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Forecasting the optimal yielding period and profitability of maize cropping system using genetic algorithm

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ABSTRACT

Due to green revolution, many researches have been carried out in the field of agriculture to forecast the optimal crop that will yield maximum profitability. The profitability can be improved by controlling the predictable and unpredictable variables involved in yielding. As many strategies are available to control the predictable variables, a need arises to forecast the unpredictable variables. In this research, the unpredictable variables have been successfully forecasted for cropping productivity using genetic algorithm. The major variables considered for maize cropping system in this research are rainfall, temperature and irrigation. The details of the rainfall, temperature and irrigation for twelve months and for eight years have been collected and given as input to the Minitab software to generate the mathematical equation. This mathematical equation has been used as the fitness function equation for genetic algorithm. Thus the genetic algorithm can generate the best optimal yielding period for maize crop cultivation and also it can be used to forecast the best optimal combination of variables that can yield best productivity. This model has helped farmers to make efficient resource allocation decisions with the aim of forecasting productivity and profitability of maize cropping system.

Keywords: Forecasting; Maize cropping system; Genetic Algorithm;

INTRODUCTION

Cropping system is a part of agricultural system which is an assemblage of components united by some form of interdependence and which operates within a prescribed boundary to achieve a profitable productivity. Specified agricultural objectives have to be adopted for the different cropping systems to maximize net income/profitability, productivity, stability, diversity, flexibility, and time-dispersion. To achieve these benefits, the parameters which have been related to the cropping system such as irrigation, rainfall, temperature, fertility of land, monsoon behaviour, rainfall, irrigation, application of fertilizers, climatic conditions, marketing facilities, prices, availability of agricultural labourers, etc need to be controlled. Currently in most of the developing countries, the control have been done only through experimentation, field research or on-farm trials. This methodologies might not be suitable for all conditions, as the methodologies depends on several parameters such as experience, territory, type of crop, type of land, type of irrigation, etc. So, these methodologies have several shortcomings and cannot be adopted universally.

Later researchers found that the mathematical relations have to be formed using mathematical models to control these parameters. In many engineering applications, it has been proved that the mathematical models can provide better results and it can be the best alternative to experimentation / observation of a real system. In India, these mathematical models have not been used on large scale cropping systems as a tool to predict and forecast the profitability in the cropping system.

Because the mathematical models can be used as the decision making tools, only if it have been provided with the insight input data. In the light of the above, it will be difficult to provide the exact data such as rainfall, temperature, etc to the mathematical models. In this type of situations, the mathematical models fail to produce better results. This issue has been addressed by many researchers for many engineering applications and found that the evolutionary and intelligent algorithms can be used to produce better results with the unpredictable input parameters. Evolutionary algorithms are now became a valuable tool for representing the unpredictable problems and in this research, genetic algorithm has been used to predict long-term productive and environmental effects of different cropping systems.

In this research, the data related to rainfall, irrigation availability and temperature had been collected for eight years in the town Karur, southern region of Tamilnadu, India. These data have been given as input to the developed genetic algorithm module. The module gives the best period for the maize crop cultivation and also the best parameter required for better yield for the required period. Thus the farmers can cultivate the maize with maximum profit.

2 LITERATURE SURVEY

Jehle et al. [9] denoted that the main objective of the cropping system is to maximize the output, so as to reap more profits. Such behaviour can be modelled using a profit function approach, production function approach, cost function approach, mathematical optimization and dynamic programming. Stokle et al [15] noted that simulation models can underestimate the yield of maize by up to 27 %, without necessarily undermining reasonability of estimates obtained. Jha et al [10] considered the climate changes on the river basin and discussed the impacts of the climatic changes on crops. Di Luzio et al [3] considered the temperature dataset for his analysis. Similarly the temperature dataset had been developed in this work. Zhang [16] developed an approach to solve the un-certainty using genetic algorithm and Bayesian model. He proved that the genetic algorithm produces comparable results. So in this work, genetic algorithm has been used. Cantelaube and Terres [2] developed a model to predict the changes in the seasons and proved that he seasonal forecasting will yield more profit for crops. Alva et al [1] developed a model for potato crop yielding system and predicated the optimal parameters that yield maximum potato cultivation. Dillion [4, 5] developed a management strategy for the small scale farmers to yield maximum profit and analysed the various factors which affects the profits. Giardini et al [7] developed a mathematical model to simulate two Cropping Systems. The models used for the profit maximization are EPIC and CropSyst Models. Grabisch [8] introduced a model based on the probability approach for crop cultivation. Fleisher [6] discussed the various factors and the parameters which influences the agriculture. Jehle and Reny [9] developed the economic theory for agriculture management and resource management. Kelton [11] simulated a model for agriculture management. Kothari [12] developed the model for simulating the profit using quantitative approach for agriculture. Lordanova [13] introduced the concept of Monte Carlo model for agriculture profitability. Staggenborg and Vanderlip [14] developed the simulation model and proved that the simulation models can be best suited for predicting the profits for cropping systems. Stockle [15] developed the mathematical model for cropping system and proved that the model in line with the real data.

From the literature it is clear that the researchers are taking different parameters for produce better yield in crops. So in this work, rainfall, temperature and the irrigation had been taken for crop yield maximization.

3. Mathematical Modelling & Implementation

In India, maize farmers are commercial and therefore driven by the profit motive. Therefore, a necessity arises in developing a mathematical model that leads to profit is more appropriate. Some of the commonly used tools used by the researchers are mathematical optimization, dynamic programming, simulation analysis, intelligent methods, etc.

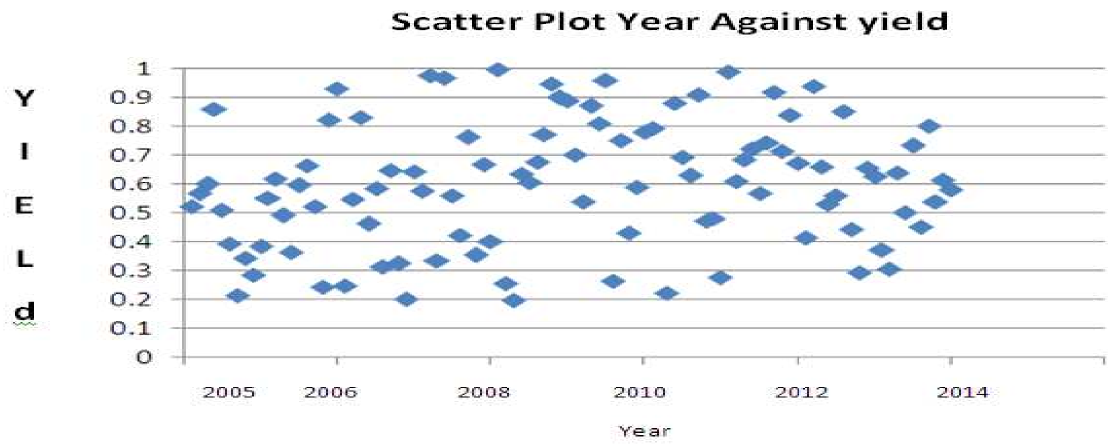

Figure 1: Minitab Scatter Data Plot

Most of these models do not predict how much of each variable input should be used to achieve optimal output and deficient in their ability to capture various dynamically changing variables. So in this research, genetic algorithm has been used to forecast and optimize the maize crop cultivation. The data for past eight year has been collected and given into Minitab software to generate a mathematical equation. The scatter data obtained from the software is given in the Figure 1. The mathematical equation has been formed and that equation has been used as the fitness function for the genetic algorithm module. The concept of genetic algorithm was introduced by John Holland in 1970. They have been widely studied and applied to optimize the non-linear functions bounded with constraints. The various stages of the genetic algorithm module are explained in the following sections.

3.1 Parent Generation

The first stage in the genetic algorithm is the initial population generation. In this research work, decimal encoding is used. The parent size has to be set as 12, as the three variables have been considered in this work. The number of parents has been set to 100 by doing sensitivity analysis. In most of the practical cases, the variables cannot be predicted in advance. So in this work, smart operator had developed to fix the values for the variables based on the available data. The sample generated parent is given in the figure 2.

Parent 1: 010028010105
Parent 2: 050031010208
Parent 3: 425049000306
Parent 4: 350045000412

Figure 2: A Sample Set of Generated Parent

3.2 Encoding

Encoding is the process of converting the user defined data into genetic understandable data. From the figure 2, the first three digits represents the average rainfall in millimetres, the next three digit represents temperature, the nest two digit represents irrigation facility and the last four digit represents the month and year of the data collected. The next stage is the crossover to inherit the best properties.

3.3 Crossover

The significant properties relevant to the problem are transferred from a set of parent to the child by means of crossover operation. Thereby the crossover operation identifies the better solution from the larger search space and in every generation it converges towards the better solution by inheriting the best properties from the best parents. The parents for the crossover were generated using random function. The developed smart operator also used to set the number of crossover sites and is given in the equation 1.

$$Cs = P_s/X \qquad (1)$$

Whereas Cs = number of crossover sites,

Ps = Number of strings in a parent

$$X = \begin{cases} Ps/3, \text{ if } 1 \leq N \leq (N/3) \\ Ps/2, \text{ if } (N/3) \leq N \leq (2N/3) \\ Ps/1, \text{ if } (2N/3) \leq N \end{cases}$$

Once the number of crossover sites has been decided by the smart operator, the crossover points have been generated randomly. Thus the number of crossover sites will be higher at the start of the generation to increase the search space and thereby identifying the best solution. As the number of generation increases, the problem converges towards the optimal solution and the lower crossover sites preserve the optimal convergence deviation from its path is the special feature of the smart operator. The sample crossover operation is shown in the figure 3. The next stage after the crossover operation is mutation.

Parent 1: 010028010105
Parent 2: 050031010205
N = 01; Ps = 12; Cs = 1;
Offspring 1: **050**028010105
Offspring 2: 010**031010205**

Figure 3: A Sample Crossover Operation

3.4 Mutation

Mutation is the process of swapping the random gene at random location to avoid stagnation at a point in the solution space. The number of mutation points has been decided by the smart operator and is given in the equation 2.

$$Ms = (Cs * X)/100 \qquad (2)$$

The mutation site and the mutant string have to be selected at random. A sample mutation operation is shown in the figure 4.

Offspring 1: 050028010105
Ms = 1; Mp = 12; Mt = 1
Offspring 1: **060**028010105

Figure 4: A Sample Mutation Operation

3.5 Fitness Function

Fitness function is used to identify the best parent from the available solution. The fitness function for the cropping problem is based on the yield and in-turn profit. The three parameters considered for this cropping problem should not be the maximum and should not be the minimum, so there a trade off exist among them. Thus Minitab software has been used to generate the non-linear function based on the pervious history of data. Some of the conditions considered while framing the fitness function are as follows.

1. Temperature should not be too high and should not be too low.
2. Irrigation need not be necessary, if the rainfall is regular and high enough.
3. Rainfall should be moderate and not too heavy, minimum rainfall should be required for the better irrigation facility.

3.6 Termination conditions

As there are various termination conditions available for terminating the genetic operations, but as this research used smart operators, the termination condition used are given as follows.

1. If 100 iterations reached.
2. If the Xij =1 for i, j = 1 to n.
3. If $V_g = V_{(g+5)}$

4 Experimental Implementation

The study area was Karur which is located in the Namakkal district, Tamilnadu, southern region of India. The data collected were categorized as primary and secondary data. Primary data are the maize output, prices, input cost, annual rainfall, irrigation and temperature for the district. Secondary data are the irrigation facilities, yielding season, market demand, water resources, fertilizers, distribution centres, etc. A survey of 30 maize farmers were done to reduce the errors in the information obtained. Average of the 20 maize farmers data have been taken for the analysis and 10 contradictory data have been left out. Lists of questionnaires were prepared, pre-tested, refined before interviews were held for the selected maize farmers. Maize growth output in the cropping system is a result of interactions between key variables in the cropping system.

In the developed genetic algorithm model, inputs (X_1, X_2 ------- X_n) used were the rainfall, irrigation and temperature. The yield function is the maximization function used as the fitness function. The model was then run to produce results (Yi) in the form of maximum yield and in-turn maximum profit. The genetic steps were re-run for 100 times to achieve high degree of accuracy.

Results of simulated yield show that the highest yield of maize averaging at 57 bags/hector and the lowest yield with only 18 bags/hector which are in line with actual yields reported in the zones considered in the research. The average district simulated yield was estimated at 35 bags/hector, which is also consistent with the actual district average. Comparison between actual and simulated maize yields revealed that simulated values are in line with the actual values and therefore they can be used for planning and decision making.

The best temperature	: 32'C
The best rainfall	: 50-75 cms
The Best irrigation	: Available
Best Month	: October 2014
Month-wise Analysis	
Jan 2014	: Not Suitable
Feb 2014	: Best Suited
March 2014	: Satisfactory with High irrigation
April 2014	: Not recommended
May 2014	: Not Recommended
June 2014	: Satisfactory with/without irrigation facilities
July 2014	: Best Suited
August 2014	: Not recommended
September 2014	: Satisfactory if night temp. is minimum of 21'C
October 2014	: Best Suited
November 2014	: Satisfactory if night temp. is minimum of 21'C
December 2014	: Not recommended

Optimal set of parameters			Best Set of Parameters			Worst Set of Parameters		
Rainfall	Max. Temp.	Irrigation	Rainfall	Max. Temp.	Irrigation	Rainfall	Max. Temp.	Irrigation
395	48	NA	410	48	A	15	29	NA
190	38	A	420	49	A	35	28	NA
405	48	NA	430	49	A	25	31	NA
200	38	A	440	50	A	45	30	NA
415	49	NA	450	50	A	55	32	NA
210	39	A	460	51	A	65	32	NA
425	49	NA	470	51	A	75	32	NA
220	39	A	480	52	A	85	33	NA
435	50	NA	490	52	A	95	33	NA
230	40	A	500	53	A	105	34	NA

Figure 5: GA Module Output

Thus this model helps the farmers to predict the suitable period for maize cultivation which can yield profitability. The model also forecast the parameters in the future, so the cultivation decisions can be taken by the farmers. The model also suggest the farmers how to control the parameters along with the seeding period. It also identifies the optimal set of parameters which gives maximum yield based on the past history. With this model the farmers can take the decision to maximize their profit. The sample output module is given in the Figure 5.

CONCLUSION

It is concluded that the forecasted result obtained from the developed genetic module for maize yield have been in line with the actual data. Thus the developed module has been validated. The developed module is efficient and consistent forecasters of productivity and profitability in cropping systems. It will help the farmers to take wise decision in yielding, to get maximum profitability.

It is also recommended that the various crops have to be considered for that place to improve farmer's access to information on alternative crops and their risks, uncertainties associated with cropping system. Further research is also required to test the models under different locations, soil types, management styles and scales of production.

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