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Research Paper

Multi-objective optimization and design of integrated farming systems using goal programming

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ABSTRACT

In the present study, the farmers' problem and their multi-objectives were incorporated in the model by considering a case study under north Indian situations. A generalized farm problem with respect to various physical and socioeconomic constraints under irrigated ecosystem of north India was used for designing the integrated farming systems through goal programming - constraint method of modeling techniques. Maximization of farm income is selected as the main objective of the constraint method of multiobjective optimization and other two objectives, viz. capital requirement and labour employment were used as the additional constraints in the constraint set. Thirty three non-dominated set of alternatives/strategies were formulated by parametrically changing the values of additional constraints. The study revealed that the maximum farm net return of ₹6,59,623 was obtained, while the other two objectives, capital requirement and labour requirement were fixed as constraints at ₹5,24,926 and 966 man days, respectively. Goal programming can be used as tool for designing individual integrated farming system on scientific basis considering the resource availability at the farm level. The single objective IFS models were developed using linear programming technique for marginal, small and medium farm situations, which proved potential to replace existing rice (*Oryza sativa* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol] system with higher profitability.

Key words : Goal programming, Integrated farming systems, Linear programming, optimization, Rice–wheat cropping system

Integrated farming systems (IFS) allow for physical reconnection of livestock to the land, and therefore offer a promising alternative archetype to the ongoing development of industrialization of crop and animal production systems (Herrero *et al.*, 2010). In integrated crop–livestock systems, animals can have multiple purposes besides the primary production of grain, milk, meat, eggs, wool etc. Animals can serve as a capital stock, contribute to nutrient cycling by their manure production and large animals can provide draught power. In well-managed integrated farming systems with limited external inputs, balanced rotations and appropriate stocking rates, nutrient cycling and organic matter use can be improved to avoid soil mining or pollution and to enhance the organic matter content and soil structure (Oomen *et al.*, 1998; Schiere *et al.*, 2002; Lantinga *et al.*, 2004; Watson *et al.*, 2005; Petersen *et al.*, 2007; Russelle *et al.*, 2007). This holds large promises for the development of sustainable farming systems (Hilimire, 2011). The planning of IFS with an array of crops, various animal types and a diverse range of other resources is complicated, as it involves many management decisions on resource allocation (Russelle *et al.*, 2007). These choices and their resulting outcomes are subject to a large range of objectives and constraints. The objectives include the need for sufficient financial returns to maintain the livelihood of farmers and farm workers, and environmental goals to safeguard the sustainability of the system. The constraints originate from biophysical conditions that can restrict the possibilities for allocating crops and rotations or from agronomic knowledge of acceptable crop sequences and cultivation practices. Moreover, the nutritional needs of animals should be balanced with feed supply and the labour and water requirement should be matched with the availability of these resources.

Model-based support can be useful in various hierarchically structured planning windows. These range from long-term strategic planning over a time-span of several years, to yearly tactical planning and short-term operational planning to schedule activities, based on the tactical plan, for a number of days or weeks. Recently, various tools have been developed and applied for integrated farming system analysis (Modin-Edman *et al.*, 2007; Bechini

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and Stöckle, 2007; Millar *et al.*, 2009; Küstermann *et al.*, 2010) and for the exploration of strategic improvements in farming systems (Groot *et al.*, 2010). However, methodologies that enable tactical planning, and that can provide rapid insight into the consequences of large ranges of farm reconfiguration options would be very helpful to inform farmers and farm advisors about the planning process of Ideally, this planning process would take the shape of an iterative innovation and learning cycle. An integrative modeling methodology to support this process would enable the analysis of synergies and trade-offs among different objectives (Groot *et al.*, 2010). Rapid inspection of the farm configurations (crops areas, animal numbers, manure application, etc.) associated with different performance levels should be possible. Pareto-based multi-objective optimization methods are well–suited to carry out such explorations of trade-offs and synergies. Goal programming is a tool, which supports evaluation and re-design of integrated farming systems in the planning processes. Goal programming is a powerful tool for handling multiple decision criteria. The LP models are based on the optimization of a single objective function. There are situations where multiple (conflicting) objectives may be more appropriate. For example, a farmer wish to make less investment on farm activities, maximize the farm income and minimize risk. In such situations, it is impossible to find a single solution that optimizes these 3 conflicting goals. In this situation, goal programming seek a compromise solution based on the relative importance of each objective.

Goal programming is an extension of linear or non-linear programming involving an objective function with multiple objectives. While developing a goal-programming model, the decision variables of the model are to be defined first, then the managerial goals related to the problems are to be listed down and ranked in order of priority. It may not be possible always to fully achieve every goal specified by the decision-maker. Thus goal programming often referred to as a lexico graphic procedure in which the various goals are satisfied in order of their relative importance.

There are 2 methods for developing solutions using goal-programming techniques. The weights method forms a single objective function consisting of the weighted sum of the goals, and the preemptive method utilizes the goals one at a time starting with the highest priority goal and terminating with the lowest, never degrading the quality of a higher-priority goals. In general, a goal-programming model performs 3 types of analysis: (i) it determines the input requirements to achieve a set of goals; (ii) it determines the degree of attainment of defined goals with given resources; and (iii) it provides the optimum solution under the varying inputs and goal structures.

In this paper, we present the goal programming as a tool for designing an integrated farming system in multi-objective environment to develop different IFS strategies for farming situations in north India.

MATERIALS AND METHODS

The study area

The study was conducted in 7 villages, viz. Hyatpur and Kotli villages in Ludhiana district in Punjab; Bhurgrahi village in Dandamukundapur district in Uttar Pradesh; and Sonali village in Panipat district and Chahalka, Bhango and Biwan villages in Nuh district in Haryana, India.

These villages are located in north India between at 28.4°N and 30.4 °N latitude and 77.1°E and 78.2 °E, 228.6 m above mean sea-level. The climate of Delhi, Haryana, western Uttar Pradesh and Punjab state is semi-arid to sub-tropical with extreme cold and hot situations, the hottest months are May and June with the mean maximum temperature ranging from 41 to 44 °C, whereas the mean minimum of the coolest months (December and January) falls in the range of 2–5 °C. The daily maximum and minimum temperature tend to rise from the first fortnight of February and maintain the trend till June and decreases from July onwards. The evapo-transpiration rate also follows pattern similar to temperature during this period. Average annual rainfall of region is about 650–900 mm, 84% of which is received during south–west monsoon. July and August are the wettest months. The relative humidity increases from June to September. The mean annual evaporation of the area is about 850 mm.

Data collection

Socio-economic surveys were conducted using both Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA) techniques in the 7 selected villages in north India from 2007 to 2010. Resource availability and interactions of the different components within the farming system were recorded for each farm by questionnaire. Cost of production and output for each enterprise, and resource flow between the enterprizes and interaction of various enterprizes were also recorded. The farming systems in the area are characterized as mostly rice (*Oryza sativa* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol] cropping system. Following pre-testing, a structured questionnaire was applied to a total of 100 farms. The head of the household was normally interviewed, although husband and wife were present throughout the interview in the majority of cases. Interview was generally conducted in the home or on the farm. Wherever needed, the information were also confirmed over phone. The data were used for construction of whole-farm models using goal programming techniques.

Problem description and case study in north Indian scenario

Generalized problems under north Indian situations are considered for the study under various physical and socio-economic constraints where rice–wheat is the dominant cropping system for quite a long period. This cropping system has led to severe degradation of land and environment. There has been reduction in production and decline in farm income irrespective of farm sizes (Sidhu *et al.*, 2007). There has been increase in production cost due to escalation of input cost. The rice–wheat has become main source of income for the majority of the farmers. The farmers of the region are classified into 4 categories, viz. marginal, small, medium and large, depending on the size of the holding (ARDB, 2011). Marginal and small farmers are dominant with more than 80% of the total farming community (ARDB, 2011).

Migration to nearby cities or towns in search of contractual employment is a common feature for the small and marginal farmers due to non-availability of farm employment, and generating employment for them at farm level is a major challenge. They have the surplus labour, while in case of medium and large farmers; labour availability for farm operations is a major problem. They largely depend on hired labour for their farm activities. The land, labour, capital availability and enterprize options for each category of farmers are presented in Table 1. These are based on information obtained through socio-economic survey, personal communication with the scientists, and interviewing the farmers adopting PRA and RRA techniques (FAO, 1995). The above discussed aspects are taken into consideration, while formulating mathematical model. Accordingly, various IFS models/strategies are developed. Sole rice–wheat system was included as base for comparison with the developed IFS models.

Mathematical modeling using linear programming

Linear programming-based model is formulated with the objective of maximization of net farm income subjected to constraints related to resource availability such as land (ha), capital (₹), labour (man-days); enterprize options such as dairy (1 unit equivalent to 0.08 ha), piggery (1 unit equivalent to 0.0025 ha), poultry (1 unit equivalent to 0.025 ha), fishery area of pond (ha), agroforestry (ha), crop (ha) for marginal, small, medium and large farm categories. Six enterprizes, namely dairy, piggery, poultry, fishery, agroforestry and crop, are represented as X_1 to X_6, respectively, for modeling purpose. Mathematical model developed using linear programming (LP) for one of the large farm situations (R-W+D+Pig+ F+ Poult+A) is presented here for developing IFS model. The data available in Gill *et al.* (2005) is used as the basis for formulation model and its objective function and constraints. Mathematical model using LP is explained as below:

$$\text{Max } Z = \sum_{j=l}^{n} CjXj \quad \text{.. 1.0}$$

Subject to

$$\sum_{j=1}^{n} aij \le bi \qquad i = 1 \text{ to } n \qquad \text{....1.1}$$

And

$$Xj \ge 0 \qquad j = 1 \text{ to } n \qquad \text{....1.2}$$

Where,

Z = total net margin; Xj = the level of the j^{th} activity; Cj = the gross margin of the j^{th} activity; aij = the quantity of the i^{th} resource required to produce a unit of jth activity; bi = the amount of the i^{th} resource available.

Objective function: Maximization of farm income

Max Z = 96405X1 + 14760900X2 + 514113X3 + 59132X4+18406X5 + 53221X6

Constraints: Restrictions on land

X1+X2+X3+X4+X5+X6 ≤ 10;

Restrictions on capital availability

178220.5X1+4624550X2+3184555X3+39137.7X4+19593.56X5 +19879.25X6≤600000;

Restrictions on labour availability

456X1+13680X2+1216X3+34.2X4+52.8X5+105X6≤1200;

Bounds

Dairy: X1 = 0.4;

Piggery: X2= 0.01;

Poultry: X3 = 0.05;

Fishery: 1.0 ≤ X4 ≤ 4.0;

Poplar (agroforestry) : 1.0 ≤ X5 ≤ 2.5;

Rice-wheat: 2.0 ≤ X6 ≤ 4.0;

Here X1, X2, X3 are fixed (various values for various IFS strategies and various farm categories). These are based on the initial infrastructure requirements such as cowshed, poultry shed and shed for piggery. Fishery, poplar and rice–wheat are having flexibilities in land allocation and used as variable. Though values suggested in Table 1 are used as the basis, these values were changed from strategy to strategy for given farm category (namely marginal, small, medium and large, here only large farm situation is presented) to suit different perspectives of the farmers in the region. The restrictions and resource position for the modeling exercise based on the farmers' options recorded in the survey.

Goal Programming Algorithms

Authors want to provide a review of different methods used in goal programming as given below:

The weights method: The method is based on representing multiple goals by a single objective function. In the weights method, a single objective function is formed as the weighted sum of the functions representing the goals of the problem.

Suppose that the goal programming model has n goals and that i^{th} goal is given as:

Minimize Gi, i = 1, 2, ………….., n.

The combined objective function used in the weights method is then defined as:

$$\text{Minimize } Z = W_1G_1 + W_2G_2 + \ldots\ldots + WnGn$$

The parameters W_i, i = 1, 2, ……………., n, are positive weights that reflect the decision maker's preferences regarding the relative importance of each goal. For example, W_i = 1, for all i, signifies that all goals carry equal weights. The determination of the specific values of these weights is subjective.

The pre-emptive method: In the preemptive method, the decision maker must rank the goals of the problem in order of importance. Given an n-goal situations, the objectives of the problem are written as:

$$\text{Minimize } G_1 = p_1 \text{ (Highest priority)}$$
$$\text{Minimize } Gn = pn \text{ (Lowest priority)}$$

The variable p is the component of the deviational variables, s_e^- or se^+, that represents goal i.

The solution procedure considers one goal at a time, starting with the highest priority, G_1, and terminating with the lowest, Gn. The process is carried out such that the solution obtained from a lower priority goal never degrades any higher priority solutions.

The goal programming results can be achieved in a more straight forward manner using the following step (Taha, 2005).

Step O. Identify the goals of the model and rank them in the order of priority:

$$G_1 = P_1 > G_2 = P_2 > \ldots\ldots > Gn = Pn$$

Set i = 1

Step 1. Solve LP_2 that minimizes Gi, and let $P_2 = P_2*$ define the corresponding optimum value of the deviational variable pi. If I = n, stop; L pn solves the n-goal programme. Otherwise, add the constraint pi = P_2^* to the constraints of the Gi-problem to ensure that the value of pi will not be degraded in future problems. Set I = I + 1 and repeat step i. As per Taha (2005), this method is equally efficient as the column-dropping rule.

Constraint method of multi objective optimisation

Constraint method is a plan-generation technique. It operates by optimising one objective while all others are constrained to some value (Loucks *et al.*, 1981; Vedula and Mujumdar, 2005). Mathematically it can be expressed as:

$$\text{Max } f_r(\mathbf{x})$$

Subjected to

$$f_m(\mathbf{x}) \geq L_m;\ m = 1,2, \ldots\ldots, r\text{-}1, r+1, \ldots\ldots, n.$$

and existing constraints and bounds m.

In the method, r^{th} objective function is chosen for maximisation from among n objectives. $f_r(\mathbf{x})$ and $f_m(\mathbf{x})$ are objective functions corresponding to objectives r and m. Maximum and minimum values that can be obtained by each objective can be used to formulate different values of L_m (L_m is bound on objective m which is later transformed as constraint in the constraint method) for the generation of non-dominated solutions based on decision maker and analyst preference.

RESULTS AND DISCUSSION

Linear-programming model

In north Indian situations, monoculture of long-established rice–wheat system has posed several challenges for its sustainability and needs to be replaced by diversified IFS (Sidhu *et al*., 2007; Behera *et al*., 2007). In this regard, an attempt was made to develop number of alternative IFS models for various farm size classes. These models are evaluated for income generation potentiality of IFS vis-a-vis rice–wheat system. Total 34 single objective models were developed consisting of 7,7,10 and 10 for marginal, small, medium and large farmers, respectively, and solved using linear Programming.

Marginal farms typically have around 1 ha of land, capital of ₹ 75,000 for investment and 500 man-days of labour per annum for allocating in different enterprizes (Table 1). Taking the marginal farmers situations into consideration, 7 IFS models were developed and denoted as IFSMA-1 to IFSMA-7 (Fig. 1a). Here IFSMA represents integrated farming systems for marginal farmers. Similar notation such as IFSSM, IFSME, and IFSLA was used for small, medium and large farms' situations. IFSMA-7 represents the common practice of taking rice–wheat cropping system as prevalent with the farmers in the region. The IFSMA-7 strategy has resulted the lowest income of ₹53,221 and employment of 105 man-days with the capital investment of ₹19,879. Out of these 7 models, IFSMA-2 consisting of 1 unit of dairy (2 dairy animal) and 2 units of piggery (40 pigs), 0.365 ha of land for fishery, 0.05 ha of agro-forestry (poplar) and 0.5 ha of rice–wheat generated the highest net income of ₹ 1,30,630 with an employment opportunity of 173 man-days. The capital requirement for this model was ₹ 62,585. Thus, land availability became the constraint for further improvement of income of the farmer, since available capital and labour were underutilized. The next best model in terms of providing maximum net benefits was IFSMA-3, which could accommodate all the enterprizes available with the farmers and generated farm income of ₹ 95,014 and employment opportunity of 141 man-days and capital investment of ₹58,985. In this case also, land became the constraint to further enhance the farm income, where his/her available capital and labour were underutilized.

A small farmer having 2 ha of land with ₹ 1,50,000 as capital for investment and 600 man-days of labour per year at his/her command has generated a maximum farm income of ₹1,88,364 (Fig. 1b) with allocation of 0.16 ha of dairy (4 animals) and 0.005 ha of piggery (2 units with 40 pigs) and 0.75 ha of fishery, 0.085 ha of agroforestry and 1.0 ha of rice–wheat system (IFSSM-3). This involved capital investment of ₹ 1,02,536 and labour requirement of 276 man-days. The lowest economic return of ₹ 1,06,442 was obtained in rice–wheat system (IFSSM-7) with a less capital requirement of ₹ 39,758 with an employment opportunity of 210 man-days. The other promising models are IFSSM-6 with return of ₹ 1,79,980 and IFSSM-2 with ₹1,39,600. These 2 models required capital investment of ₹ 62,782 and ₹ 1,50,000 with employment opportunity of 278 and 225 man-days respectively. Like the marginal farmers situations, here also, land became the constraint for further increase of farmers' income except in IFSSM-1 and IFSSM-2, where land resource is underutilized and capital becomes constraint to further improve the farm income.

Medium farmer typically has around 4 ha of land, capital of ₹ 3,00,000 for investment and 900 man-days of labour per annum for allocating to different enterprises. Ten enterprise options IFSME-1 to 10 are proposed. The IFSME-10 represents the common practice of taking rice–wheat cropping system as prevalent with the farmers in the region. This model has generated an income of ₹ 2,12,884 and employment of 420 man-days round the year with the capital investment of ₹ 79,517 (Fig. 1c). The highest return of ₹ 2,90,893 was obtained with IFSME-2, which involves 0.16 ha (4 animals) under dairy, 0.005 ha (40 pigs), 0.05 ha (4,000 poultry birds), 1.0 ha, 0.5 ha and 2.02 ha under fishery, agroforestry, and rice–wheat system respectively. In this model, land and labour were underutilized and further improvement of the farm income was limited due to lack of capital availability. As a whole there was 36.7% additional income with IFSME-2 as compared to rice–wheat system (IFSME-10) alone.

Large farmers are in the most advantageous position with highest level of resource availability and the minimum level of resource constraints. The large farmers usually have a resource availability of 10 ha of land, ₹ 6,00,000 of capital and 1200 man-days/year of labour. Taking the resource availability and constraints at farmers command into considerations, 10 farm models, IFSLA-1 to 10 are developed (Fig. 1d). A large farmer generated a maximum farm income of ₹ 7,26,115 with IFSLA-9. At this level of income, the enterprizes such as rice–wheat, fishery, dairy, and piggery played a promising role. However, model did not include the enterprise poultry and agroforestry. Model involved a capital investment of ₹4,04,468 and created an employment opportunity of 972 man-days. The benefit: cost ratio was 1.798. The model has generated 36.43% higher income than the farmers practice of sole rice-wheat systems (IFSLA-10), where a

Table 1. Enterprise options of different farm categories under varying resource availability and constraints for north Indian situations

Farm characteristics	Marginal	Small	Medium	Large
A. Resource availability[a]				
Land availability (ha)	1.0	2.0	4.0	10.0
Capital availability (₹)	75,000	150,000	300,000	600,000
Labour availability (man-days)	500	600	900	1200
B. Enterprise options[b]				
Dairy (units)[1]	1	2	4	5
Piggery (units)[2]	1	2	2	4
Poultry (units)[3]	-	1	2	2
Fishery (ha)	0.25	0.5	1	2
Agroforestry	0.15	0.25	0.5	1
Crop (ha)	0.5	1.25	2.5	7.5

a = Information is based on interview with the farmers of the villages in the case study region and scientists involved in on-farm research in that area

b = numbers refer to the average options for different enterprizes in the region by different categories of farmer which were recorded/observed/inferred during the process of socio-economic survey/interview with the farmers.

[1]Land requirement for one unit of dairy (2 cows) is 0.08 ha; [2]Land requirement for one unit of piggery (20 pigs) is 0.0025 ha; [3]Land requirement for one unit of poultry (2000 birds) is 0.025 ha

farm income of ₹ 5,32,210 was generated and created an employment opportunity of 1,050 man-days. The IFSLA-3 which involved all the components of farming systems available with farmers, has generated a farm income of ₹6,89,634 and created employment opportunity of ₹1,018 man-days and required capital investment of ₹5,43,003. Other models, which were found promising, were: IFSLA-4 and IFSLA-5 with farm income of ₹6,42,261 and ₹6,07,375 which created an employment opportunity of 1,105 and 879 man-days respectively. However, in both the cases the land became the constraint for further increase the income. The IFSLA-1 did not show improvement over the rice–wheat system, but model accommodated other enterprises also, which are important to provide regular income to the farmer as well as minimizes risks due to diversification (Fig. 1d).

In the above sections, various strategies for marginal, small, medium and large farms are presented, which can be implemented in real farm situations. Developed models are generalized and can be extended to any given land, capital and labour availability.

Multi-objective optimization using goal programming

In real world IFS situations, farmers face difficulty in considering several objectives simultaneously, which are conflicting in nature such as farm return, capital requirement and labour employment. In addition, farmers like to produce enough food for the farm family by utilizing his/her resources effectively including land. In this situation, Goal Programming method can be employed for achieving a practical and multi-objective solution for farmers. Accordingly, strategies are developed using Goal Programming for typical large farm situations (IFSLA -3).

In the present study, Constraint method of multi-objective optimization is used. Maximization of farm income is selected as the main objective in the Constraint method of multi objective optimization and other 2 objectives–capital requirement and labour employment–are used as the additional constraints in the constraint set. Thirtyfour non-dominated set of alternatives are formulated by parametrically changing the values of 2 additional constraints. The results are presented in Table 2.

It was observed that with the increase of capital requirement and decrease of labour employment, farm income increased (policy 16). Thereafter farm income is decreased with decrease of labour employment and capital requirement (policy 27). Again from policy 28 to 31, with the increase of capital requirement and decrease of labour employment, the farm income increased. Thereafter farm income was decreased with the decrease of labour employment and capital requirement (policy 32 and 33). Supplementary information, such as area under fishery (ha), area

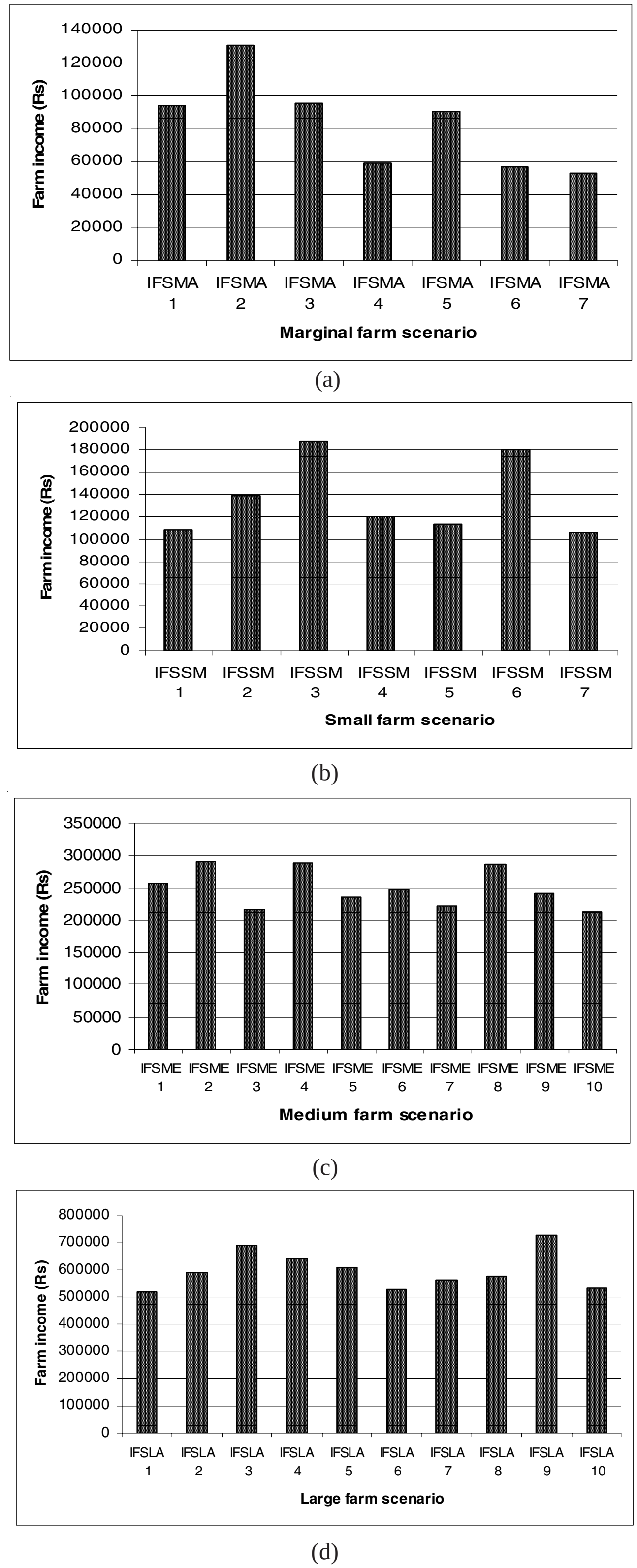

Fig. 1. Farm income for various integrated farming system models: (a) Marginal farms; (b) small farms; (c) medium farms; and (d) large farms. The models IFSMA 7, IFSSM 7, IFSME 10, and IFSLA 10 represent farm income of sole rice–wheat system of respective situations

Table 2. Payoff matrix based on constraint method of analysis

Strategy	Capital (×₹10³)	Labour (Man-days)	Farm returns (×₹10³)	Fishery (ha)	Agro forestry (ha)	Rice–wheat (ha)	Total land (ha)
1	434.80	904	532.20	1.506	1	4.000	6.965
2	439.13	895	535.29	1.692	1	3.850	7.000
3	443.46	890	539.50	1.854	1	3.750	7.064
4	447.79	885	543.71	2.015	1	3.650	7.125
5	452.12	880	547.93	2.176	1	3.550	7.190
6	456.44	875	552.14	2.338	1	3.449	7.248
7	460.77	870	556.36	2.499	1	3.349	7.310
8	465.10	860	559.25	2.691	1	3.192	7.342
9	469.40	855	563.43	2.850	1	3.092	7.403
10	473.70	850	567.61	3.011	1	2.992	7.464
11	478.00	845	571.79	3.172	1	2.892	7.524
12	482.00	840	575.59	3.323	1	2.796	7.579
13	488.00	835	581.94	3.536	1	2.678	7.675
14	492.00	830	585.74	3.687	1	2.582	7.729
15	496.00	825	589.53	3.839	1	2.484	7.783
16	500.31	820	593.73	4.000	1	2.385	7.845
17	499.37	815	591.19	4.000	1	2.337	7.797
18	495.00	810	584.28	3.895	1	2.323	7.678
19	490.00	805	576.56	3.771	1	2.316	7.547
20	485.00	800	568.84	3.647	1	2.309	7.416
21	480.00	795	561.12	3.523	1	2.302	7.285
22	475.00	790	553.40	4.000	1	2.294	7.154
23	470.00	785	545.68	3.275	1	2.287	7.022
24	460.00	775	530.24	3.026	1	2.273	6.759
25	450.00	770	516.12	2.749	1	2.316	6.525
26	440.00	765	501.99	2.470	1	2.359	6.920
27	435.00	757	493.48	2.365	1	2.317	6.143
28	505.00	966	638.26	3.299	1	4.000	8.759
29	510.00	960	643.17	3.485	1	3.885	8.830
30	515.00	955	648.24	3.667	1	3.778	8.906
31	524.93	950	659.62	4.000	1	3.623	9.080
32	523.03	940	654.55	4.000	1	3.527	8.987
33	521.14	930	649.48	4.000	1	3.430	8.890
max	524.93	966	659.62	4.000	1	4.000	9.080
min	434.80	757	493.48	1.506	1	2.273	6.143
Diff	90.13	209	166.14	2.494	0	1.727	2.937

under rice–wheat (ha) and total land occupied by all enterprizes was also provided. It was observed that maximum and minimum areas occupied by fishery among 33 strategies were 4 and 1.506 ha. In case of agroforestry, consistent occupation of land 1 ha was observed. It was observed that maximum and minimum areas occupied by rice-wheat among 33 strategies were 1 (4.00 ha) and 24 (2.273 ha). Finally, land occupied was maximum of 9.0 ha (strategy 31) and minimum of 6.143 (strategy 27).

With the help of goal programming, the individual integrated farming system can be designed successfully on scientific basis. Using goal-programming constraint method, number of alternative strategies (33) were developed, out of which suitable strategies can be implemented in the real farm situations. This method provides an opportunity to estimate one important objective (target), while changing the values of other objectives. The changing objectives were considered as additional constraints. The study revealed that the maximum farm net return of ₹6,59,623 was obtained, while the other 2 objectives, i.e. capital requirement and labour requirement, were fixed as constraints at ₹5,24,926 and 966 man-days respectively. Linear-programming models were developed for marginal, small and medium farm situations, which proved potential to replace existing rice–wheat system with higher level of profitability.

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