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Identification of optimal crop plan using nature inspired metaheuristic algorithms

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ABSTRACT

The present study deals with the identification of optimal crop plan to improve the net benefits from the farming activities for the study area under consideration.Three nature inspired metaheuristic techniques namely Differential Evolution (DE), Genetic Algorithm (GA), and Particle Swarm Optimization (PSO) are investigated to identify the most efficient crop plan to maximize the net farm benefits. Different resource constraints considered for the study are maximum available land area, ground water availability and cropped area for different crops. The obtained results are compared with the solutions from LINGO, software for Linear Programming (LP). The results reveal the net benefit per ha derived using DE, PSO, GA and LINGO are 73841.69, 73439.08, 70555.99 and 73841.65 Indian Rupees (INR) respectively for *kharif* crops and 20184.71, 20172.78, 19860.80 and 20184.70 ₹ (INR) respectively for *rabi* crops.

Key words: Crop plan, Differential Evolution (DE), Genetic Algorithm (GA), Linear programming, Metaheuristic, Particle Swarm Optimization (PSO)

Agriculture is an important sector of Indian economy which contributes around 17 to 18% to the country's GDP and it is also known for its largest share in employment generation. To tackle the increasing food demand of the country's rapidly growing population, there is always a need to improve the food production. To increase the production and productivity along with farmer's income, crop planning is required with desirable amount of resources. The central objective of optimal crop planning is to search for an optimal combination of different resources and crops in order to maximize the overall contributions while concurrently satisfying a set of constraints such as availability of land, water and capital etc. Some important works are as follows- crop selection (Brunelli and Von-Lucken 2009), crop planning (Sarker and Quaddus 2002, Sarker and Ray 2009, Adeyemo *et al.* 2010), irrigation planning (Adeyemo and Otieno 2009, Raju *et al.* 2012, Chetty and Adewumi 2014) etc. These models include linear to non-linear forms, where computational intelligence techniques such as evolutionary and nature inspired algorithms have also been explored satisfying the food demand, land availability, capital constraint and other constraints. Sarker *et al.* (1997) presented a linear programming model to determine the area to be used for different crops for maximum contribution. Jain *et al.* (2017) presented a linear programming based framework for developing model for optimum cropping pattern for sustainable land and water use to maximize net income. Jain *et al.* (2018) also reviewed different methods used for crop planning and also suggested some improved techniques for crop planning. Keeping the disadvantages of conventional optimization techniques in mind, currently evolution based meta-heuristic techniques are being used. Recently nature inspired computing techniques such as- Evolutionary Algorithms, Swarm Intelligence have helped in solving complex problems and provide optimum solution. These techniques have been successfully studied and applied extensively in the last three decades in agriculture, engineering and various other fields. Pant *et al.* (2010) investigated performances of evolutionary optimization techniques namely Evolutionary Programming (EP), Genetic algorithm (GA), Particle Swarm Optimization (PSO), and Differential Evolution (DE) to develop optimal crop plans and compare the results with each other and also with LINGO, a popular software used for solving LPP models. Among the class of Differential Evolution (Storn and Price 1997) DE/rand/1/bin is the most successful and widely used strategy. Adeyemo and Otieno (2009) presented the application of differential evolution algorithm to a constrained optimization problem of irrigation water use. Adeyemo *et al.* (2010) studied differential evolution algorithm for single objective optimization to maximize total

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net benefit from farming. Ketsripongsa *et al.* (2018) studied three improved Differential Evolution (DE) Algorithms to maximize the profit from farming activities and compared the results with LINGO.To develop efficient cropping pattern and to maximize the farm benefits, Genetic algorithm (Kuo *et al.*2000, Raju and Kumar 2004, Mansourifar *et al.* 2013, Islam and Talukdar 2014 and Olakulehin and Omidiora 2014) was applied and results are compared with Linear Programming (LP). Bou-Fakhreddine *et al.* (2016) introduced Multi-Crop planning (MCP) optimization model for cropping pattern and water allocation as a nonlinear programming problem using Simulated Annealing (SA) and Particle Swarm Optimization (PSO). Sarma *et al.*(2006) explored Genetic-Algorithms to the non-linear formulation of the optimal cropping pattern problem. Nagesh Kumar *et al.* (2006) compared GA with linear programming (LP) for optimal reservoir operation and concluded that GA yielded results at par with LP in maximizing crop yields. Pramada *et al.* (2017) studied the application of GA for the groundwater management of a coastal aquifer. Shabir and Singla (2016) compared the performance of GA with the PSO. Rath and Swain (2018) investigated optimal cropping pattern using various swarm intelligence techniques like genetic algorithm (GA), particle swarm optimization (PSO) to formulate an efficient cropping pattern for maximizing net returns.

For the present study, three most popular metaheuristic optimization techniques such as GA, PSO, DE are investigated for optimal crop plan. The models have been applied to find the optimal cropping pattern with the objective of maximizing the farm benefits using different constraints such as land area and ground water availability for the area under study. Finally, the results are compared with the output from LINGO, software based on LP models.

MATERIALS AND METHODS

Genetic Algorithm (GA): Prof. John Holland (Holland 1975) was the first to introduce Genetic algorithm which mimics the process of natural selection where the best fitted individuals are selected to produce offspring for the next generations. These offsprings inherit the features of the parents to the next generation and creates better individuals. GA consists of five phases namely- i. initialization of the population, ii. fitness function, iii. selection, iv. cross over and v. mutation.

Genetic algorithm starts with a set of randomly generated individuals or candidate solution called as population. An individual contains several genes which are joined into a string to form a chromosome (solution). The fitness function also helps to identify the best fitted individuals which are ranked from best to worst based on fitness values. Individual with higher selection probabilities are given higher rank than individuals with poor selection probabilities. Selection of the best fitted individuals helps to carry forward the chromosome that holds excellent genetic materials for the next generations. After selection of the parent chromosomes, new offsprings are produced by the merging the genetic materials of the parent chromosomes

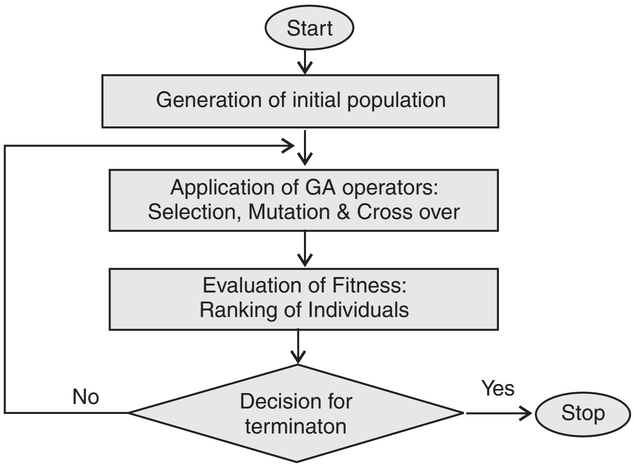

Fig 1 Flowchart of genetic algorithm.

is termed as Cross-over operation. In the next operation, the newly arisen genetic constituents are added into the chromosome is called as mutation. This process is represented in the form of a flowchart in Figure 1.

Differential evolution: Differential evolution algorithm (Storn and Price 1997) optimizes problem by improving the candidate solutions iteratively according to a given measure of quality. For a *d*-dimensional optimization problem, a population of *n* solution vectors or chromosomes or genomes x_i (i = 1,2,...,n) are initially generated. For t^{th} generation, it can be noted as $x_i^t = (x_{1,i}^t, x_{2,i}^t, ..., x_{d,i}^t)$. Differential evolution consists of three steps: mutation, crossover, and selection.

For each generation, three distinct vectors (x_p, x_q and x_r) are chosen at random and adonor vector is generated by mutation scheme- $v_i^{t+1} = x_p^t + F(x_q^t - x_r^t)$; where, F ∈ [0, 2] is a user defined parameter. The crossover rate is controlled by a user defined crossover parameter Cr ∈ [0, 1]. A uniformly distributed random number is generated and cross over operation is given as-

$$x_i^{t+1} = \begin{Bmatrix} u_i^{t+1} & if\ f(u_i^{t+1}) \le f(x_i^t) \\ x_i^t & otherwise. \end{Bmatrix}$$

In the next step, the fittest individual is selected as follows-

$$x_i^{t+1} = \begin{Bmatrix} u_i^{t+1} & if\ f(u_i^{t+1}) \le f(x_i^t) \\ x_i^t & otherwise. \end{Bmatrix}$$

The algorithm is represented in the form of a flowchart given in Fig 2.

Particle Swarm Optimization (PSO): In 1995, Dr Kennedy and Dr Eberhart (Kennedy and Eberhart 1995) developed PSO inspired by the movement of bird flocking or fish schooling. Each single solution is called as "particle". The movement of the particles is determined by two main components: position and velocity. The various steps (Shabir and Singla 2016) are given below-i) Initialize the particles with random velocities and position within the predefined search space. ii) Each particle has a real valued fitness score, i.e. value of objective function. iii) Compare the fitness

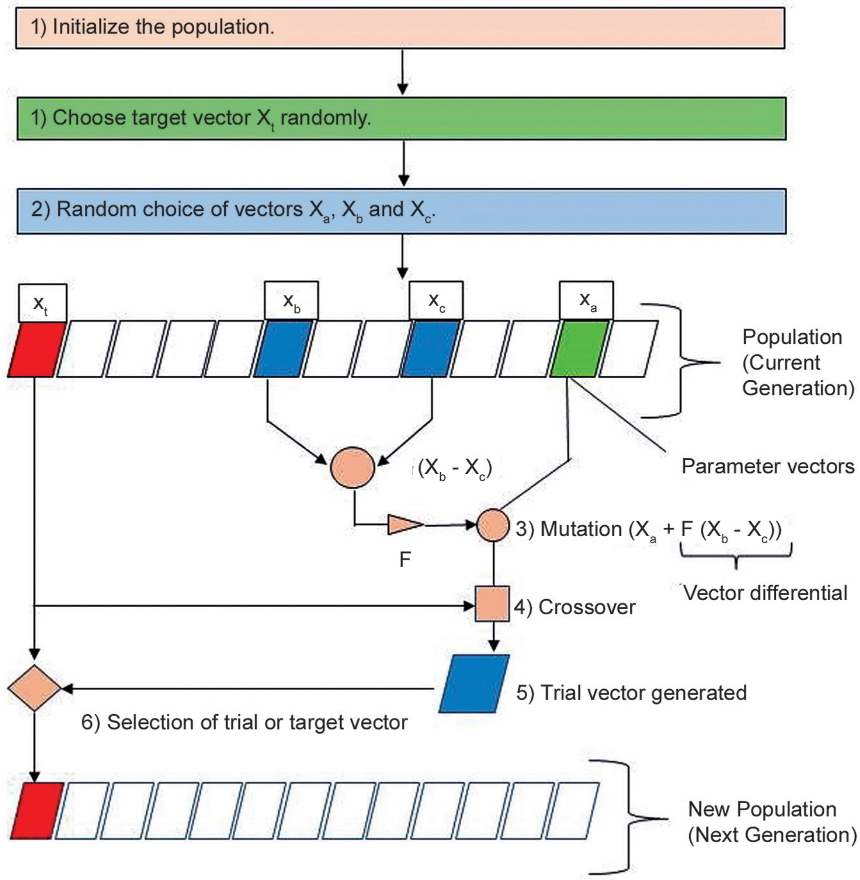

Fig 2 Flowchart of differential evolution algorithm.

value with the current value of particle's p best. Update the current value when it results better than pbest and set it as new pbest value as well as update the current location also and set the pbest location to the current location.iv) Now compare the fitness value with the previous overall best which is called as gbest. Update the current value by gbest if it gives better value than gbest. v) Final step is to assign the best values to their corresponding position and velocity of the swarm particle.This process is represented in the form of a flowchart in Fig 3.

Linear programming: Linear programming is a simple optimization technique to represent complex relationships between variables through linear functions to identify optimum values. Here a brief description of linear programming is depicted:

The general structure of a linear programming model consists of three parts:

A linear function to be maximized or minimized

Maximize or minimize $\sum_{j}^{n} P_j x_j$ (1)

Problem constraints of the following form:

$\sum_{j}^{n} a_{ij} x_j \leq b_i$; $for i = 1,2,3....m$ and $j = 1,2,3...n$ (2)

Non-negative variables $x_j = 0$

The expression (1) being optimized (min and/or max) is called the objective function. x_j are unknown decision variables. a_{ij} and b_i are constants. To solve the problem we need to find unknown vector x_j that optimizes the objective function and also satisfies the equality or inequality constraints. For the current study we have used LINGO software for linear programming formulation.

Data description: The study is primarily based on data collected from the "Comprehensive Scheme for Studying the Cost of Cultivation (CoC) of Principal Crops", Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. Under this scheme, data were gathered from a sample of 300 farm households in 30 tehsils spread across three agro-climatic zones of Punjab for the block year ending 2013-14. The other secondary data sources were used, viz. Central Ground Water Board (CGWB), Ministry of Water Resources; Statistical abstracts of Punjab, various issues.

Model formulation: A linear programming based optimization model is used for the study. The model maximizes net benefit from crops production and yields the optimal crop plan. Crop planning model for two seasons, i.e. *rabi* and *kharif* has been formulated in the study.

Objective function: The mathematical representation of the objective function is given by:

$$MAX\ Z = \sum_{i}^{n} [(Y_i * P_i * A_i) - (C_i * A_i)] \quad (3)$$

Notations:

i = 1, 2 … n; n = Number of crops considered in the study area; n= 6 (for *kharif* season) and n=7 (for *rabi*

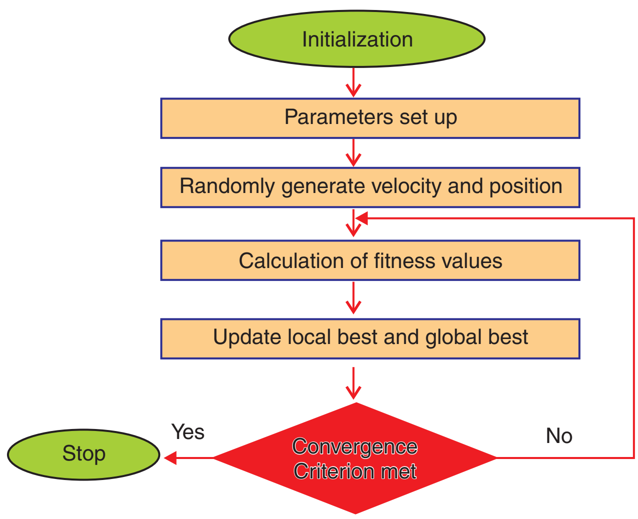

Fig 3 Basic framework of PSO algorithm.

season); Z = Net profit; y_i = Yield of ith crop per unit area; p_i = price of each crop in the market (both main product and by-products) (₹/kg); C_i = (cost of seed)$_i$ + (cost of labour)$_i$ + (cost of machines)$_i$ + (cost of animal labour)i + (cost of fertilizers and manures)$_i$ + (miscellaneous costs)$_i$; A_i = Area under ith crop.

Constraints: The objective function is bounded by a set of constraints, regarding water limitations and total land area.

(a) Water availability constraints: $\sum (W_{ri} * A_i) \leq W_t$ (4)

where, W_{ri} = Water requirement for each Crop (m^3); W_t = Total available water.

b. Constraint regarding total available area for cultivation:

$$\sum A_i \leq A_t \quad (5)$$

where, A_t = Total available area for cultivation.

c. Non negative constraints: $A_t \geq 0$ (6)

d. Min-max area constraints: $L_{bi} \leq A_i \leq U_{bi}$ (7)

where, L_{bi} = Lower bound of area for each crop, L_{bi} = Upper bound of area for each crop.

In the above model, Equation (3) represents the objective function to maximize the net returns from crops and yields optimal crop plan. Equations (4) to (7) represent constraints. Ground water availability constraints which should be less than or equal to the total ground water available is given by Equation (4) and land availability constraints which should be less than or equal to the total area available are given by Equation (5). Index i represents various crops namely: Paddy (basmati and non-basmati), Maize, Sugarcane, Cotton and Guar for *kharif* season and Wheat, Potato, Pea, Mustard, Maize, Sunflower and Barley for *rabi* season. A minimum crop area constraint has been specified on each crop so that area occupied by crops does not fall below a minimum threshold value.

Experimental settings: Selection of parameter value is foremost important task to study nature inspired optimization technique. In the present investigation, the experimental settings are done by hit and trial method and the settings which gave best result are presented in Table 1. Carlisle and Dozier (2000) studied different parameter settings for PSO and more efficient and stable values are used for the study. Maximum number of generations for all the algorithms was set at 500.

Table 1 Experimental settings for GA, DE and PSO

GA settings		DE settings		PSO settings	
Population size	70	Population size	70	Population size	70
Encoding	Real	Crossover constant (CR)	0.5	Inertia weight (w)	0.729
Crossover rate	0.5	Scaling factor (F)	0.85	Acceleration constants C_1 and C_2	2.041 and 0.948

Table 2 Result obtained for *kharif* crops

Crop	Allocated area ('000 ha)			
	DE	PSO	GA	LINGO
Paddy (basmati)	1074.99	1075.00	1054.43	1075.00
Paddy (non- basmati)	3039.99	3039.09	2962.95	3040.00
Maize	217.59	217.60	214.27	217.60
Sugarcane	112.00	112.00	110.73	112.00
Cotton	579.6	550.78	454.99	579.60
Guar	14.99	14.90	10.97	15.00
Profit (₹/ha)	73841.69	73439.08	70555.99	73841.65

Table 3 Result obtained for *rabi* crops

Crop	Allocated area ('000 ha)			
	DE	PSO	GA	LINGO
Wheat	4099.90	4100.00	4055.23	4100.00
Potato	111.03	111.04	109.10	111.00
Pea	7.99	2.60	5.36	8.00
Mustard	49.59	49.60	37.44	49.60
Maize	239.99	240.00	227.44	240.00
Sunflower	31.99	32.00	23.12	32.00
Barley	20.79	20.80	12.37	20.80
Profit (₹/ha)	20184.71	20172.78	19860.80	20184.70

RESULTS AND DISCUSSION

In this section, a comparative study between DE, GA, PSO and LINGO has been carried out. Result shows the areas allocated (Thousand ha) to *kharif* and *rabi* crops which are presented in Table 2 and Table 3 respectively. DE presents net benefit of ₹ 73841.69 and ₹ 20184.71 for *kharif* and *rabi* crops respectively, which is almost similar to the result given by LINGO module which resulted net benefit of ₹ 73841.65 and ₹ 20184.70 for *kharif* and *rabi* crops respectively. Following above mentioned parameter settings, PSO provides net benefit of Rs 73439.08 and Rs 20172.78 for *kharif* and *rabi* crops respectively. Surprisingly GA did not provide very good results as compared to other algorithms for the present study, where GA shows the net benefit of Rs 70555.99 and Rs 19860.80 for *kharif* and *rabi* crops respectively. Graphical representation of objective function values for *kharif* and *rabi* crops are given in Fig 4(a) and Fig 4(b) respectively. Distribution of crops with respect to the areas for *kharif* and *rabi* crops are also presented in Fig 5 respectively. It is found that other than GA, DE and PSO performed either better or almost equally with the LINGO module.

Conclusion

The present article consists of development of an optimal crop plan model based on cost of cultivation data collected from Punjab, India. The mathematical models presented in the current study are linear in nature subject to various

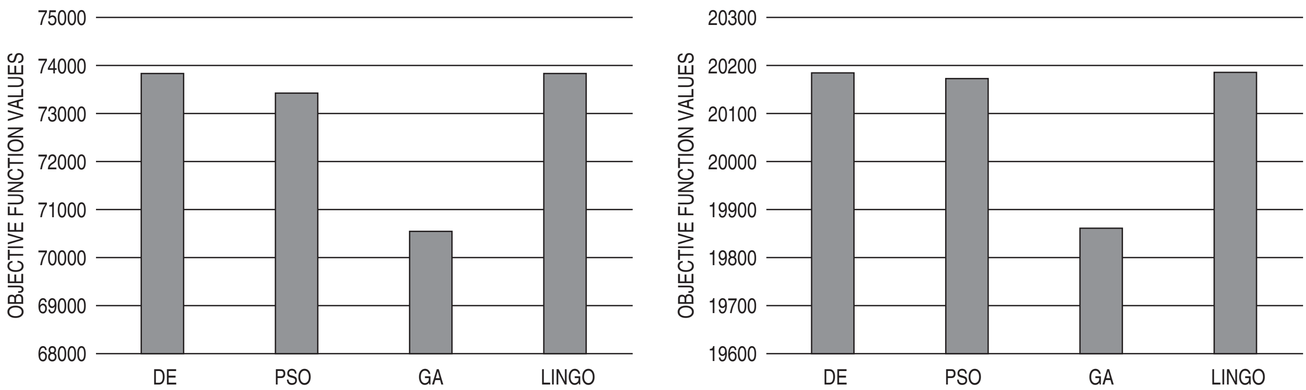

Fig 4 Objective function values obtained by DE, PSO, GA and LINGO for *kharif* and *rabi* crops respectively.

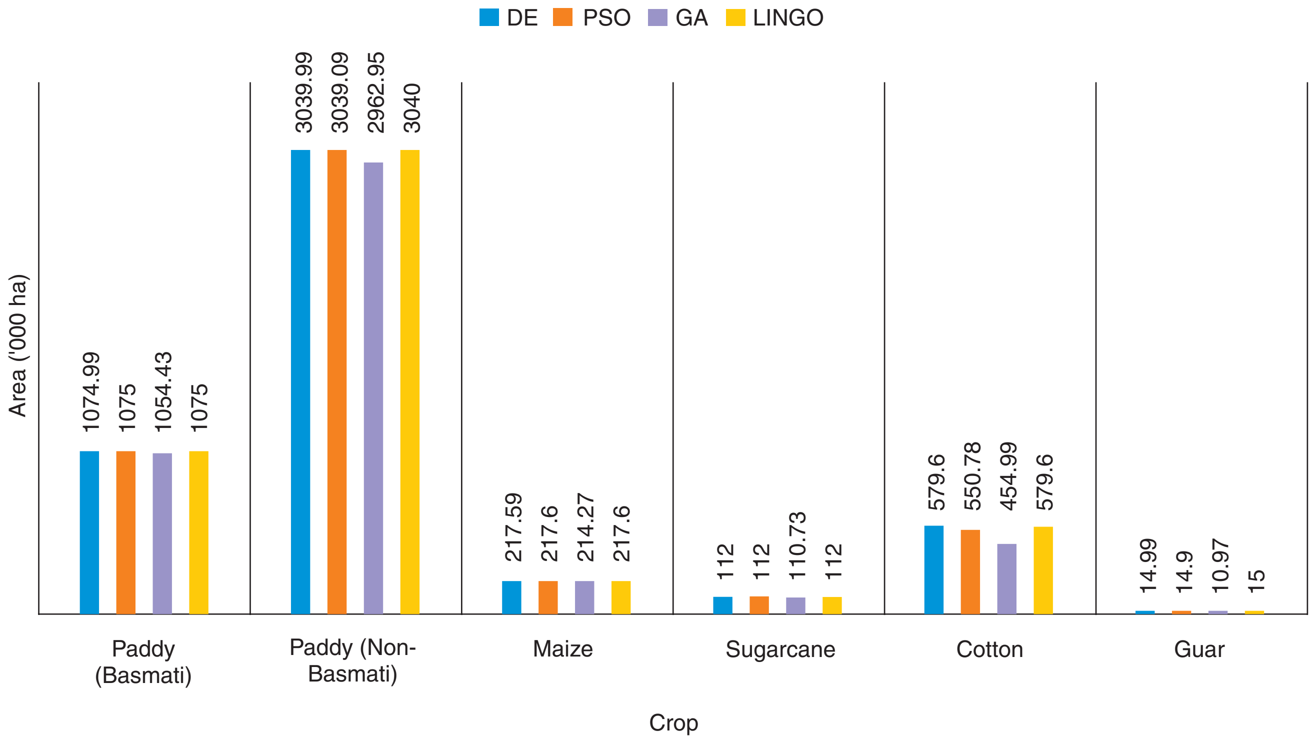

Fig 5 Distributions of *kharif* crops with respect to the area obtained by DE, PSO, GA and LINGO.

constraints. For the present study, we have used three popular optimization techniques namely Differential Evolution, Genetic algorithm and Particle Swarm Optimization and compared their performances with LINGO, software used for solving LPP models and also with each other. Here, it is seen that PSO and DE performed equivalently or better in contrast to LINGO. Whereas, GA, which has been most frequently encouraged for solving such types of problems didn't give pleasing results in comparison to LINGO and other nature inspired optimization techniques used in the study. However we are making further research on the enactment of Genetic Algorithm on this kind of problems. Among the remaining techniques, i.e. DE and PSO none of the algorithm can be called a clear winner, but considering the consistency of performance we may say that DE gave slightly better results under the given parameter settings in case of both *kharif* and *rabi* season crops. Such nature of studies are very advantageous for agriculture dependent country like India and can be protracted further for resolving more complex problems.

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