Global Journal of Research in Engineering
Volume 11 Issue 4 Version 1.0 April 2011
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
ISSN: 0975-5861

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By Gopi.Annepu, K.Venkata Subbaiah, N.R.Kandukuri
Andhra University

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Classification: GJRE-J Classification: FOR Code: 070101

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Land Allocation Strategies Through Genetic Algorithm Approach–A Case Study

Gopi.Annepu[α], K.Venkata Subbaiah[Ω], N.R.Kandukuri[β]

Abstract - Development of agriculture depends on optimal land allocation. The development towards optimal utilization of land under cultivation and thereby increasing the production of crops and profit with less fertilizer consumption have to be taken into consideration in agriculture planning. In this paper different agriculture strategies are developed and accordingly, single objective optimization models are formulated with net profit, production of crops and fertilizer consumption as objectives and availability of cultivable land, agriculture labor, agriculture machinery and water as constraints. To illustrate the models a case study of Visakhapatnam district, Andhra Pradesh, India is presented and are solved through GA.

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I. Introduction

In developing countries, the agricultural sector's performance determines overall economic growth, trade expansion, and increased income-earning opportunities. Implementing policies that encourage greater agricultural productivity, Profitability and sound environmental management is very much needed. In today's globalized world every sector of the economy needs to reorient itself to meet the changing demand. This is very much required as the need patterns of the individuals are getting transformed by the intensity of the local and global forces. The rural sectors of the developing countries are not exceptions in this regard. The sudden boom in food retail sectors has also changed the orientation and status of farming from purely individualistic to group oriented activities in India. At this instance it is inevitable for a country like India to improve its agriculture production not only to meet the demand of food grains for the growing population but also to improve the economic conditions of the majority population who live in rural areas. As a result of losing land due to growing population and industrialization, the production of crop per unit area must be increased by proper utilization of resources. One way of increasing production of crops is by increasing the area under cultivation. Planning of crops is the most crucial factor of Agriculture Planning which depends on several resources like availability of land, water, labour, machinery and capital.

Ahmad et al. (1990) used LP model for developing optimal farm plans for small farmers in Leiah Tehsil and Faisalabad. Srinivasa Raju and Nagesh Kumar (2000) developed a LP irrigation planning model for the evaluation of irrigation development strategy and applied to a case study of Sri Rama Sagar project, Andhra Pradesh, India with the objective of maximization of net benefits. Singh et al. (2001) used a LP model to reach optimized crop pattern at various available water levels. Ishtiaq Hassan et al. (2005) presented a model to determine the optimum cropping pattern of Punjab in Pakistan. Mohmoud et al. (2009) adopted a LP model to find the optimal cropping pattern, in Taybad of Khorasn Razavi state in Iran. Felix and Judith (2010) developed an LP planning model for a Farm Resource Allocation Problem and applied to a Case Study of small scale commercial farmers in Zimbabwe.

Haouari and Azaiez (2001) presented a mathematical programming for determining crop pattern in dry lands under scarce of water resources. Willem et al. (2006) applied a genetic algorithm to minimize agricultural nitrogen deposition in nature reserves.

As evolutionary algorithms offer relatively more flexible way to analyze and solve realistic engineering problems is increased. The best known algorithms in this class are Genetic Algorithms (GAs).The Genetic Algorithm (GA) imitates the natural Darwinian evolution process, was originally conceived by John Holland (1975) of the University of Michigan, Ann Arbor.

Two important flavors of GA are Binary GA and Real parameter GA. The binary GA is not suitable to achieve any arbitrary precision in the solution. The more the required precision, then the larger is the string length. If the string length is large, the population size is large (Goldberg et al., 1992), thereby increasing the computational complexity of the algorithm. To overcome this difficulty and to increase the precision it is more logical to represent the variables which are continuous by real parameter values (floating point numbers). Real coded or floating point representation has a very good usage because of the empirical findings that real codlings have worked well in a number of practical applications. The real parameter GA has also the advantage of less required storage space than the binary GA because a single real parameter value represents the variable instead of m (bits) integers. Also

About[α,β] - Selection Grade Lecturer, Department of Technical Education, Government of Andhra Pradesh, India – 530 007
About[Ω] - Professor, Department of Mechanical Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India – 530 003

real parameter GAs deal with real parameter values and bring the GA technique a step closer to the classical optimization algorithms (Deb, 2001).

In this paper, single objective optimization models are developed by considering the strategy of the decision maker/ policy makers. Further the models are solved through real parameter Genetic Algorithm approach.

II. Model Formulation

Enhancing productivity growth in a sustainable way that makes economic, social and environmental sense and delivers food security is key issue in determining the strategies for growth in agriculture sector. The highest leverage point could be a shift from individual crop-focused research to an eco-region specific strategy. Agricultural research and development strategies must take into account natural resource endowments and also the prevailing socio-economic conditions (as reflected in current crop patterns, yields, market access and so on) under which farmers work.

In this context, three objectives namely, maximization of production, maximization of profit and minimization of fertilizer consumption are modeled by considering the strategies with social, economic and environmental sense for optimal land allocation. The following steps explain the formulation and complete solution procedure for optimal allocation of land for major crops under three strategies.

a) Notations

L = Total area of land (hectares) available under cultivation

EMD = Estimated number of man days (days) available throughout the year.

EMH = Estimated number of machine hours (hrs.) available throughout the year.

$[WA]_s$ = Total amount of water (cm) available during the seasons s.

$[PR]_{cvs}$ = Production (quintal) per unit area of land cultivated for the variety v of crop c during the seasons s.

$[Md]_{cvs}$ = Man days (days) required per unit area of land cultivated for the crop c, variety v during the season s.

$[mh]_{cvs}$ = Machine hours (hrs.) required for tillage per unit area of land cultivated for the variety v of crop c during the season s.

$[WC]_{cvs}$ = Amount of water consumed (cm) per hectare of land cultivated during a season s for the crop c of variety v.

$[HP]_{cvs}$ = Harvest price (Rs. /quintal) of the variety of v of crop c cultivated during the season s.

$[MSP]_{cvs}$ = Minimum support price (Rs.) declared by the government for the variety v of crop c during the season s.

$[N+P+K]_{cvs}$ = Nitrogen, Phosperous and Potassium (kg/hectare) required for the variety v of crop c during the season s.

$[H]_{cvs}$ = The area of land required for cultivating the crop c, variety v, during the season s in hectares.

b) Strategies

Three strategies namely, societal, economic and environmental are considered in this study.

Societal Strategy: Increase in agricultural productivity must be accelerated to bring down current levels of food insecurity and meet the food and income needs of new populations. Hence, due consideration shall be given for Maximization of production. To meet the demand of food-stuff the annual production of all the major crops must be maximized. The mathematical formulation of the objective is shown below.

$$Maximize\ Production(Z_1) = \sum_{c=1}^{C} \sum_{v=1}^{V} \sum_{s=1}^{S} [H]_{cvs} * [PR]_{cvs}$$

Subject to constraints given in section 2.3

Economical strategy: The agricultural sector's performance determines overall economic growth, trade expansion, and increased income-earning opportunities of farmers. Implementing policies that encourage, Profitability is very much needed. To increase the economical and social status of the farmers the net profit must be maximized. The mathematical formulation of the objective is shown below.

$$\text{Maximize Profit}(Z_2) = \sum_{c=1}^{C} \sum_{v=1}^{V} \sum_{s=1}^{S} [MSP]_{cvs} * [PR]_{cvs} * [H]_{cvs} - \sum_{c=1}^{C} \sum_{v=1}^{V} \sum_{s=1}^{S} [HP]_{cvs} * [PR]_{cvs} * [H]_{cvs}$$

Subject to constraints given in section 2.3

Environmental strategy: The challenge relating to this, land area is to maintain its fertility status and protect against degradation due to soil erosion, chemicalization, water logging and Stalinization and alike problems. Use of chemical fertilizer is held responsible for soil degradation and environmental pollution. The reason for adverse impact of chemical fertilizer is because of excessive, indiscriminate and non-judicious use. To reduce the environmental pollution and cost of fertilizer the fertilizer consumption must be minimized. The mathematical formulation of the objective is shown below.

$$Minimize\ fertlizer\ consumption\,(Z_3)=\sum_{c=1}^{C}\ \sum_{v=1}^{V}\sum_{s=1}^{S}[H]_{cvs}*[N+P+K]_{cvs}$$

Subject to constraints given in section 2.3

c) Constraints

In agriculture planning, optimal land allocation depends on various constraints. The mathematical formulations of the constraints considered in this work are as follows.

Land (C_1) : It is necessary to utilize the land in all seasons because of its limited availability.

$$\sum_{c=1}^{C}\sum_{i=1}^{s}\sum_{V=1}^{S-i+1}[H]_{cvi}-\sum_{c=1}^{C}\sum_{i=1}^{s}\sum_{v=0}^{S-i}[H]_{cvi}\le L$$

$$where\,[H]_{coi}=0\ for\ all\ c,\ i\ and\ s=1,2...S;$$

After harvesting a crop in a season, the available land can be reutilized for cultivating the crops in the next season.

$$\sum_{c=1}^{C}\sum_{i=1}^{S-1}[H]_{c,s-i,i}-\sum_{c=1}^{C}\sum_{v=1}^{S-s+1}[H]_{c,v,s}=0\ for\ s=2,3,...S$$

Agriculture labour (C_2): It is necessary to utilize the agriculture labour in all seasons, because of the limited availability of laborers.

$$\sum_{c=1}^{C}\sum_{v=1}^{V}\sum_{s=1}^{S}[md]_{cvs}*[H]_{cvs}\le EMD$$

Agriculture machinery (C_3): It is necessary to utilize the agriculture machinery for tillage in all seasons, because of the limited availability of machinery.

$$\sum_{c=1}^{C}\sum_{v=1}^{V}\sum_{s=1}^{S}[mh]_{cvs}*[H]_{cvs}\le EMH$$

Water (C_4): To meet the production level of each crop, it is necessary to utilize available water in all seasons.

$$\sum_{c=1}^{C}\ \sum_{v=1}^{V}\sum_{s=1}^{S}[WC]_{cvs}*[H]_{cvs}\le[WA]_s\ for\ s=1,2..S$$

d) Obtaining Solution through GA

Three single objective optimization models are developed under each strategy with respective objective functions Z_1, Z_2 and Z_3. The formulated models may be solved through various optimization techniques. In this study a real parameter GA approach is used to solve models

The mechanism of real parameter GA consists of the following components.

- Genetic representation for potential solutions to the problem
- An initial population of potential solutions
- Evolution function (fitness function) that plays the role of the environment, rating solutions in terms of their fitness
- Genetic operators that alter the composition of children (reproduction, crossover and mutation)
- Values for various parameters that the GA uses (population size, number of generations, probabilities of applying genetic operators)

III. Case Study

The model formulated in the previous section is explained with a case study of Visakhapatnam district in Andhra Pradesh, India. According to the climatic conditions, two cropping seasons Kharif and Rabi are considered. The main crops cultivated during Kharif (June to September) and Rabi (October to February) seasons are Paddy, Black Gram, Green Gram, Ragi, Maize, Groundnut, Chillies, Sugarcane. Sugarcane is perennial crop and occupies the land in both the seasons. After harvesting the crops of short period in the Kharif season, the same land is utilized for cultivating late variety of Maize. Similarly in the Rabi season after harvesting the early variety of crops Black Gram and Green gram, the same land is utilized for cultivating late variety of same crops. In the model formulation, the crops are numbered as c = 1 for Paddy, c = 2 for Black ram, c = 3 for Green Gram, c = 4 for Ragi, c = 5 for Maize, c = 6 for Groundnut, c = 7 for Chillies and C = 8 for Sugar Cane, Seasons are denoted as S = 1 for Kharif and S = 2 for Rabi, Varieties are denoted as V = 1 for first variety or early variety and V = 2 for second variety or late variety. The data for the available resources, defined coefficients of objectives and constraints are presented in Table 1 and 2.

Table 1: Data of available resources

Land under cultivation in Kharif season (hectares)	L_1	230068
Land under cultivation in season (hectares)	L_2	38359
Man days(days)	EMD	58300000
Machine hours (hrs)	EMH	15292800
Water during Kharif season (cm)	$[WA]_1$	23656516
Water during Rabi season (cm)	$[WA]_2$	15265830

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Table 2: *Data for the co-efficients of objectives and constraints*

Coefficients	Season	Paddy	Black Gram	Green Gram	Ragi	Maize	Ground nut	Chilli	Sugarcane
Production (qtl/hect)	Kharif Rabi	16.83 19	4.2 6.7(6.5)	3.94 3.4(3.5)	5.95 15.5	14.26(13.5) 88.3	11.16 22.41	44.65 12.43	420
Market price (Rs/qtl)	Kharif Rabi	850 850	2520 2520(2520)	2520 2520(2520)	915 915	840 (840) 840	2100 2100	2200 2200	108
Harvest price (Rs/hect)	Kharif Rabi	8836 9975	6002 9574(9289)	5630 4859(5002)	2874 7487	7330(6939) 45386	16104 32338	63046 17552	35280
M/c hours (hrs/hect)	Kharif Rabi	4 6	0 0	0 0	4 4	(4) 4	6 6	4 4	8 8
Man days (days/hect)	Kharif Rabi	150 175	52 60 (58)	54 45 (48)	52 54	96 (92) 98	75 75	603 658	155
Fertilizer (kg/hect)	Kharif Rabi	135 135	100 100 (100)	100 100 (100)	100 100	180 (180) 180	110 110	160 160	200
Water (cm/hect)	Kharif Rabi	130 130	35 40 (40)	35 40 (40)	40 45	50 55	45 60	55 60	180

Note: The data shown in brackets corresponds to the late variety of crops.

a) *Strategies*

Societal Strategy

$$Maximize\ Production(Z_1) =$$

$16.83*H_{111}+19*H_{112}+4.2*H_{211}+6.7*H_{212}+6.5*H_{222}+3.94*H_{311}+3.4*H_{312}+3.5*H_{322}+5.95*H_{411}+15.5*H_{412}+14.26*H_{511}+88.3*H_{512}+13.5*H_{521}+11.16*H_{611}+22.41*H_{612}+44.65*H_{711}+12.43*H_{712}+420*H_{811})$

Subject to constraints given in section 3.2

Economical Strategy

$$Maximize\ Profit(Z_2) =$$

$(14306*H_{111}+16150*H_{112}+10584*H_{211}+16884*H_{212}+16830*H_{222}+9929*H_{311}+8568*H_{312}+8820*H_{322}+5444*H_{411}+14183*H_{412}+11978*H_{511}+74172*H_{512}+11340*H_{521}+23436*H_{611}+47061*H_{612}+98230*H_{711}+27346*H_{712}+45360*H_{811})-(8836*H_{111}+9975*H_{112}+6002*H_{211}+9574*H_{212}+9289*H_{222}+5630*H_{311}+4859*H_{312}+5002*H_{322}+2874*H_{411}+7487*H_{412}+7330*H_{511}+45386*H_{512}+6939*H_{521}+16104*H_{611}+32338*H_{612}+63046*H_{711}+17552*H_{712}+35280*H_{811})$

Subject to constraints given in section 3.2

Environmental Strategy

Minimize Fertilizer Consumption (Z_3) =

$H_{111}*(70+35+30)+H_{112}*(70+35+30)+H_{211}*(20+50+30)+H_{212}*(20+50+30)+H_{222}*(20+50+30)+H_{311}*(20+50+30)+H_{312}*(20+50+30)+H_{322}*(20+50+30)+H_{411}*(50+30+20)+H_{412}*(50+30+20)+H_{511}*(100+50+30)+H_{512}*(100+50+30)+H_{521}*(100+50+30)+H_{611}*(30+40+40)+H_{612}*(30+40+40)+H_{711}*(80+50+30)+H_{712}*(80+50+30)+H_{811}*(80+20+100);$

Subject to constraints given in section 2.3.1 to 2.3.4.

b) *Constraints*

Land in Kharif season

$H_{111}+H_{211}+H_{311}+H_{411}+H_{511}+H_{611}+H_{711}+H_{811}<=230068;$

Land in Rabi season

$H_{112}+H_{212}+H_{312}+H_{412}+H_{512}+H_{612}+H_{712}<=38359;$

Reutilization of land in next season

$H_{212}+H_{312}-H_{222}-H_{322}=0;$

$H_{211}+H_{311}-H_{521}=0;$

Agriculture labor

$150*H_{111}+175*H_{112}+52*H_{211}+60*H_{212}+58*H_{222}+54*H_{311}+45*H_{312}+48*H_{322}+52*H_{411}+54*H_{412}+96*H_{511}+98*H_{512}+92*H_{521}+75*H_{611}+75*H_{612}+609*H_{711}+658*H_{712}+155*H_{811}<=58300000;$

Agriculture machine hours

$4*H_{111}+6*H_{112}+4*H_{411}+4*H_{412}+4*H_{511}+5*H_{512}+4*H_{521}+6*H_{611}+6*H_{612}+4*H_{711}+4*H_{712}+8*H_{811}<=15292800;$

Water in Kharif season

$130*H_{111}+35*H_{211}+35*H_{311}+40*H_{411}+50*H_{511}+50*H_{521}+45*H_{611}+55*H_{711}+180*H_{811}<=23656516;$

Water in Rabi season

$130*H_{112}+40*H_{212}+40*H_{222}+40*H_{312}+40*H_{322}+45*H_{412}+55*H_{512}+60*H_{612}+60*H_{712}+180*H_{811}<=15265830;$

c) *Obtaining Solution through GA*

The multi objective problem converted to a single objective problem and is solved through real parameter genetic algorithm. The real coded GA used to find the optimum solution implements a tournament selected scheme, where two solutions are compared and the best in terms of objective function value is selected. Crossing over is done by the simulated binary crossover SBX operator which works with two parent solutions and creates two offspring (Deb and Agarwal, 1995). To create a mutated value, the polynomial mutation operator (Deb, 2001) is used. The exponents used for SBX and mutation are 2 and 100 respectively. Constraints are handled using Deb's parameter-less approach (Deb, 2000).

In most of the constrained optimization problems, the fitness function is obtained by adding a penalty proportional to the constraint violations to the objective function value. The constraint handling methods can be classified into five categories (Michalewicz et al. 2000). They are the methods based on preserving feasibility of solutions, penalty function, feasible over infeasible solutions, decoders and hybrid methods. Among these methods the method feasible over infeasible solutions is found to have more efficient and more robust than the penalty based methods (Deb, 2000). This method sometimes called as Deb's penalty parameter less approach and the same is used in the present work.

As GAs do not have a mathematical convergence, a parametric study is carried out by varying crossover probability (Pc), mutation probability (Pm), population size (Ps), and number of generations (Gn). By this study the best value of the each objective function was found with the best set of GA parameters obtained. The best GA parameters obtained are Pc=0.81, Pm=0.01, Ps=30,Gn=150.

IV. Results and Discussion

Table 3 shows the results obtained for optimal land allocation for Societal, Economical and Environmental strategies for eight major crops through GA by considering the best combination of GA parameters.

Table 3: Optimal land allocation

S1. No.	Crops	Decision variables	Societal Strategy	Economical Strategy	Environmental Strategy
1.	Paddy	H_{111}	95717.061	95591.791	98782.757
		H_{112}	3998.393	3841.478	3985.636
2.	Black Gram	H_{211}	3999.996	3993.851	3998.554
		H_{212}	2999.86	2999.754	2999.131
		H_{222}	2999.703	2999.993	2996.617
3.	Green Gram	H_{311}	1999.993	1993.141	1986.469
		H_{312}	3998.561	3999.956	3998.911
		H_{322}	3997.853	3986.554	3995.135
4.	Ragi	H_{411}	29999.835	29999.236	26368.929
		H_{412}	997.784	998.401	739.977
5.	Maize	H_{511}	6976.733	6999.994	6996.454
		H_{512}	1986.27	1999.998	1824.971
		H_{521}	6999.987	6999.993	6997.61
6.	Ground nut	H_{611}	5674.112	5999.481	5992.744
		H_{612}	1999.968	1999.829	1882.969
7.	Chillies	H_{711}	997.949	999.979	730.743
		H_{712}	2999.983	2999.888	2999.919
8.	Sugarcane	H_{811}	49999.973	49999.967	48700.802
Total land allocated in			228344.014	228403.284	225978.328

The results exhibits that the total land utilization for eight major crops in kharif season with societal, economical and environmental strategies are 87.96%, 88.05 and 87.17% respectively. Similarly, land utilization in rabi season are 67.72%, 67.32% and 66.28%. It also shows that there is a maximum land allocation (228403.284 hectares) by economical strategy as compared with other strategies. Comparison of land allocation for eight major crops among three strategies is shown in the figure 1.

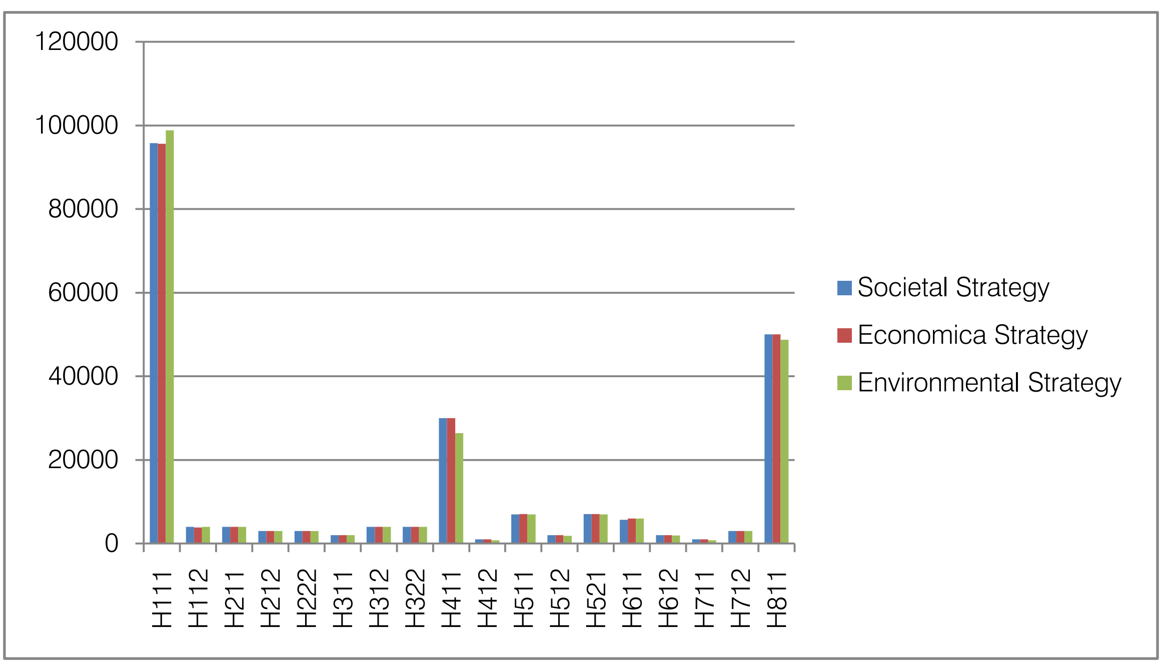

Figure 1: Land allocation for eight major crops

From the figure 1 it is observed that there is marked difference in land allocation in environmental strategy for the crops - paddy (H111), Maize (H111) and sugarcane (H811) when compared with the other strategies.

Table 4: *Level of achievement of Objectives under different strategies*

S.no	Objectives	Societal Strategy	Economical Strategy	Environmental Strategy
1	Production	23532072 (99.99%)	23532161 (100%)	22987090 (97.68%)
2	Profit	1492216509 (99.91%)	1493427936 (100%)	1471302386 (98.52%)
3	Fertilizer consumption	32918096 (99.13%)	32920473 (99.13%)	32632926 (100%)

Note: Figures within the parenthesis indicate the Percentage of attainment to its maximum or minimum value as of the case of the objective

The attainment levels of various objectives in percentage are given in table 4. From the results it is observed that production and profit objectives are maximum with economical strategy. With environmental strategy, fertilizer consumption is minimum. Further, one can observe that the societal strategy is also competing with other two strategies. Level of achievement of Objectives under different strategies is shown in figure 2.

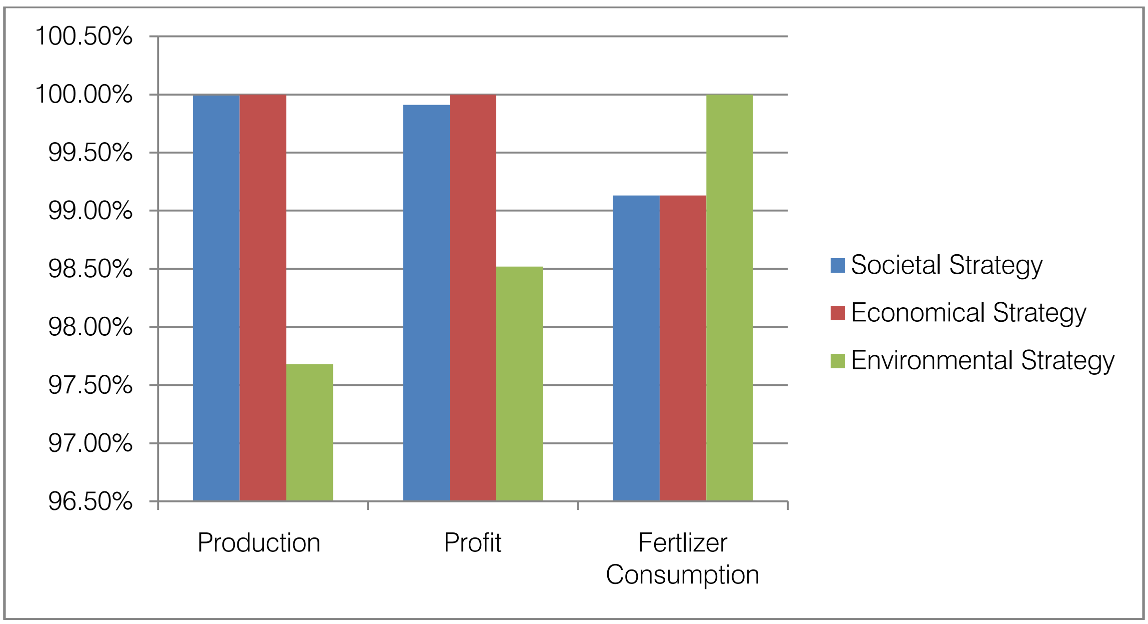

Fig 2: *Level of achievement of Objectives*

From figure 2, it is observed that there is variation in level of achievement of the objectives with environmental strategy when compared to the other strategies.

V. Conclusion

This paper presents three strategies for optimal allocation of land for eight major crops in two seasons and for two crop varieties of Visakhapatnam district in Andhra Pradesh, India. The models proposed in this paper are solved through real parameter GA for optimal solution by parametric study.

The land planning based on the results achieved with the help of genetic algorithm will lead towards a development strategy in the rural sector through agriculture. In a country like India whose rural economy is mostly agriculture based, a sustainable development in the context of globalization is only possible by way of improved land, societal, economical and environmental strategies by reorganizing land allocation system for various agricultural activities keeping in view of the local and market requirements. This model is based on single objective optimization depending on the strategy of the agriculture planners subject to the resource and conditional constraints. By using this model the cultivated land can be reorganized to get maximum satisfaction of the stakeholders of the rural area and hence lead to sustainable development in agriculture. The model developed does not taken care of uncertainty in the objectives and constraints. Future researchers may also include vagueness and stochastic uncertainty in decision variables, coefficients, objectives and constraints.

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