Designing an Automated Multi-Objective Optimization Model for Integrated and Sustainable Farming

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ABSTRACT

The challenges of climate change, water and food scarcity have created the need for planning tools that assist in the agricultural decision-making process. This study aims to propose a multi-objective automated optimization model that uses an embedded comprehensive database to maximize the economic return whilst ensuring minimal water consumption. The suggested model capitalizes on big data in farming and greenhouses to filter all viable scenarios for a given soil, climate properties, and water availability. Evolutionary and genetic algorithms are employed to assess the long-term production, profitability, and water consumption of the scenarios. This study describes how the automated model operates through applying it to a case study to optimize the use of a land plot in Giza, Egypt, for farming purposes. The research opens the door for further application of the proposed model in different contexts both regionally and internationally, thus playing a vital role in the water and food nexus.

INTRODUCTION

Agriculture and farming have always been vital industries in supplying humans with essential food, energy resources and conducive living environments (Ryu et al. 2015). Today the challenges of climate change, resource depletion and rapid urbanization have led to the need for new sustainable approaches to meet the demands of the growing population and help create self-sustaining communities with minimal resources. In recent years, the Egyptian agriculture sector became one of the most susceptible industries to the impact of climate change (McCarl et al. 2015). Despite the extensive individual and organizational efforts in developing databases and tools that provide farmers with crop based information, the available tools today are not fully comprehensive as they are either directed to a specific climatic zone, such as the European Cooperative Program for Plant Genetic Resources (ECPGR) database mostly covering European cultivated crops, or they are field specific tackling single or few parameters at a time such as the WCA Info Net which is an online platform providing support for water conservation in agriculture (ECPGR 2020; FAO 2020). This research proposes a multi-objective automated optimization model titled ELUOM "Economic Land Utilization Optimization Model" which enables its users to identify efficient and economic approaches pertaining to utilizing a land plot for farming purposes. The research also aims to showcase the benefits of using such a model in overcoming the intuitive non-scientific decision-making process when it comes to land utilization for farming which might not offer a sustainable or an optimum return. The model bridges the gap previously discussed as it utilizes a highly detailed yet comprehensive database that is not limited to a single climatic zone or a single objective. At the core of the automated optimization model is the comprehensive relational database that links different plants to their plantation requirements including soil, water and climatic needs. A thorough account on the creation of the relational database currently being utilized in the optimization model is explored in a study by Hosny et al. (2021). Meanwhile this paper focuses on the design and operation of the automated optimization model which evaluates and selects the optimum option among different viable scenarios for the crops to be planted and the area of each crop for a period of 20 years. The viable scenarios are chosen based on filtering the database according to environmental, soil and water conditions. In this paper, a case study is presented where real data pertaining to an actual land in Giza, Egypt was inputted in the model. The results were then compared to crops currently being cultivated to verify the model outputs and the success in relation to the above objectives.

LITERATURE REVIEW

With the advent of technology, a surge in researchers and practitioners' interest in exploring the prospects of integrating technology and big data into farming and landscaping can be witnessed. A study Ryu et al. (2015) showcased an automated connected farming system available on smartphones and tablets that can be used for monitoring and growing crops. The study presented how remote sensors and the Internet of Things (IOT) system can be utilized to control water, light and temperature systems to provide the optimal conditions for crops 'growth and cut down water consumption and carbon emissions (Ryu et al. 2015). The system further also provides expert knowledge to novice farmers and users helping them to effectively and efficiently create an optimal condition to control their farming environment and manage their resources (Ryu et al. 2015). Similarly, a study by Hosny et al. (2017) highlights the difficulties that landscape designers often face in achieving design and aesthetic objectives while at the same time creating cost-efficient landscapes. The research proposes an automated interface, SEOUL "Sustainable and Environmentally Friendly Optimizer for Urban Landscaping'' which filters information fetched from databases containing entries pertaining to plant dimensions, bloom season, salt tolerance, irrigation and light demand (Hosny et al. 2018; Hosny et al. 2017). This allows designers to achieve an optimum use of the land while cutting down water consumption and carbon emissions through careful plant selection. Moreover, Sönmez and Sari (2006) work recording agricultural resources and greenhouses in the region of Antalya using remote sensing and geographic information systems is another example of how technological advances can be useful in the agricultural sector. Meanwhile a study by Wolfert et al. (2017) clarifies that the advantages of applying big data in agriculture are not limited to increasing crop production, but it also improves the efficiency of the entire supply chain thus eliminating food security and sustainability concerns. While the analysis of previous literature has shown a significant shift towards the design and application of smart tools that capitalizes on the proliferating role of technological advances and big data when it comes to farming and landscaping , there is still a need for a comprehensive databases and multi-objective optimization models that helps users identify efficient and economic approaches pertaining to utilizing a land plot for either open field farming or the use of greenhouses.

AUTOMATED OPTIMIZER DESIGN AND OPERATION

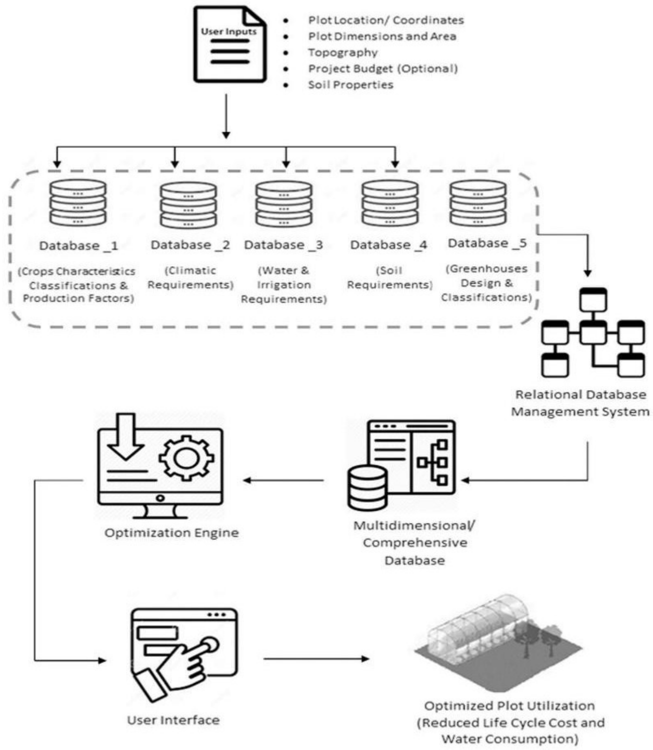

Figure 1. Elucidates the overall framework for the design and implementation of the integrated sustainable farming optimizer along with users' input to the model.

In this research a multi-objective automated optimization model for integrated and sustainable farming is proposed (demonstrated in Figure 1). At the core of the ELUOM model lies a relational database which was created through gathering data from experts and literature on crops' characteristics, survival conditions, and crops' production. The database includes seven main categories which help the model in the decision-making process including: crop classification, soil parameters, water parameters, crop characteristics, irrigation systems, climatic conditions and production factors. Further details pertaining the construction of the comprehensive database is covered in (Hosny et al. 2021). As for the proposed optimization model, it relies on evolutionary and genetic algorithms to select the optimal crop type and greenhouse design for the plot of land while minimizing water demand and lifecycle cost and maximizing the return on investment thus creating a self-sustainable system. The process of crop selection and optimization is divided into two phases: Filtration & Optimization. First, in the filtration phase, land parameters & climatic conditions are compared against the crops' critical survival limits to eliminate non eligible crops. Factors enhancing the crops endurance to the parameters are taken into consideration such as greenhouses, where the controlled temperature provided is considered when performing the filtration. After the filtration phase comes the optimization phase where the remaining crops and greenhouses selections are further narrowed down to reach the best crop variations whether for cultivation in open fields and/or greenhouses. The main objective is to identify the best cultivation scenario that has the highest life cycle return (measured by Net Present Value NPV) and minimizes water usage. This is done by utilizing an objective function that maximizes profit while minimizing water consumption. In order to calculate the potential profit of cultivating each crop, information related to the fixed and operating costs related to open field farming and greenhouses are provided to the model. Information pertaining to the variable and fixed costs for setting up and operating open field farming and greenhouses will either be inserted by the user or fetched from the crops and greenhouses databases. Many of the crop data in Egypt are collected through the economic affairs sector under the Ministry of Agriculture and Land Reclamation. They include the area, yield, production and average cost of the field crops. In the model, a neural network approach was used to forecast the cost of crops four years in advance through the evaluation of the current economic conditions based on leading macroeconomic indicators. A neural network model was developed using the software Neural Designer for every crop with the economic indicators (Egypt indicators from the world bank: Total reserves, Inflation, Exports of goods and services, GDP, Official exchange rate and Agriculture, forestry and fishing value added) as the inputs and the cost as the output. The model had 85% training cases and 15% testing cases. The total average error for the testing cases was 6% which is acceptable. Similarly, the operating costs which include but are not limited to land rent, water consumption, energy and fuel needed to operate harvesting machines and controlling the temperature inside the greenhouses were also included in the calculations. The land rent will be inputted by the user. As for the water, the user will only input the price per m3. The amount of water and energy needed for each crop whether it is cultivated in an open field or in a greenhouse are already embedded in the database. Such information is acquired from previous literature and surveys conducted with industry professionals both locally and internationally. The total water consumption is calculated based on the database information and the given climate conditions through Eto (i.e. crop evapotranspiration) calculations for the average possible cultivation period for each crop. Average selling prices for different crops are entered by the user or he can choose to apply the official pricing in the different seasons in Egypt according to El-Oboor Market website. Given the previous data, a life cycle cost study is conducted to determine the NPV for all possible cultivation scenarios. The objective function is then used to determine which of these scenarios produces the greatest profit and demands the least water.Initial available investment (set by the user) and land size are set as constraints for the evolutionary algorithm model to run.

CASE STUDY

Figure 2. Input of Case study parameters in the model.

Case Study Overview and Model Inputs:

A case study was conducted to test the ELUOM model and validate its output. The land of interest is agricultural land in the Qata district, in Giza, Egypt. The land area is 20 feddan and the soil type is mostly sandy with ESP 10% and soil depth 1000 cm. The landowner cultivates cucumber and peas in successive cycles without the use of greenhouses. The EC water is 450ppm, meanwhile the chloride, boron and sodium content are 350ppm, 1.2ppm and 3ppm respectively. Other decision making financial and energy parameters were inputted to the model as shown in Figure 2. The information provided is based on the current land practices and actual figures used in the Giza land. The cost per cubic meter of domestic water is 1.5 EGP. Several financial parameters such as the 75,000.00 EGP per feddan allocated investment capital for utilizing this specific land plot available for farming. The cost of labor man hour is between 20.00 to 25.00 EGP, based on labor costs currently in the land. Electricity Rate/kWh was obtained based on the irrigation class rate to be 0.65 LE from the landowners. Inflation rate of 5.1% was used reflecting the average rate in Egypt in the past few years based on the national statistics provided by the Central Bank of Egypt and the future discounted rate was determined to be 8.75% also based on the national statistics of the Central Bank of Egypt.

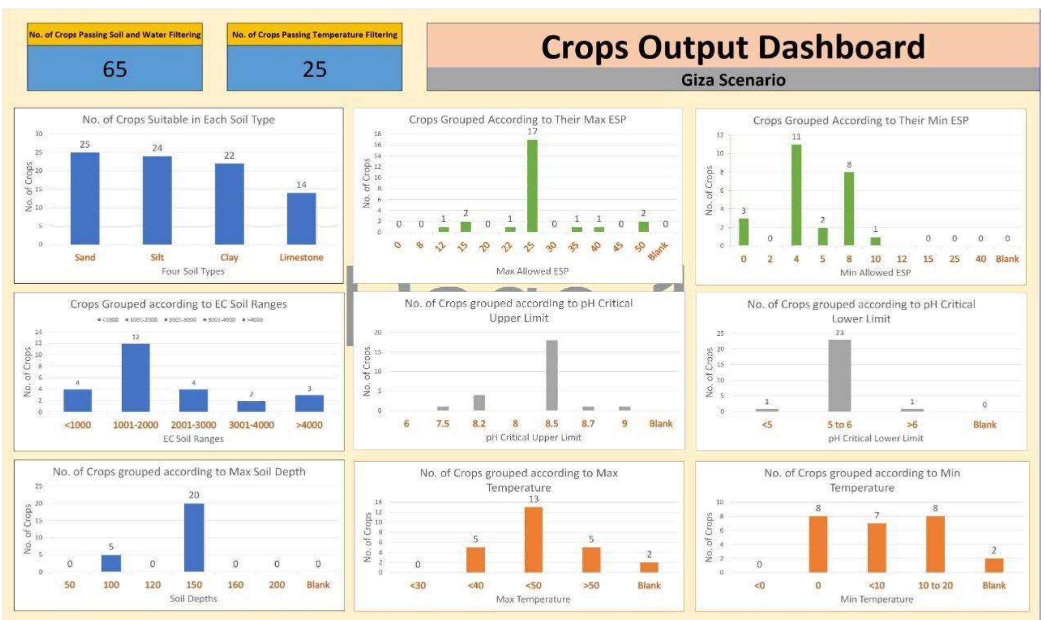

Figure 3. Dashboard summarizing the filtration phase output for Giza plot.

Filtration Phase:

Upon applying the first filtration phase, there are 65 different crops found to be suitable for cultivation in this land. After applying the temperature filter 25 different crops are found to be suitable for cultivation, which verifies the functionality of the database. Among the filtered crops are peas and cucumbers which is what is currently being cultivated in the land, hence the filtration process results are validated. Below is a list of the filtered crops after removing 2 crops that had their temperature values missing and thus not eligible to continue in the optimization phase. The filtered crops are shown in the dashboard below in Figure 3**,** analyzing the properties of the crops filtered and highlighting the most suitable range of crops in the land. The large variety of crops found to be suitable for cultivation emphasizes the great potential of applying optimization to support farmers and landowners to the best utilization of their lands. In the following stage, the choice of possible greenhouse types and greenhouse crops will be provided to the landowner. For example, in this case study since the land of interest is in Egypt, which is a Subtropical region, the recommended greenhouse types are Tunnel, Arch and Ridge & Furrow. The level of technology in the greenhouse will be taken into consideration and the most profitable scenario for crop production over a period of 20 years will be provided to the landowner.

Optimization Phase:

A) Current agricultural practices at Giza land (Before Optimization)

Looking at the financial cycle of the land, it is clear that the land owners were targeting a short-term profitability that limits the use of their capital. The owners, although have on hand 1.5 Million EGP as investment cost, chooses to invest roughly 0.6 Million EGP in short term crops. This is because these crops provide a fast turnover and require a low initial investment capital. Currently the landowners plant cucumber and peas with the season variation. The expected outcomes of such a plantation according to our model are as follows (See Table 1&2). These findings were adjusted according to the inflation rates and were verified by the land owner to be within his expected revenue range.

Table 1. Current cultivation practices in Giza land.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% Land Utilization	**100**	**100**	**100**	**100**	**100**	**0**	**100**	**100**	**100**	**100**	**0**	**0**
Peas	30	30	30	30	30	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Cucumber	**0**	**0**	**0**	**0**	**0**	**0**	30	30	30	30	**0**	**0**

Table 2. Current cultivation practices in Giza land per feddan.

Parameter	Value	Unit
Objective Function- Expected NPV (20 Years)	4,706,351.00	LE
Estimated Initial investment	511,887.00	LE
Estimated First year Revenue	258,341 .00	LE
Estimated Water quantity Used/year	146,112	m3
Average Daily Water Quantity	400	m3/day
Max Land utilization percentage	100	%
Return/ Water quantity	32.2	LE/m3

B) Optimized agricultural practices in Giza Land

After performing our optimization on the selection of crops, the model suggested a better alternative in terms of both water consumption and the NPV of the land in the long term. Instead of targeting short-term turnover and saving on the initial capital investment, the model suggests utilizing almost all of the available funds into a variety of both long-term crops (trees & palm trees) and short-term ones (Less than a year crops). The results of the model are to utilize the land in planting the following crops: Sweet Potatoes, Beets, Lemon Trees, and Bananas. Table 3 shows the distribution of the plants over the period of a year and the land utilization percentage. The results of the recommended management practices are summarized in Table 4. Four crops were selected out of the 23 crops that went through optimization. 2 crops are trees and the other 2 are field crops. This combination shows how the land is utilized to a great extent while using all the available capital and meeting all the constraints imposed through water requirements or plot area. Also, it is worth noting that the model takes into account the different durations for which each crop can be planted within its allowed interval. For instance, if a crop can be planted anytime starting from October to December and requires three months thus ending late December to late February, the model will account for the different three intervals that the crop can be planted during.

Table 3. Recommended cultivation practices in Giza land

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% Land Utilization	**97**	**97**	**63**	**63**	**63**	**63**	**97**	**97**	**97**	**97**	**63**	**97**
Sweet Potatoes	**0**	**0**	**0**	**0**	**0**	**0**	10	10	10	10	0	0
Beet	10	10	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	10
Lemon Trees	10	10	10	10	10	10	10	10	10	10	10	10
Bananas	9	9	9	9	9	9	9	9	9	9	9	9

Table 4. Optimized cultivation practices in Giza land.

Parameter	Value	Unit
Objective Function- Expected NPV (20 Years	18,505,969.00	LE
Estimated Initial investment	1,498,280.00	LE
Estimated First year Revenue	920,290 .00	LE
Estimated Water quantity Used/year	151,996	m3
Average Daily Water Quantity	415.5	m3/day
Max Land utilization percentage	97	%
Return/ Water quantity	121.8	LE/m3

C) Results & Discussion of Current Vs. Recommended Agricultural Practices

The optimization model has led to a great increase in the expected financial return while maintaining a low water quantity usage that is viable in the expected return/1 m3 of water value. All of the model constraints were met and the land area utilization percentage was maintained above 60%. The analysis shows that with the current landowner approach the NPV/Initial Capital investment approximately gives for every 1 EGP invested 9.19 EGP are generated in profit. The optimized scenario estimates the same value to be around 12.35 EGP for every invested 1 EGP. With the same budget, the user may have selected to plant less feddans of the crops chosen in the optimization phase allowing him to generate more profit from the same initial investment whilst lowering the water consumed per 1 LE of return. The percentage of land utilization (97%) gives room for other kinds of investment (for vacant 2,520 m2). The optimized solution generates approximately threefold greater maximization of the objective function versus that provided by current practice. (see Table 5), clearly illustrating the added value the model provides. Also, the analysis demonstrates to the user how tripling his initial investment will affect his profits over a period of 20 years which should provide support to the user in taking the decision to aim for long term investments to maximize his profits. Overall with regard to the Giza land, the model is effective in maximizing the return on investment while minimizing the water demand.

Table 5. Giza Case Study Comparison.

Parameter	Current practices	Optimized practices
Objective Function-Expected NPV (20 Years)	4,706,351.00	18,505,969.00
Estimated Initial investment	511,887.00	1,498,280.00
Utilized investment/available investment	34.2%	99.8%
First year Revenue	258,341 .00	920,290 .00
Water quantity Used/year	146,112	151,996
Average Daily Water Quantity	400	415.5
Land utilization percentage	100	97
Return (LE)/ 1 m3 Water	**32.2**	**121.8**

CONCLUSION

This study presents the framework for designing a state-of-the-art automated optimizer with a comprehensive database for sustainable and economic land utilization for open field and/or greenhouses farming. The optimization model is designed in response to the gap in the market when it comes to comprehensive crop databases and multi-objective optimization models for planning land utilization. The study also showcases the application of such optimization tools on a land plot in Giza, Egypt. The automated model was able to narrow down the selection of crops to be planted to those with maximum return on investment of the project that utilizes the minimum water quantity per economic return ratio. Not only does this assist in the early planning of agricultural operations, but also help overcome the typical intuitive process of selecting how a land is utilized, which does not necessarily provide optimal or sustainable return. Albeit its addressed potentials, the limitations of the optimization model at this current stage is that the growth duration period for crops included in the model is an average value, meanwhile for more accurate results the growth duration period should be per hardiness zone. Other limitations include the fact that the optimization phase that comes after the filtration process so far does not opt for greenhouses' crops. This is due to the high initial costs of greenhouses and the fact that the available capital in the cases mentioned is limited due to owners' focus on short-term investments. Future iterations of the model could give the user the freedom to choose what objectives he/she wants to achieve and optimize for. Future work can also include adding more data for crops that could grow in other countries. This opens the door for the model to penetrate international markets. Further additional features like including the images of crops will assist with improving the visualization of the model outputs. To sum up, the optimization model presented in this study is an example of how integrating technology into farming and landscaping can help in sustainably managing available land and expanding green communities in the region while bridging the gap between multiple industries and fields including data analytics, project organizational management and agronomics.

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