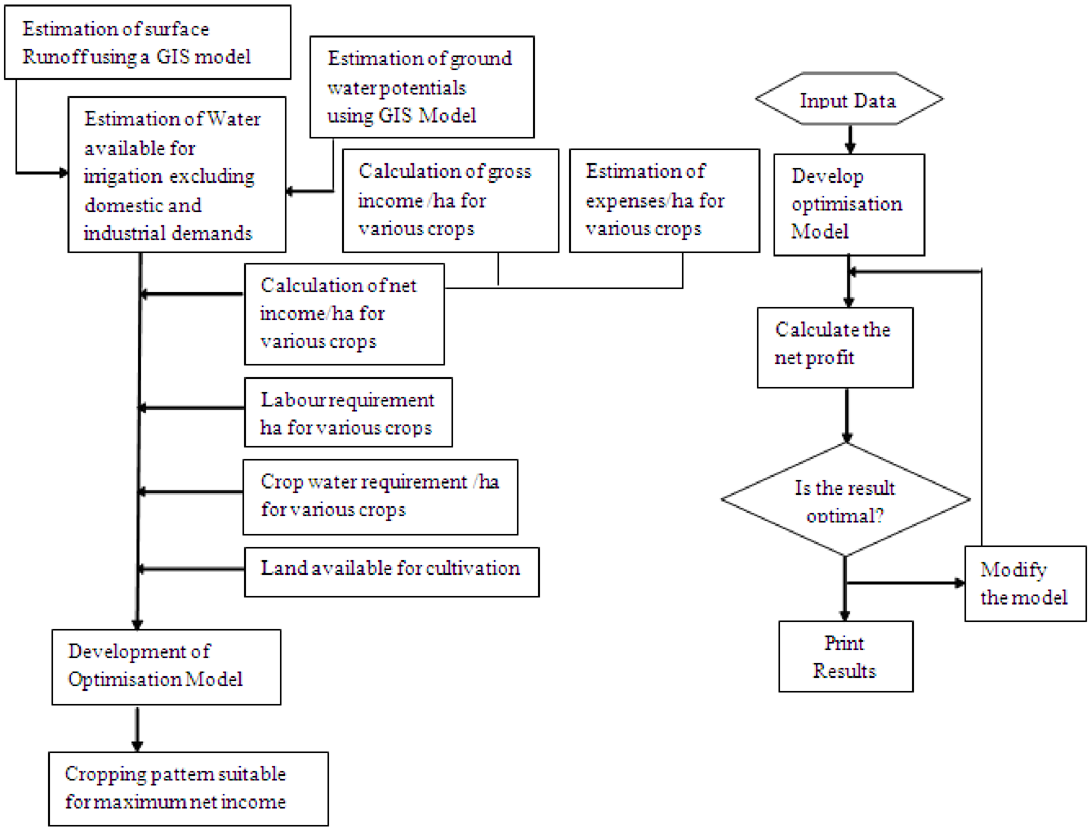

Fig.2 Optimization Model

Existing Cropping Pattern

The details about the cropping pattern followed in the basin were collected from Directorate of Statistics, Coimbatore for a period spanning from 1995 - 2005. It was found that, in the upper catchment, coconut, sugarcane, banana, onion, vegetables, arecanut, turmeric, grapes and maize are cultivated. In the middle reach cereals, sorghum, maize, banana, turmeric, cotton and vegetables are grown. In the lower reach of the river Noyyal, the major crops are maize, sorgum, cotton and tobacco. The total cultivable area in the basin is around 1,01,387 hectares. Out of the total cultivable area, 48,231.3 hectares are under direct irrigation. The remaining area comes under rain fed crops and lift irrigation.

Crop Water Requirement

Assessment of water requirement for various crops throughout the crop period is an important factor to plan and to implement command area development programmes. The crop water requirement for various crops is shown in Table 1.

Table 1. Crop Water Requirement

Sl. No.	Crop	Crop water requirement / year/ ha(m)	Sl. No.	Crop	Crop water requirement / year/ ha(m)
1	Coconut	0.33	20	Gingelly	1.00
2	Turmeric	0.55	21	Tobacco	0.90
3	Grapes	0.87	22	Tapioca	1.50
4	Sugarcane	2.20	23	Fodder	0.90
5	Banana	1.50	24	Curry leaves	0.50
6	Maize	1.25	25	Coriander	0.90
7	Paddy	2.40	26	Green gram	0.40
8	Cotton	1.30	27	Black gram	0.40
9	Groundnut	1.10	28	Red gram	0.40
10	Sunflower	0.80	29	Lady's Finger	0.90
11	Onion	0.45	30	Ribbed gourd	0.20
12	Brinjal	0.52	31	Snake Gourd	0.20
13	Chillies	0.52	32	Bitter Gourd	0.20
14	Arecanut	1.80	33	Bottle Gourd	0.20
15	Marigold	0.90	34	Beans	0.25
16	Mango	0.32	35	Cabbage	1.20
17	Sorhum	1.00	36	Leafy veg.	1.20
18	Cumbu	0.90	37	Tomato	0.66
19	Ragi	0.80	38	Cauliflower	0.33

Objective Function

In order to obtain the optimal cropping pattern which will maximize the net profit, an optimization model based on linear programming technique has been formulated. The objective function of the optimization model is shown below:

Maximize net annual profit, Max Z = $\sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij} N_i$

where, i is an index that refers to surface water, When i is one, it refers to surface water and refers to groundwater, when it is two; j is the Crop number; A_{ij} is the area under jth crop with surface water or groundwater irrigation and N_j is the net profit from the j^{th} crop considering the income and expenditure such as labour cost, seed cost, fertilizer cost etc., and n is the number of crops.

Constraints

Apart from the non-negativity constraints, three important constraints are used in the model. The first constraint is based on water requirement. The water requirement should not be more than the available water. The second constraint is on the total area of cultivation. The total area of land to be cultivated should not be more than the land available for cultivation. The third constraint considered is the labour constraint.

Water Requirement Constraint

The total water requirement for all the crops scheduled to be grown in the basin, should be met from the groundwater or surface water resources available. Therefore water requirement constraint has been given as

$$\sum_{j=1}^{n} A_{ij} W_j \leq SWR$$

Where, i =1, W_j = water requirement of the j^{th} crop and SWR is the surface water resources available.

$$\sum_{j=1}^{n} A_{ij} W_j \leq GWR$$

Where, i =2, W_j = water requirement of the j^{th} crop and GWR is the ground water resources available.

Area Availability Constraint

The cultivable land for various crops under irrigated and rainfed cultivation must not exceed total available cultivable area in the basin. In order to utlilise the available surface water and groundwater in an effective manner, the total cultivable area has been divided into area under direct irrigation and area under lift irrigation and the following constraints are formulated.

$$\sum_{j=1}^{n} A_{ij} \leq DIA$$

Where i = 1, A_{ij} is the area under direct irrigation for j_{th} crop and DIA is the available cultivable area under direct irrigation.

$$\sum_{j=1}^{n} A_{ij} \leq LIA$$

Where i = 2, A_{ij} is the area under lift irrigation for j_{th} crop and LIA is the available cultivable area under lift irrigation.

Labour Constraints

Depending upon the requirement of labour for each crop/per hectare, the labour constraint has been formulated. The total available men and women agricultural labourers available in the study area is around 91,55,260 and 1,22,45,112 respectively. The total required men labourers should not exceed the available workers in the basin area and the women labourers should not exceed the available limit. This will result in the following labour constraints.

$$\sum_{i=1}^{2} \sum_{j=1} M_i \leq TM$$

$$\sum_{i=1}^{2}\sum_{j=1} {}_{i}M_{i} \leq {}^{T}W$$

Where M_j and W_j are the men and women laborers required for a jth crop/ha. TM and TW are the men and women labourers available in the basin respectively.

Cost and Net Benefits

Based on the agricultural inputs and crop yield in the study area, the value of net profit per hectare for each crop has been calculated considering the crop yield, market price of crops and cost of production or expenses/ha Which includes seed cost, fertilizer cost, land preparation cost, labour cost etc. For the major crops, the expenses for the various components such as seed cost, land preparation cost, labour cost etc., has been obtained from the Directorate of Statistics and Department of Agriculture, Tamilnadu. The values of the net profit were calculated for all the crops cultivated in the basin and the values are shown in Table 2.

Table 2. Net Profit of Crops

Crop	Net Profit (Rs.)
Coconut	77990.3
Turmeric	56563
Grapes	80818
Sugarcane	51870
Banana	109421
Maize	12720
Paddy	42780
Cotton	52858
Groundnut	23959
Sunflower	44781
Onion	93242
Brinjal	83461
Chillies	47868
Arecanut	126674
Marigold	21563
Mango	128070
Sorghum	30331
Cumbu	25984
Ragi	13041

Crop	Net Profit (Rs.)
Gingelly	26774
Tobacco	68838
Tapioca	69876
Fodder	85931
Curry leaves	55081
Coriander	14498
Green gram	23489
Black gram	22625
Red gram	28750
Lady’s Finger	28503
ribbed gourd	25144
snake gourd	37988
bitter gourd	193599
bottle gourd	33764
french beans	27293
cabbage	56069
Leafy veg.	41174
tomato	44805
cauliflower	53599

The optimization model was used to get possible cropping pattern from various strategies of land and water resources allocation. The runoff value for the basin was found to be 596.5 Mm^3, for an average annual rainfall with 75% dependability using a rainfall-runoff model developed by the authors. From a GIS based groundwater estimation model developed by the authors, the volume of water stored in the aquifer was found to be 707.3 Mm^3. The water requirement per annum for other demands such as domestic requirement, requirement for industries were calculated using the data collected from Directorate of Statistics, Tamilnadu. The water requirement for other demands was estimated to be 203.3Mm^3. It was assumed that for other requirements except irrigation, only groundwater is utilized. With this assumption, the available groundwater for irrigation was estimated to be 504 Mm^3.

The present Cultivated area in Noyyal river basin is 1,01,387 ha. The details of the existing cropping pattern are shown in Table3. From the Table.3, it can be seen that coconut is the highly cultivated crop. This is followed by paddy, sugarcane and maize in the same order.

Table 3. Details of Existing Cropping Pattern (Values in Hectares)

Crop	Case 1	Case 2	Case 3	Case 4	Case 5
Coconut	25888	0	30420	31624	18727
Turmeric	1715.8	0	3431	3431	6000
Grapes	324	0	0	0	350
Sugarcane	9228.9	0	0	0	10000
Banana	3201.5	0	6402	6402	1030
Maize	8832.7	0	17664	17664	18991
Paddy	10591	0	0	0	10600
Cotton	2727	0	5453	5453	2727
Groundnut	5078	0	0	2006	1500
Sunflower	1418	0	2835	2835	1420
Onion	782	0	1564	1564	800
Brinjal	212	0	0	0	215
Chillies	87	0	174	174	87
Arecanut	519	55181	1037	1037	2000
Marigold	292	0	0	0	300
Mango	715	12352	1429	1429	2000
Sorghum	1275	0	2550	2550	1275
Cumbu	64	0	127	127	64
Ragi	37	0	0	0	37
Gingelly	2473	0	4945	5125	2500
Tobacco	472	0	944	944	1000
Tapioca	375	0	0	0	365
Fodder	1451	0	2903	2903	3916
Curry Leaves	433	0	0	0	430
Coriander	22	0	43.9	43.9	22
Green Gram	292	0	584	584	2145
Black Gram	247	0	495	495	250
Red Gram	209	0	0	419	210
Lady,S Finger	1000	0	0	0	175
Ribbed Gourd	684	0	0	0	175
Snake Gourd	3000	0	280	3000	175
Bitter Gourd	3250	33851	6500	3250	2000
Bottle Gourd	1850	0	0	0	175
Beans	400	0	0	0	175
Cabbage	1300	0	2600	1300	1000
Leafy Vegetables	1000	0	0	1000	175
Tomato	4500	0	9000	4500	1000
Cauli Flower	1700	0	0	1700	175

Note: Case 1: Existing Cropping Pattern

Case 2: Area for all crops unlimited

Case 3: Area under each crop is limited to a maximum value of twice the existing area

Case 4: Area under vegetables is limited to the existing area and for other crops, area is limited to twice the existing area

Case 5: Area under each crop is limited to a value estimated based on per capita demand and population.

RESULTS AND ANALYSIS

Case 1

The first case considered was existing cropping pattern. For the existing cropping pattern, the water requirement is 1,07,462 ha-m. The requirement of men and women labourers is 91,55,620 and 1,22,45,112 respectively. The net profit that can be obtained by adopting the existing cropping pattern is 832.96 crores. The existing cropping pattern is shown in Fig.3.

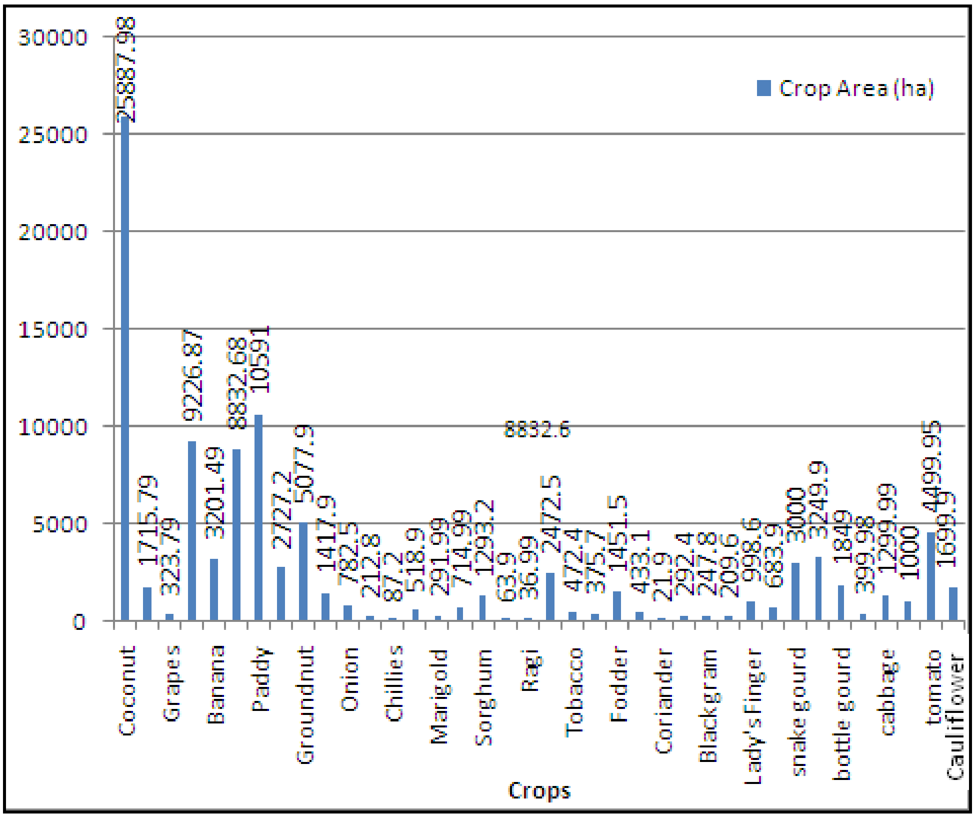

Fig. 3 Existing Cropping Pattern

Case 2

In order to maximize the profit, an attempt has been made to optimize the cropping pattern. In the first attempt, no restriction was made for limiting the area of any crop. The optimization model consists of one objective function, six constraints, 38 crops, 76 variables and 76 non-negativity constraints. Since the size of the problem is large, the software MATLAB 6.5 was used to find out the optimal cropping pattern. A matlab program was written and the problem was solved. The optimal cropping pattern obtained is shown in Fig.4 and also given in Table 3. It is seen from Fig.4 that only three crops were found in the optimal cropping pattern. The crops found were Arecanut(55181 ha), Mango(12352 ha) and Bittergourd (33851 ha). The net profit is 1779 Crores. This is 113.6% higher than the existing cropping pattern. However, this combination of crops will not be feasible due to problems in marketing. Moreover essential crops such as rice sugarcane, maize etc. are not found in the optimal cropping pattern. Hence various constraints are imposed in the optimization model to find out a feasible optimal cropping pattern.

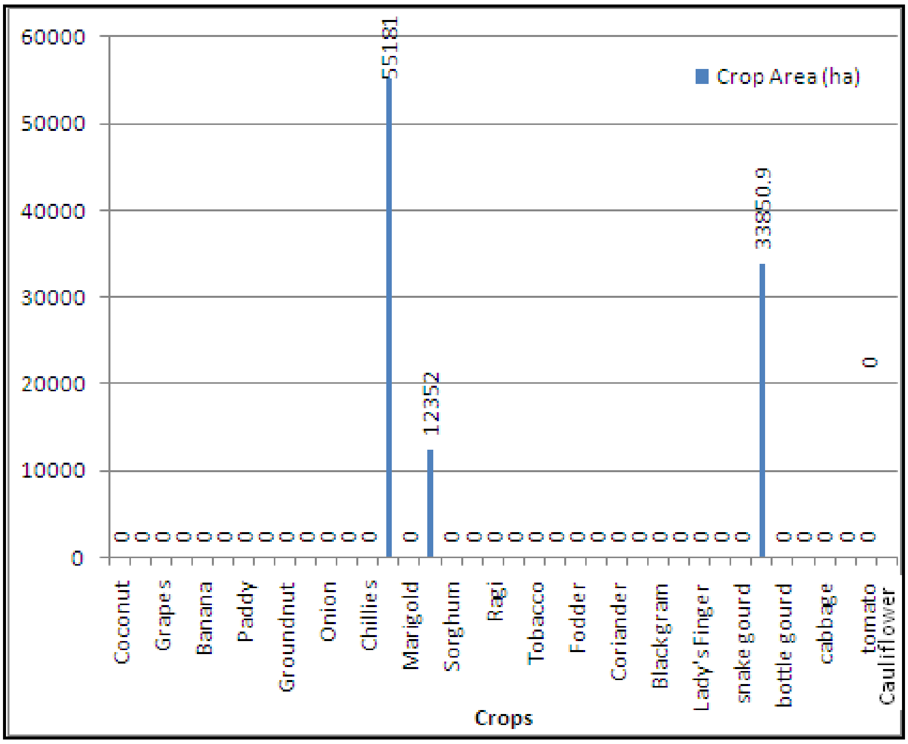

Fig.4 Cropping Pattern when the area restriction was not imposed

Case 3

In case 3, the maximum cultivable area for each crop is given a limiting value of twice the existing area. In this case, the number of constraints is 82 and the non-negativity constraints are 76. The optimal cropping pattern obtained is shown in Fig.5 and Table3. The net profit is 1104 Crores. This is 32.47% higher than the profit under the existing cropping pattern. From the figure, it is observed that Coconut, Maize, Bittergourd, tomato and banana are the crops to be grown in major portion of the study area. It is seen that the area under coconut cultivation has increased by about 17.5%. The area under maize, bitter gourd, tomato, onion and banana has increased by 100%. It is interesting to note that the area under the crops grapes, sugarcane, paddy, groundnut, brinjal, marigold, ragi, tapioca, curry leaves, redgram, lady,s finger, ribbed gourd, bottle gourd, beans, leafy vegetables and cauliflower is found to be zero. The net increase in the profit in this case is Rs.271.1 Crores. Even though this solution will be a profitable one from the point of view of the farmers, this solution cannot be accepted as a good solution since the area under the important crops such as paddy, groundnut etc. is zero.

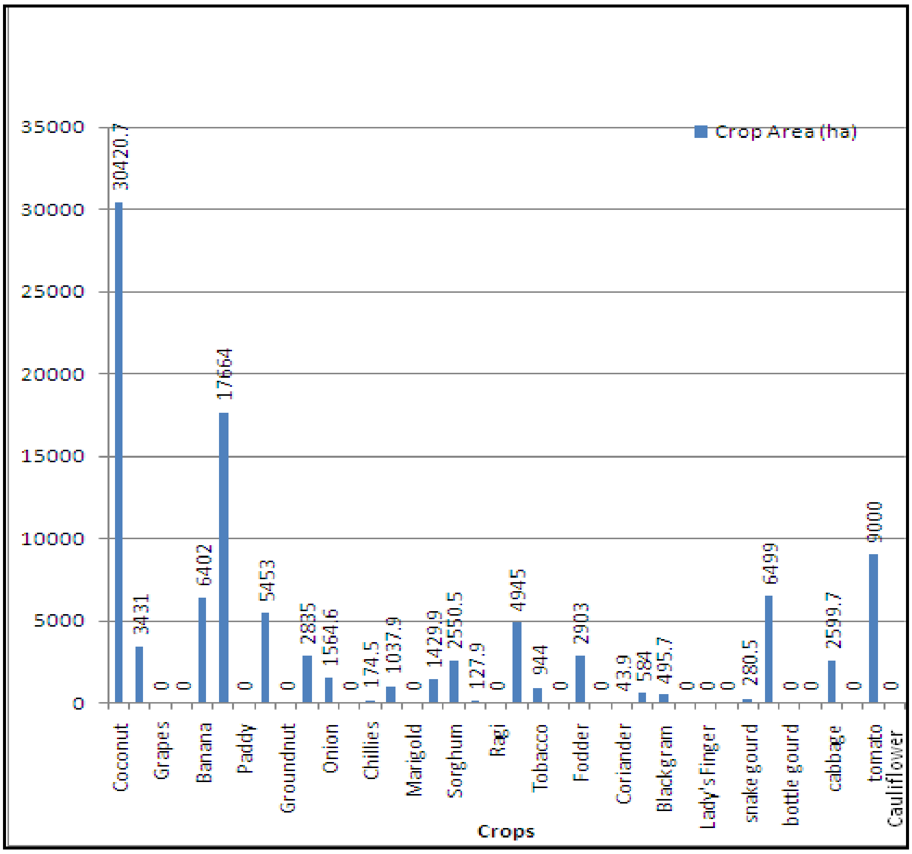

Fig. 5 Area under each crop is limited to a maximum value of twice the existing area

Case 4

In case 4, the cultivable area all crops except vegetables were limited to a maximum of twice the existing area of these crops and for vegetables, the area of cultivation is limited to the existing values. The optimal cropping pattern obtained is shown in Fig.6 and Table 3. The net profit is 1021.6 Crores. This is 22.6% higher than the profit for existing cropping pattern. From the figure, it is observed that Coconut, Maize, Banana, Tomato, Cotton and Gingelly are the crops to be grown in major portion of the study area.

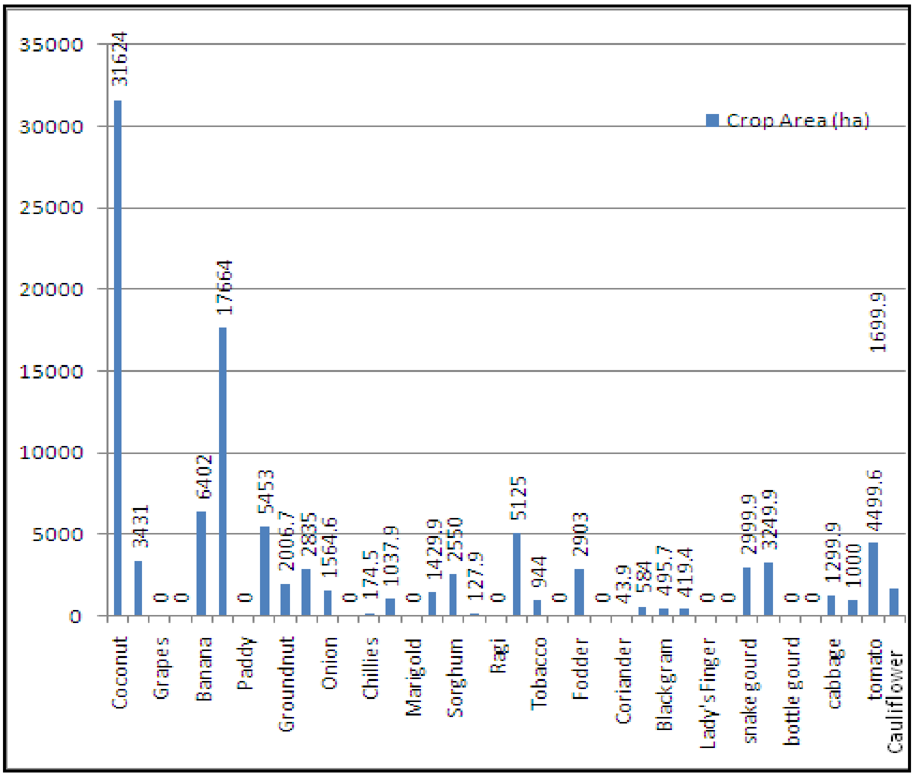

Fig. 6 Area under Vegetables limited to the existing area and for other crops area is limited to twice the existing area

Case 5

In order to obtain a realistic optimal cropping pattern which will satisfy the requirements of population, the percapita consumption of various crops were collected from different sources. The per capita consumption of each crop was multiplied by the population of Noyyal river basin to obtain the requirement of Noyyal basin. From the requirement, the minimum area required for each crop has been obtained. These values are given as minimum required areas for essential crops such as coconut, sugarcane, banana, paddy, cotton, groundnut, sunflower, etc. For non-essential crops such as bittergourd, arecanut, mango, tobacco, turmeric, cabbage, snake gourd, chillies, cauliflower, etc. the areas are limited to a maximum value. The maximum cultivable area for the non-essential crops was based on the marketing potential of these crops. The optimal cropping pattern obtained is shown in Fig.7 and Table.3.

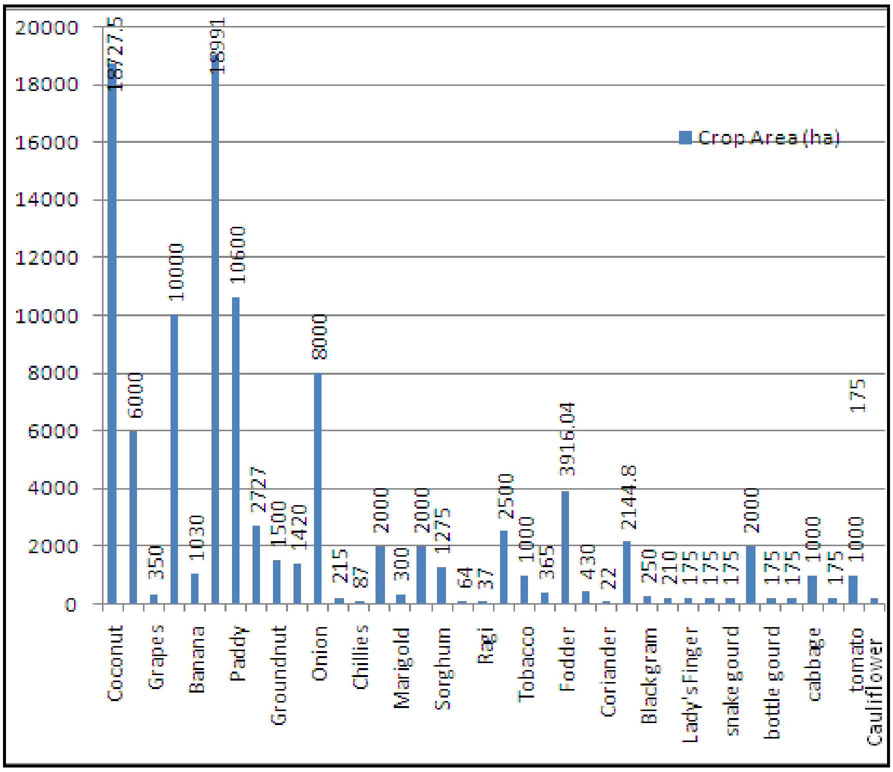

Fig.7 Area under each Crop is based on the Per capita Demand and Population

The profit was found to be 937.2 crores. This is 12.5% higher than the profit for the existing cropping pattern. The cropping pattern obtained is given in the Table 3. It can be seen that by cultivating the crops as suggested by the optimization model, the farmers can generate an additional income of Rs.104.04 Crores in a year using the same resources.

The profit values obtained for the various cases are shown in the Table 4.

Table 4. Net Profit in Rupees

Case	Net Profit	% increase in Profit
1	8329600000	0
2	17790000000	113.5
3	11040000000	32.4
4	10216000000	22.6
5	9372000000	12.5

From the Table.4, it is found that the net profit is maximum for Case 2 (When the area for all crops are unlimited). The total cultivable area in the basin has been utilized. This result does not meet the requirement of the regional population. Hence constraints have been introduced. In all the cases, the net profit obtained is higher than that of the existing cropping pattern. Case 5 is the most practical case since the limitations on crop area are based on the per capita consumptions.

CONCLUSION

A linear programming model has been presented for obtaining optimal cropping pattern for Noyyal river basin. This program considers the net profit for each crop, labour requirement for each crops and the water requirement. When the area restriction was not imposed, maximum profit can be obtained. However, the results will not be feasible since only few crops are to be cultivated. Hence, the minimum area required for each crop was worked out based on the per capita demand and the population. This model will be a feasible model. The profit obtained from this case was found to be 937.2 Crores which is 12.5% higher than the existing cropping pattern. Hence, by adopting the revised cropping pattern, the farmers of Noyyal river basin can get more profit with the same resources.

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