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MULTI-OBJECTIVE CONSTRAINED ALGORITHM (MCA) AND NON-DOMINATED SORTING GENETIC ALGORITHM (NSGA-II) FOR SOLVING MULTI-OBJECTIVE CROP PLANNING PROBLEM

Sams Jarin[1], Mst. Khaleda Khatun[2] and Amir Akramin Shafie[3]
[1,2]Department of Computer Science and Engineering, Malaysia
[1,2]Rajshahi University of Engineering and Technology, Malaysia
[1,3]Mechatronics Engineering Department, Faculty of Engineering, Malaysia
[1,3]International Islamic University Malaysia, Kuala Lumpur, Malaysia
E-Mail: sams.ruet@gmail.com

ABSTRACT

Crop planning problem is a multi-objective optimization problem. It is related to many factors such as land type, capital, demand etc. From very earlier years, people have been trying to find out a best solution for crop planning to get more profit in exchange of less investment and cost. In this paper, we formulate a crop planning problem as a multi-objective optimization model and try to solve two different versions of the problem using two different optimization algorithms MCA and NSGA. In this two algorithms, they provide superior solutions to maximize total net benefit and minimize total cost. We investigate these algorithms here as a linear crop planning model and use them to acquire the maximum total gross margin according with minimum total working capital in order to satisfy some constraints. We also compare the performance of these two algorithms and analyse the solution from the decision-making point of view.

Keywords: crop planning problem, multi-objective optimization, evolutionary algorithm.

INTRODUCTION

In the present world, the developing countries like Bangladesh, India, Pakistan etc. are over populated countries and lands of those countries are reducing day by day. Those countries have to import their basic foods every year from the rest of the world. Along with various other factors many factors such as unscientific method of cropping, natural calamities, absence of a proper nation-wide cropping program has been identified as a significant factor [1] responsible for low agricultural output. So it is the burning issue to develop a scientific method which can produce more crops using the less land and appropriate crop-mix. So the algorithms for solving crop planning problem are the main things of this paper. Optimization techniques are widely used for solving complex practical problems in resource allocation, transportation and logistics, project selection, planning and scheduling. Optimization problem exists in agricultural system such as crop selection [2], single country wide crop planning [3-4], optimum crop planning in irrigation [5-6], irrigation planning [7], sustainability trade-offs in cropping system [8] and also inland allocation [9]. These optimization problems were formulated in mathematical model and solved by different optimization techniques ranging from single to multi-objective and from linear to non-linear.

Multi-objective optimization techniques are used for multiple objects which maximize some objects while minimize others. In this paper, we solve multi-objective mathematical model using non-dominated sorting genetic algorithm and multi-objective constrained algorithm. Our main intention is to provide better production using less land and cost. Evolutionary algorithms (EAs) have been applied successfully to solve both single and multi-objective optimization problems. We chose EAs because these are a strong contender for problems with non-convex, discontinuous and multimodal functions. We can avoid any simplifications that are necessary for modelling complex problem. EAs are more suitable for multi-objective optimization because of their capability of simultaneous optimization of conflicting objective functions and generation of a number of alternative solutions in a single run.

Multi-objective optimization is a very important research topic in optimization because of multi-criteria nature of most real world decision problems. In this paper, we study the nature of multi-objective solution produced by an evolutionary algorithm and compare them with two conventional multi-objective methods. Non-dominated sorting genetic algorithm is used by solving a simple multi-objective test problem. We use NSGA and MCA for solving multi-objective crop planning problem to observe the behaviour in realistic problem. We resolve the crop planning model using these two algorithms and compare the result.

RELATED WORK

In this era of technology, the Multi objective optimization (MOO) system has been developing for many different purposes in different areas of technology. Multi-objective optimization problem such as multi-objective crop planning problem [1] was solved using linear, constrained and genetic algorithm. Crop planning in single and multi-objective optimization was explained by differential evolution algorithm [2]. Irrigation planning

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was also cracked by genetic algorithm [7]. Multi-objective land-use planning [10] was developed using genetic algorithm. Estimation of optimal crop plan also recognized using nature inspired meta heuristics [11]. A lot of works have been already done for a single object optimization problem. A single objective land allocation model was expressed there by genetic algorithm. Planning and costing agriculture's adaptation to climate change in the salinity-prone cropping system of Bangladesh [12] was solved. Optimization for cash crop planning using genetic algorithm [13] was established. Optimization of the cropping pattern in Saudi Arabia using a mathematical programming sector model (Ahmed M) was exposed. Optimal irrigation crop planning under water scarcity conditions [8] was also resolved. Recently optimization of crop pattern under different field ownerships [6] was solved using genetic algorithm.

A CROP PLANNING PROBLEM

Crop planning is related to many factors such as the type of lands, yield rate, weather conditions, and convenience of the agricultural inputs, crop demand, capital availability and the cost of production. Some of these factors are measurable and can be quantified. However, factors like rainfall, weather condition, flood, cyclone and other natural calamities are difficult to predict [14]. However, if the available information can be utilized properly, it may provide valuable suggestion in spite of the exclusion of non-quantifiable factors. The country like Bangladesh, under consideration, grows a wide variety of crops in different seasons and it has different types of lands. In here, we consider only single, double and triple-types of cropping land for our work. The yield rate, the cost of production and the return from crop are functions of soil characteristics (fertility and other soil factors), region, the crop being produced, cropping pattern and method (crop being produced and their sequence, irrigation, non-irrigation, etc.). For a single-cropped land, there are a number of alternative crops from which the crop that have to be cultivated in a year may be chosen. Similarly there are many different combinations of crops for double-cropped (two crops in a year) and triple-cropped (three crops in a year) lands. Different combinations give different outputs [1]. The utilization of land for appropriate crops is the key issue for the crop-planning problem in this paper. The problem is to provide an annual crop production plan that determines the area to be used for different crops while fulfilling the demand, land, capital, import and region limitations. The crop planning problem looks like a well-structured optimization problem. In the past, this problem was formulated as a single objective linear program and the corresponding model was then solved using a standard optimization solver [3]. The output of such a model would assist to plan annual crop harvesting which would maximize the return from a given area of land. This model can be designed either as a farm level or country wide crop planning [3]. Implementation of the new model for a country wide planning is very tough where the agriculture development agency of the country is interested to see how the current practice differs from the optimal solutions. The agency has influenced over the majority of individual farmers for crop selection as the agency provides loan to the framers, in terms of agricultural inputs and money. Beside the single objective optimal solution, the agency is also interested to see how the gross margin varies with the working capital to be distributed in a given year. In this section, the single objective model has been revised for better understanding and reformulated as a bi-objective model to incorporate working capital as the second objective function.

A CROP PLANNING MODEL

Among single-cropped land, double-cropped land and triple-cropped land we will describe the crop planning model for single-cropped land. The model is described below:

Index:

i) For a crop which can be considered for production

j) A crop combination made up from (i).

k) Land type

Set:

CE set of crops that can be imported

CAL set of crops having area limitation

CIL set of crops having import limitation.

Variables:

X_{ijk} Area of land to be cultivated for crop i of crop combination j in k type land.

I_i Amount of crop i that should be imported Parameters:

n number of alternative crops for single-cropped land

$N1_j$ a crop in each j for single-cropped land, j= 1,…..n.

YR_{ijk} yield rate, which is the amount of production per unit area for crop i of crop combination j in land type k.

CP_{ijk} variable cost required per unit area for crop i of crop combination j in land type k.

P_i market price of crop i per metric ton

B_{ijk} gross margin that is the benefit that can be obtained per unit area of land from crop i of Crop combination j in land type k = (P_i * YR_{ijk} – CP_{ijk}).

IC_i gross margin from import of crop i (=Market revenue-import cost).

D_i yearly demand of crop i

L_k available area of land type k

LT_k land type co-efficient for land type k=1

C_a working capital available, this indicates the total amount of money that can be used for covering variable cost.

A expresses the area suitable and available for crop i when k=1.

IL upper limit of total crop import.

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Objective function 1:

The first objective is to maximize the total gross margin (from cultivated plus imported crops) that can be obtained from cropping in a single crop year. We calculate the maximum total gross margin through Equation. (1) measured by Ruhul A. Sarker [3].

$$\text{Maximize}, Z_1 = \sum_{j=1}^{n} \sum_{i \in N1_j} B_{ij(k=1)} X_{ij(k=1)} + \sum_{i \in CE} IC_i I_i \quad (1)$$

The first term represents the gross margin from single crop land and the second term represents the gross margin from imported crop. Note that there is only one crop for each j in single crop land.

Objective function 2:

The second objective is to minimize the total working capital required. Equation. (2) shows the calculation process of minimizing the total working capital [1].

$$\text{Minimize}, Z_2 = \sum_{j=1}^{n} \sum_{i \in N1_j} CP_{ij(k=1)} X_{ij(k=1)} \quad (2)$$

Constraints:

The optimization method must be fulfilling some constraints. In this method, we use six types of constraints which are described below.

(i) Demand constraint:

The sum of local production and the imported quantity of crop i in a year must be greater than or equal to the total requirements in the country. Therefore, we can mention it as demand constraint [1] and can be measured through Equation. (3).

$$\sum_{i} \sum_{k} YR_{ij(k=1)} X_{ij(k=1)} + I_{i \in CE} \geq D_i \quad \forall i \quad (3)$$

(ii) Land constraint:

The total land used for a given type of land must be less than or equal to the total available land of that type. So land type constraint [1] can be declared as in Equation. (4)

$$\sum_{i} \sum_{j} LK_k X_{ijk} + I_{i \in CE} \leq L_k \quad (4)$$

Here, for k=1, the coefficient (LK_k) is 1.

(iii) Capital constraint:

The total amount of money that can be spent for covering the variable costs in crop production must be less than or equal to the working available capital demonstrated in Equation. (5). Note that minimization of capital requirements is one of our two objectives formulated above. This additional constraint [1] basically sets the upper bound of capital availability.

$$\sum_{j=1}^{n} \sum_{i \in N1_j} CP_{ij(k=1)} X_{ij(k=1)} \leq C_a \quad (5)$$

(iv & v) Area and import bound constraint:

Due to soil characteristics and regional aspects, in some regions, the amount of area to be used for certain crops is restricted. Equation. (6) and (7) are known as area and import bound constraint [3]. For example, the unsuitability of certain lands for fruit cultivation needs to set an area limit for fruits. This is true only for single-cropped land. Similarly, a constraint needs to be set for import restriction as there is an upper limit on the importation of some crops.

$$\text{Area bound} = \sum_{i \in CAL} X_{ijk} \leq A, \quad \forall j = 1, k = 1 \quad (6)$$

$$\text{Import bound} = \sum_{i \in CIL} I_i \leq IL \quad (7)$$

(vi) Non-negativity constraint:

The decision variables must be greater than or equal to zero [3] and can be expressed as Equation. (8) and (9).

$$X_{ijk} \geq 0 \qquad \forall i, j, k \quad (8)$$

and

$$I_i \geq 0 \qquad \forall i \quad (9)$$

SOLUTION APPROACH

In this study, to explain the multi-objective solutions, we have to use two evolutionary multi-objective algorithms. The evolutionary algorithms are: (i) multi-objective constrained algorithm (MCA) and (ii) non-dominated sorting genetic algorithm (NSGA-II). We briefly discuss these two algorithms here and solve the crop planning problem.

Multi-objective constrained algorithm (MCA)

Multi-objective optimization is a very important research topic in optimization and computing disciplines because of the multi-criteria nature of most real-world decision problems. There is no universally accepted definition of 'optimum' in multi-objective problems as in single-objective optimization, which makes it difficult to

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even compare results of one method to another. The aim in a multiple objective optimization problem is to arrive at a set of pare to optimal solutions. The Pare to solution points are also known as non-dominated solutions in the sense that no other points would dominate them.

The pseudo-code of the Multi-objective Constrained Algorithm (MCA) is provided below:

1. t ←0
2. Generate M individuals representing a population: Pop(t) = {$I_1, I_2, \ldots, I_M$} uniformly in the variable space.
3. Evaluate each individual: Compute their objectives and constraints i.e., $f_k(I_i)$ and $c_j(I_i)$; for i=1,2,…,M individuals, k=1,2,….,O objectives and j=1,2,...,Q constraints.
4. Select two parents P_1 and P_2. (The procedure for selection is described below).
5. Create two children C_1 and C_2 via crossover and mutation of P_1 and P_2.
6. Repeat steps (4) and (5) until M children are created.
7. Evaluate M children.
8. Merge M parents and M Children to form a population of size 2M.
9. Rank 2M solutions
10. Retain better performing M solutions from the above 2M solutions.
11. t←t + 1.
12. If t <T_{max} then repeat steps (4) through (10), Else Stop.

T_{max} denotes the maximum number of generations.

Parent selection

The procedure for selecting a parent P_1 is described below and the same applies to selecting P_2.

a. Select two individuals (R_1 and R_2) from the population of M solutions using a uniform random selection.
b. If R_1 is feasible and R_2 is infeasible: R_1 is selected as the parent and vice versa.
c. If both R_1 and R_2 are infeasible: One which has the minimum value of the maximum violated constraint is selected as the parent.
d. If both R_1 and R_2 are feasible and R_1 dominates R_2: R1 is selected as parent and vice versa.
e. If both R_1 and R_2 are feasible and none dominates each other: A random selection is made between R_1 and R_2.

Crossover and mutation

We have used two point cross over and interchange mutation for step 5.

Ranking

The procedure for rank computation is as follows:

a. Separate the set of 2M solutions to a set of feasible and a set of infeasible solutions.
b. Perform a non-dominated sorting to assign ranks to the solutions in the feasible set.
c. Rank the solutions in the infeasible set based on their maximum value of a violated constraint.
d. Update the ranks of the solutions in the infeasible set by adding the rank of the worst feasible solution to each.

Retaining M solutions

The procedure to retain M solutions from a set of 2M solutions is presented below:

a. Rank the set of 2M solutions. (The procedure for ranking is described below).
b. If the number of rank=1 solutions (i.e. non-dominated solutions) is less than or equal to M, select top M solutions based on their rank and copy them to the new population.
c. If the number of rank=1 solutions is more than *M*, follow the following steps:

i. Select the solutions which have a minimum value (assuming minimization in all objectives) in any of the objectives and copy them to the new population.
ii. For every variable, copy two solutions to the new population which has its minimum and the maximum value if they have not been copied yet (including step i).
iii. For the remaining rank=1 solutions, the sequence of who goes in first to the new population is decided as follows:

A. Compute the score by inserting the solution into the new population once at a time. The score is the minimum Euclidean distance computed between the solutions attempting to enter with all other existing solutions in the new population based on the objective function space. Scaled values are used for the score computation i.e. the objective space is scaled using the maximum and minimum values in each dimension based on the set of rank=1 solutions.
B. The solution with the highest score is allowed to go into the new population unless it has been copied earlier in which case the solution with the next score goes in.
C. The steps (1) and (2) are repeated until the new population has a size of M.

Properties

The properties of the algorithm are:

(a) A feasible solution is always preferred over an infeasible solution. This is a commonly adopted practice, although one might argue that it's better to retain a marginally infeasible solution rather than a bad feasible solution.
(b) Step (i) in the above procedure ensures that the endpoints in the objective space are inserted into the new population and the extent of the non-dominated front is preserved.

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(c) Step (ii) is a means to maintain variable diversity i.e. to include a possibility of retaining variable values which might be useful.

Euclidean distance:

Euclidean distance is computed between two individuals with their objectives function through Equation. (10). It is a measure of how close two individuals are. It is measured when two individuals have the same rank. Minimum Euclidean distance with same rank is always preferred.

$$\text{Distance} = \sqrt{(\text{f1} - \text{f2})^2 + (\text{g1} - \text{g2})^2} \quad (10)$$

Where,

f1=objective function 1 for population one. f2=objective function 2 for another population. g1=objective function 1 for population one. g2=objective function 2 for another population.

Non-dominated sorting genetic algorithm (NSGA-II)

The non-dominated sorting genetic algorithm is one of the well-known multi-objective optimization algorithms. The difference between the conventional single objective GA and NSGA-II lies with the assignment of fitness of an individual. There have been several improvements to the original algorithm and the latest form is referred as NSGA-II [15]. The fitness of an individual in NSGA-II is based on the non-domination level of an individual within a population size of M. Selection, recombination, and mutation operators are used to create a child population of size M. Thereafter, the total population (M parents and M children) is sorted according to non-domination. The new parent population is formed by adding solutions from the first front and continuing to other fronts successively till the size exceeds the population size of M. The crowded comparison operator comes into play if the number of solutions at a particular non-domination level exceeds the number that can be accommodated in the new parent population. Diversity is preserved by the use of crowded comparison criterion in the selection and in the phase of population reduction.

The pseudo-code of the non-dominated sorting genetic algorithm (NSGA-II) is given below:

1. $t \leftarrow 0$
2. Generate M individuals representing a population: $Pop(t) = \{I_1, I_2, \ldots, I_M\}$ uniformly in the variable space.
3. Evaluate each individual: Compute their objectives and constraints i.e., $f_k(I_i)$ and $c_j(I_i)$; for i=1,2,…,M individuals,
4. k=1,2,….,O objectives and j=1,2,...,Q constraints.
5. Rank the population.
6. Select two parents P_1 and P_2. (The procedure for selection is described below).
7. Create two children C_1 and C_2 via crossover and mutation of P_1 and P_2.
8. Repeat steps (4) and (5) until M children are created.
9. Evaluate M children.
10. Merge M parents and M Children to form a population of size 2M.
11. Rank 2M solutions
12. Retain better performing M solutions from the above 2M solutions.
13. $t \leftarrow t + 1$.
14. If $t < T_{max}$ then repeat steps (4) through (10), Else Stop.

T_{max} denotes the maximum number of generations.

Ranking M population

After computing objectives and constraints of M population we rank them according to their fitness value. The chromosome of highest fitness value gets the highest rank.

Parent selection

After ranking we select the parent. In this work we use Elitism Selection.

Rank 2M solution

The procedure for rank computation is as follows:

a. Separate 2M solution to a set of feasible and a set of infeasible solution according to their maximum value of violated constraints.
b. Perform a non-dominated sorting with ascending order to assign ranks to the solutions in the feasible and infeasible set.
c. Update the ranks of the solutions in the infeasible set by adding the rank of the worst feasible solution to each.

Retaining M solution

The procedure to retain M solutions from a set of 2M solutions is presented below:

i. Rank 2M solution.
ii. If the number of rank=1 solutions (i.e. non-dominated solutions) is less than or equal to M, select top M solutions based.
iii. On their rank and copy them to the new population.
iv. If the number of rank=1 solutions is more than M, follow the following steps:

a) Select the solution which has the maximum fitness value.
b) If the more solutions have the same rank then compute their crowding distance and take the maximum crowding distance value.
c) If the feasible solutions are less than M solution then take the infeasible solution according to their rank and crowding distance.
d) If the more solutions have the same rank then compute their crowding distance and take the maximum crowding distance value.

Properties

The properties of the algorithm are:

(a) A feasible solution is always preferred over infeasible solution.

(b) The crowding distance does not depend on the violation constraint.

RESULT ANALYSIS

In this paper, we calculate the result of sixteen different types of crop and sixteen combination of each type of crop. In this section we discuss only four types of crop and four combination of each type of crop. We calculate constraints, demand and capital for four types of crop. The total constraints for four types of crop which are used to calculate actual solution are given below:

Table-1. Total constraints data.

Crop Type	Demand D_i (MT)	Land L_k(Hectors)	Capital C_a (TK)
Crop 1	37	12	6000
Crop 2	50	12	3000
Crop 3	80	12	6000
Crop 4	150	12	4000
Total	317	48	19000

Comparison between MCA and NSGA-II

We solve the crop planning problem using MCA and NSGA−II for different types of crop combination and compute their objective function. For solving the problem we need to maximize the total gross margin while minimize the total cost. We solve for crops ranges from 4 to 16. Here is the comparison table for different type of crops with total benefit and total cost in a year.

Table-2. Comparison between MCA and NSGAII.

Number of crop type	MCA		NSGAII	
	Gross Margin Maximize Z_1 (TK)	Working Capital Minimize Z_2 (TK)	Gross Margin Maximize Z_1 (TK)	Working Capital Minimize Z_2 (TK)
4	158600	18800	125000	18500
6	248450	27900	209000	29020
8	323340	36500	262530	39400
10	482380	48250	425360	52130
12	623460	60350	532010	65560
14	783470	77800	678230	79300
16	951250	89500	820150	98520

According to the above Table a bar chart is described below which shows the performance comparison between two algorithms MCA and NSGA−II. The X axis represent the first objective function that is the total gross margin and the Y axis represent the number of crops.

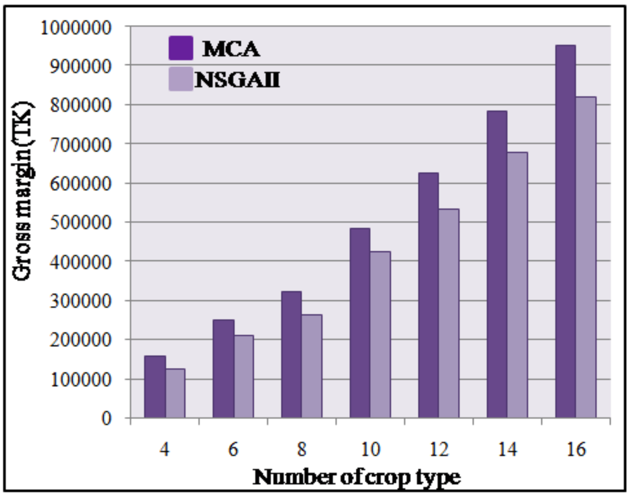

Figure-1. Comparison between MCA and NSGAII with number of crops and total gross margin.

The graph showes that when we increase the number of crops the total gross margin are also increase but the increasing rate for MCA is greater than NSGA-II. According to the table 5.1 a bar chart is described below which shows the performance comparison between two algorithms MCA and NSGA-II. The X axis represent the second objective function that is the total working capital and the Y axis represent the number of crops.

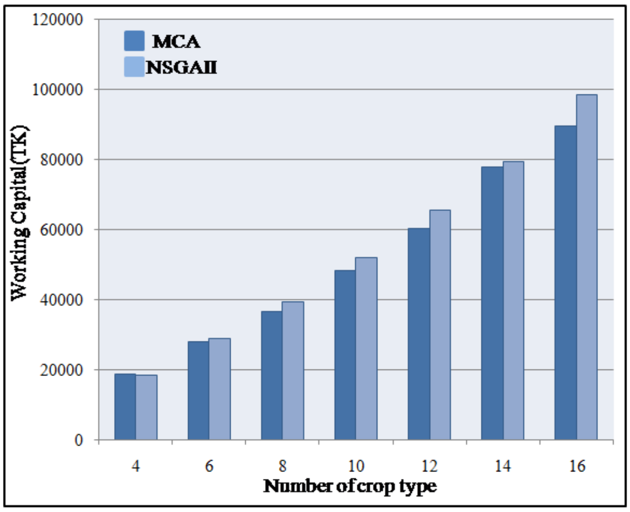

Figure-2. Comparison between MCA and NSGAII with number of crops and total working capital.

From the above chart we see that for small crop type such as four crop types, the working capital for MCA is greater than NSGA-II. When we increase the crop combination the working capital are also increased for NSGA-II rather than MCA.

CONCLUSIONS

In this paper, we study two multi-objective optimization techniques and interpret the solutions of multi-objective optimization model as linear crop planning model. In all our experiments we have used the same random number generator with the same seeds for two multi-objective optimization techniques, MCA and NSGA-II in order to ensure that the initial population is identical. The probability of crossover was set to 0.90 and the number of generations allowed was 1000. We solve the problem for different types of crop range from 4 to 16. We solve the problem only for single cropped land. The key problem of this model was to maximize total gross margin while minimize total working capital and have satisfied some constraints. We solve this problem in C language based platform. The crop planning problem considered in this paper has a single bounded feasible region. The constraints of this instance in the form of 'less than equal to' (≤) and 'greater than equal to' (≥). One might expect locating feasible solutions for these problems are easier as compared to the ones with equality constraints.

In this paper, we compare the performance between MCA and NSGA-II for solving crop planning problem. Although we solve the problem for small number of crop types, in all our experiments NSGA-II struggled to find feasible solutions in too many runs. In our observation we see that NSGA-II is better for small number of crop types and MCA is better for large number of crop types. So, for huge amount of data NSGA-II failed to find feasible solutions but not MCA.

We solve the problem in this paper only for single cropped land, in future we try to solve the problem for double cropped land and triple cropped land. We intend to solve the problem for large amount of data as one of our future research. We will add more constraints and solve the problem using real dataset in real world work.

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REFERENCES

[1] Sarker, R. and Ray, T. 2009. "An improved evolutionary algorithm for solving multi-objective crop planning models". Computers and Electronics in Agriculture, 68(2), 191-199.

[2] Adeyemo, J., Bux, F. and Otieno, F. 2010. "Differential evolution algorithm for crop planning: Single and multi-objective optimization model". International Journal of the Physical Sciences, 5(10), 1592-1599.

[3] Sarker, R. A., Talukdar, S. and Haque, A. A. 1997. "Determination of optimum crop mix for crop cultivation in Bangladesh", Applied Mathematical Modelling, 21(10), 621-632.

[4] Patcharanuntawat, P. 2007. "Optimization for cash crop planning using genetic algorithm: A case study of Upper Mun Basin, Nakhon Ratchasima province (Doctoral dissertation, Mahidol University)".

[5] Millie Pant1, RadhaThangaraj, Deepti Rani, Ajith Abraham, Dinesh Kumar Srivastava. 2010. "Estimation of optimal crop plan using nature inspired metaheuristics", ISSN 1 746-7233, England, UK, World Journal of Modelling and Simulation Vol. 6 (2010) No. 2, pp. 97-109.

[6] Raju, K. S. and Kumar, D. N. 2004. "Irrigation planning using genetic algorithms." Water Resources Management, 18(2), 163-176.

[7] Montazar, A. and Snyder, R. L. 2012. "A multi-attribute preference model for optimal irrigated crop planning under water scarcity conditions". Spanish journal of agricultural research, 10(3), 826-837.

[8] Alabdulkader, A. M., Al-Amoud, A. I. and Awad, F. S. 2012. Optimization of the cropping pattern in Saudi Arabia using a mathematical programming sector model. Agricultural Economics (Zemědělská Ekonomika), 58(2), 56-60.

[9] Deb, K., Pratap, A., Agarwal, S. and Meyarivan, T. A. M. T. 2002. "A fast and elitist multiobjective genetic algorithm: NSGA-II". Evolutionary Computation, IEEE Transactions on, 6(2), 182-197.

[10] Lin, C. H. and Lin, P. L. 2010. "A New Non-dominated Sorting Genetic Algorithm for Multi-Objective Optimization". INTECH Open Access Publisher.

[11] Matthews, K. B. 2001. "Applying genetic algorithms to multi-objective land-use planning (Doctoral dissertation, The Robert Gordon University)".

[12] Ashish Ghosh," Evolutionary Algorithms for Multi-Criterion Optimization: A Survey", International Journal of Computing and Information Science, vol. 2, No. 1, April 2004.

[13] Raquel, C. R. and Naval Jr, P. C. 2005, June. "An effective use of crowding distance in multi-objective particle swarm optimization". In Proceedings of the 7th Annual conference on Genetic and Evolutionary Computation (pp. 257-264). ACM.

[14] Amir, I. and Fisher, F. M. 1999. "Analyzing agricultural demand for water with an optimizing model". Agricultural systems, 61(1), 45-56.

[15] Rio G. L. D'Souza, K. Chandra Sekaran, and A. Kandasamy," Improved NSGA-II Based on a Novel Ranking Scheme", Journal of Computing, Volume 2, Issue 2, February 2010, ISSN 2151-9617.