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Genetic algorithm-based optimization for enhancing crop yield and resource efficiency in agriculture

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Abstract

Maximization of crop yield with minimization of resource inputs is one of major problem faced by different agricultural practices. Global food security depends on achieving sustainable crop yield and resource efficiency in agriculture. Promising approach to handle these optimization problems is offered by Genetic Algorithms that is based on iteratively evolving solutions based on natural selection and genetic inheritance principles. This paper presents the application of Genetic Algorithm in optimizations of agricultural practices, with a special focus on increasing crop yield and resource efficiency. The findings of this paper highlight essential role Genetic Algorithms plays in promoting sustainable practices, revolutionizing agricultural decision-making, and granting robustness in the face of evolving environmental challenges and economic pressures.

Subject Classification: *Primary 68W40, Secondary 68W50.*

Keywords: *Genetic algorithm (GA), Optimization, Sustainability, Resource efficiency, Optimal solution.*

1. Introduction

Significant challenges are there in order to meet the escalating demand for food in a sustainable manner that is further intensified by global warming, resource depletion, and environmental degradation. Agriculture forms the backbone of global food security as it plays an important role in providing nourishment for a growing population that is

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expected to exceeds nine billion by 2050 [1]. Traditional agricultural practices that are dependent on empirical knowledge and historical practices are insufficient and inadequate in addressing these different new types of challenges [2].

Management of different resources such as nutrients, water and pesticides are essential for enhancing crop yield and ensuring long-term agricultural sustainability. Optimization of agricultural productivity with minimizing resource use and environmental impact has emerged as a critical necessity for managing sustainable issues [3]. Risk associated with climate change and soil degradation can be decreased by applications of these algorithms for optimizing agronomic practices associated with local soil and climatic circumstances [4].

In the case of agriculture, the Genetic Algorithm can assure optimization in allocation of resources, including nutrients and water, while adapting to unstable environmental conditions and minimization of resource wastage [5]. Biological evolution processes simulation forms the base of these Genetic Algorithms, where potential solutions known as individuals are represented as chromosomes that are further composed of gene variables. In order to achieve improved suitability towards defined objectives these obtained solutions go through a process of selection, crossover also known as recombination and mutation over successive iterations. These algorithms are dynamic and hence they can also adapt to varying conditions and constraints which makes them suitable for agricultural environments where factors such as weather, soil conditions, and pest pressures are constantly evolving and varying [6]. Multiple objectives and constraints can be handled by these algorithms simultaneously, allowing for the optimization of multi agricultural parameters such as nutrient levels, irrigation schedules, and pesticide application frequency [7].

The objective of this paper is to explore and demonstrate the application of Genetic Algorithm in enhancing crop yield and resource efficiency in agriculture. Focus is on integrating Genetic Algorithms into agricultural decision support systems to optimize the management of essential agronomic parameters like nitrogen (N), potassium (K), phosphorus (P), temperature, ph, humidity, and rainfall. These variables play critical roles in determining crop growth, nutrient uptake, and susceptibility to environmental stressors. The comparison between the results obtained using a standard approach without optimization and those achieved after applying a Genetic Algorithm optimization is presented in this work to indicate the importance of Genetic Algorithms.

2. Literature review

A growing body of literature demonstrates the efficiency of Genetic Algorithms in optimizing various aspects of agricultural systems. Genetic Algorithm supported deep learning solution methods are proposed for forecasting crop yield which surpasses the gradient-based approaches for convergence and prediction accuracy [8]. The prospective for predicting crop yield depends on different parameters like climate, water factors and soil characteristics has emerged as important research area as advancement of technology resulted in advancement of agriculture [9]. A Genetic Algorithm can also be applied successfully for maintaining stratification that will help in predicting required Nitrogen [10]. Genetic Algorithm can also be combined with various other methods and technique to derive optimal solution [11].

The Genetic Algorithm can also generate economic benefits and lower transportation losses incurred by trade distribution centers for distributing agriculture products [12]. These algorithms are very efficient for optimizing the integrated problem in manufacturing process [13]. They can also be used for the single machine scheduling problem. Improvement is also suggested on the crossover operation for the problem [14]. Genetic Algorithms are used for larger multi-objective optimization model that can take into account different factors like time, profit, quality and resources with various weights assigned for each factor to reach to a near-optimum answers as per users' significance [15].

A multi-objectives optimization model for project scheduling is established with a new evolutionary strategy to optimize the most important decisions that affect any specified project [16]. Genetic Algorithms are also used for maintenance and project scheduling [17]. Optimization of irrigation scheduling using soil water with the help of genetic algorithms leads to cost saving [18]. Use of Genetic Algorithms in optimization process of Irrigation Pumping Stations resulted in minimization of the total annual cost, consists of maintenance and operation costs alongside depreciation cost of the primary investment [19]. Genetic Algorithms are also used in managing different environment constraints [20].

Despite significant advancements in the application of Genetic Algorithms for agricultural optimization, several gaps remain in the available information. While Genetic Algorithms have been successfully applied to optimize various agricultural parameters, their integration with real-time data remains limited. The large-scale implementation of these algorithm is still not there. There is also need for more comprehensive multi-objective optimization frameworks. The scalability of Genetic Algorithms to large-scale agricultural problems remains a challenge. Climate change introduces new challenges for agricultural optimization. Agricultural optimization is inherently interdisciplinary, involving agronomy, soil science, hydrology, ecology, economics, and social sciences so different disciplines need to be considered.

The Agriculture Recommendation Dataset from Kaggle is chosen for work done in this paper. It offers a valuable resource for developing and testing GA-based optimization models. This dataset consists of critical features such as soil nutrients (N, P, K), temperature, humidity, pH, and rainfall, along with crop labels, providing a comprehensive basis for optimization studies [21]. This paper will show that Genetic Algorithm model optimizes the values of nutrients and environmental variables, resulting in significantly improved objective metrics. This demonstrates the effectiveness of GA in enhancing crop yield and resource efficiency.

3. Work Done

The optimization process focused on several key variables that are applicable to agriculture including Nitrogen (N), Potassium (K), Phosphorus (P), Humidity, Temperature, Ph, Rainfall.

Formation of an objective metric that suggests the overall efficiency and throughput of the agricultural system is the first goal. The objective metric formed is a function of the key variables, which needs to be optimized. The objective metric shown below is taken as a ratio of the sum of soil nutrients to the sum of environmental factors. This metric can be represented mathematically as:

$$Objective\ Metric = \frac{N+P+K}{Temperature+Humidity+pH+Rainfall}$$

This formula represents

The numerator consists of the total amount of key soil nutrients (N, P, K). The denominator is the combined effect of environmental factors (Temperature, Humidity, pH, Rainfall).

The objective metric above clearly represents balance between various input nutrients and the environmental factors. Higher values of this metric indicate better efficiency and potential crop yield.

The initial values for these variables were found based on the calculations of mean or average values from the dataset. These values indicated typical conditions or practices before application of any specific optimization strategy is applied. Before optimization, the values for Nitrogen, Phosphorus, and Potassium were relatively lower as compared to the optimized values found later as found during initial calculation.

Using a Genetic Algorithm the values of these variables were optimized to maximize a specific objective function. In this case, the objective function was designed to maximize a metric related to crop yield and resource efficiency. As for example after optimization, significant increases were observed in the values of Nitrogen, Phosphorus, and Potassium, indicating that the Genetic Algorithm found solutions that could potentially enhance crop yield.

Before Optimization, the initial objective metric related to crop yield or resource efficiency was calculated based on the initial variable values. It provided a baseline or starting point for comparison as shown in figure 1.

After Optimization, the optimized objective metric was calculated using the values obtained after applying the Genetic Algorithm. This metric should ideally be higher than the initial metric, indicating an improvement in crop yield or resource efficiency.

The optimized values of Nitrogen, Phosphorus, Potassium, and other variables are crucial as they represent the recommended levels or configurations that the Genetic Algorithm determined as optimal for maximizing the objective metric.

After optimization, the values of Nitrogen, Phosphorus, and Potassium increased, suggesting that the crops are now potentially receiving more optimal nutrients to support growth and yield as shown in comparison of figure 2.

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Sample of Agriculture Recommendation Data:
    N   P   K  temperature   humidity        ph    rainfall label
0  90  42  43    20.879744  82.002744  6.502985  202.935536  rice
1  85  58  41    21.770462  80.319644  7.038096  226.655537  rice
2  60  55  44    23.004459  82.320763  7.840207  263.964248  rice
3  74  35  40    26.491096  80.158363  6.980401  242.864034  rice
4  78  42  42    20.130175  81.604873  7.628473  262.717340  rice

Objective Metric Before Optimization:
Initial Variables: [50.551818181818184, 53.36272727272727, 48.14909090909091, 25.616243851779544, 71.48177921778637, 6.469480065256364, 103.46365541576817]
Initial Objective Metric: 0.7344963793287079 (maximized)
 The best solution found:
 [139.99982297 144.99747476 204.98840194   8.82608504  14.26128466
   3.50481596  20.21248064]

 Objective function:
 -10.468736095624696
```

Figure 1

Showing sample data and metric before optimization

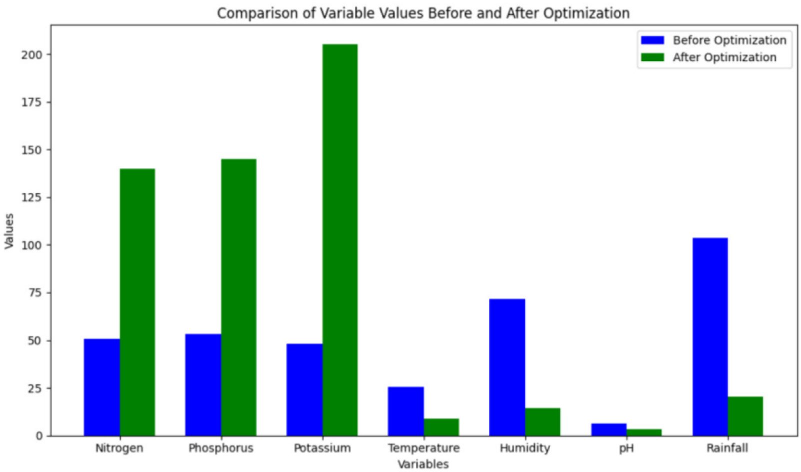

Figure 2

Comparison value before and after application of Genetic Algorithm

In conclusion, optimization techniques like Genetic Algorithms play a crucial role in modern agriculture by optimizing variables related to crop growth and resource management. They help in achieving higher crop yields, improving resource efficiency, and supporting sustainable agricultural practices.

4. Conclusion

Results of this work can act as a base for implementation of Genetic Algorithms on complex agriculture problems. Results indicate that what value of different factors can be used in order to minimize environment impact on agriculture. But agricultural systems are highly complex, involving interactions between numerous variables such as soil types, crop varieties, weather patterns, pests, diseases, and management practices. The simplistic objective function used in this paper may not capture all these complexities adequately. The performance of Genetic Algorithm can be sensitive towards different parameters like crossover rate, mutation rate, population size and termination criteria. Tuning these parameters optimally can be challenging and may impact the quality of the optimization results.

Optimization focused solely on maximizing yield or resource efficiency may neglect other important aspects such as environmental sustainability, biodiversity, and socio-economic impacts on farmers and communities. Future work can be done on more real time data that can be obtained from sensors, weather stations, and satellite imagery.

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