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Original Article

Design, Simulation, and Mapping of the Palm Fronds Composting Process in Saudi Arabia via the Combination of SuperPro-Designer and GIS Software

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Abstract *- Based on data from the Ministry of Agriculture's Agricultural Statistical Yearbook from 1999 to 2013, the study uses Geographic Information Systems (GIS) methodologies to predict the expansion of palm tree agriculture and the shift in date production by the Saudi Arabia 2030 vision. In order to give an effective way to convert solid palm frond trash into organic fertilizer, SuperPro Designer is then utilized to model a palm frond composting process. Additionally, this paper uses SuperPro-Designer version 14 software to simulate, design, and do a cost analysis for palm frond composting for the first time in order to construct a batch-mode composting facility. The first stage in the design process was to choose the batch operation mode. The resulting analysis was then used to register the components in the software. The flow diagram was created with a dryer, a shredder, and two aerobic digestion reactors. All operational conditions related to the breakdown reaction of cellulose, hemicelluloses, lignin, and mummification were established, along with the temperature and pressure of the composting process. Moreover, batch mode was used to perform energy and material balances. Additionally, the finished composted product is compared to the literature for validation. Additionally, the plant's Total Capital Investment (TCI), which comes to about $20,482,696, was calculated using the program. The complete cost estimate that was presented contained direct and indirect expenses, operational costs, revenues, a description of the fixed capital estimate, yearly Cost, materials cost, annual operating cost, and equipment specification.*

Keywords *- GIS, ArcGIS 10.4, Geostatistical analysis, Palm fronds, Waste, Organic fertilizer, Environment, Simulation, SuperPro-Designer.*

1. Introduction
1.1. Palms Date Trees

An adult date palm tree may produce between 40 and 400 kilograms, making it one of Saudi Arabia's most important seasonal commodities. Irrigation and fertilization, variety quality and suitability for the planting site, palm tree age and vigor, soil fertility and depth, pollination efficiency and pollen source, and resilience to pests and diseases that damage palm trees are some of the elements that affect their production [1]. The palm date tree includes palm fronds. Saudi Arabia (KSA) is the world's second-largest producer of date fruits due to its enormous number of date trees. The amount of solid trash produced by these trees is also among the greatest in the world. The palm fronds make up the majority of these solid wastes. [2] According to reports, 200*10^6 tons of palm date garbage are produced annually in Saudi Arabia. It may be difficult to dispose of this solid trash. Therefore, solutions are required to address this issue. The organic elements included in palm fronds, primarily lignin, cellulose, hemicelluloses, ash, protein, and moisture [3], enable them to be used in various treatment processes to turn waste into valuable goods. Numerous therapeutic approaches have been documented in the literature [4, 9]. Aerobic digestion, gasification, and pyrolysis were among the several treatment techniques employed in Saudi Arabia [10-15]. Composting, also known as Aerobic Digestion, is one of these therapeutic methods [16-26]. The process of breaking down organic materials to lower their volume and create fertilizer is known as aerobic digestion [27, 28]. The thermophilic and mesophilic phases are two crucial stages of the composting process. The temperature reaches 40°C during the mesophilic phase, when the digesting reactions begin, but with little conversion. The second stage will have a high conversion rate and be at a temperature higher than 40°C [29-31]. Reaching the maximum conversion could take up to 100 days [32].

The interaction of glucose with oxygen raises the temperature from the first to the second stage by producing carbon dioxide, water, and energy [33]. Accordingly, the lignin will break down into vanillic acid and vanillin as the primary components of the palm fronds decay [34-37]. Glucose is created when cellulose and hemicellulose combine with water. After the protein breaks down into amino acids and phenolic acids, humic acid is created [38].

In the second stage, the glucose will react with the oxygen to produce CO2 and energy. Thus, CO_2, N_2, O_2, NH_3, and H_2O will be expelled in the vent [39]. Fertilizer can be applied to the residual solid material [40-42]. SuperPro-Designer software was used to create the simulation used in this paper. The literature on mimicking the aerobic decomposition of palm fronds to create fertilizer is lacking. Compared to other applications, SuperPro-Designer software is invaluable for this purpose because it contains specific helpful tools designed specifically for aerobic digestion [43].

1.1.1. Recent Studies (Last Five Years) that Focus on Composting and Simulation Tools

These studies demonstrate the increasing interest in using simulation technologies like Machine Learning, GIS, and SuperPro Designer to improve waste management strategies, optimize composting processes, and advance sustainable practices.

To forecast composting results based on input factors including ambient temperature, mixture composition, and initial feedstock volume, a number of machine learning models (Decision Tree Regressor, Linear Regression, XGBoost Regression, K-Neighbors Regressor) were created. Vassilis and Gerasimos Lyberatos conducted the study [44]. After being trained on data from 88 composting batches, these models showed good accuracy in predicting compost maturity, process duration, and final product quantity. The study highlights how AI can improve resource management and make real-time adjustments to optimize composting processes.

Recent advancements in sensor technologies and data-driven composting systems that employ Artificial Intelligence (AI) and the Internet of Things (IoT) enable real-time monitoring of temperature, moisture, oxygen levels, and gas emissions in compost piles. By constantly modifying moisture and aeration levels, these devices reduce greenhouse gas emissions and the likelihood of anaerobic conditions [45].

Machine learning Models (Linear Regression, Decision Tree Regressor, K-Neighbors Regressor, Support Vector Regression, XGBoost Regression) were developed to predict the outcomes of a food waste composting process using ambient temperature and mixture composition as inputs. When tested on 44 batches of food waste, the models did remarkably well in predicting the composting outcome [46].

A hybrid GIS and Multi-Criteria Decision-Making (MCDM) model was used in a study in Hosaena Town, Southwest Ethiopia, to identify the ideal sites for solid waste disposal. The study examined a range of data, including slope, soil, land use, and road networks, to identify and prioritize suitable sites [47]. GIS was utilized in a study to map Depok City's solid waste output and collection. GIS can be used to manage and simulate the technological, social, economic, and environmental constraints associated with waste management [48].

The novelty research, "Design, Simulation, and Mapping of the Palm Frond-to-Compost Conversion Process in Saudi Arabia by Combining SuperPro-Designer and Geographic Information Systems Software," is unique in several significant ways, including the use of modern software, data accessibility, study area development, sustainable solid waste management, and a multidisciplinary methodology. Moreover, this study represents the first study in KSA that combines SuperPro-Designer and GIS software for performing design, simulation, prediction, and mapping of the palm frond-to-compost conversion process.

1.1.2. The Research Problem and its Significance

a) Several significant obstacles motivate the design, simulation, and mapping of the Saudi Arabian palm frond composting process utilizing SuperPro Designer and GIS software.
b) Underutilization of Agricultural Waste: A consequence of date palm production, palm fronds are often burned or thrown away, polluting the environment and creating missed chances for sustainable waste management.
c) Efficient Composting Procedures Are Needed: Current composting techniques might not be tailored to the unique qualities of palm fronds, leading to longer composting times and inconsistent product quality.
d) Lack of Geographic Data Integration: The effectiveness of waste management techniques may be limited by current composting projects' failure to properly utilize geographic information systems to locate ideal composting sites or track trash flow.
e) Sustainability Objectives: Saudi Arabia's Vision 2030 places a strong emphasis on environmentally friendly measures; however, the solid waste management is the most important aspect.

1.2. Geographic Information Systems (GIS) and Spatial Interpolation Methods

GIS is described as a fundamental and globally applicable set of practical tools for organizing, converting, recording, analyzing, and displaying data, particularly spatial data [49]. Data visualization is also made possible by the use of GIS technology for data processing and display [50]. Analysis, statistics, and reporting products are more difficult for users to understand than visual display data. The three essential uses of GIS that are covered in this study are data integration, data visualization, and data analysis. Interpolation is the process of estimating unknown data values from known data values. Many different academic subjects use various interpolation techniques. One of the most basic methods, linear interpolation, requires the knowledge of two points and the constant rate of change between and beyond them [51].

The majority of current research typically requires 3D modelling of the Earth's surface. Digital Terrain Model (DTM) is used to derive the 3D models. Various interpolation techniques are used to derive the DTMs. The number of control points and the surface's structure can affect the interpolation techniques used. To define a surface, this study compares and interprets various interpolation techniques [51]. Regular data can be transformed into a scattered sampling pattern or vice versa with the proper interpolation technique [52-54]. Spatial interpolation models can be divided into two main categories:

- Models that employ arbitrary parameter values, like deterministic models like IDW; and
- Statistical models whose parameters are calculated objectively from the data, like Kriging.

2. Methodology

2.1. Description of the Base Map

As shown in Figure 1, Saudi Arabia is located between latitudes 16°21'58 "N and 32°9'57 "N and longitudes 34°33'48 "E and 55°41'29 "E. The nation is located in the tropical and subtropical desert zone, which has a dry environment and high temperatures throughout much of it, according to data from the Food and Agriculture Organization. Nearly the entire land is desert, and the winds that arrive there are typically dry. There are significant differences in daily temperatures as well as between seasons and geographical areas due to the aridity and comparatively clear skies.

2.2. Interpolation Techniques and the Real Data used

In this paper, based on the real data and the main categories, seven interpolation techniques were used to evaluate the best method of forecasting the growth of the palm agriculture areas, including Inverse Distance Weighting (IDW), Ordinary Kriging (OK), Simple Kriging (SK), Universal Kriging (UK), Indicator Kriging (IK), Probability Kriging (PK), and Disjunctive Kriging (DK) using ArcGIS 10.4 [55](See Table 1 and Figure 2).

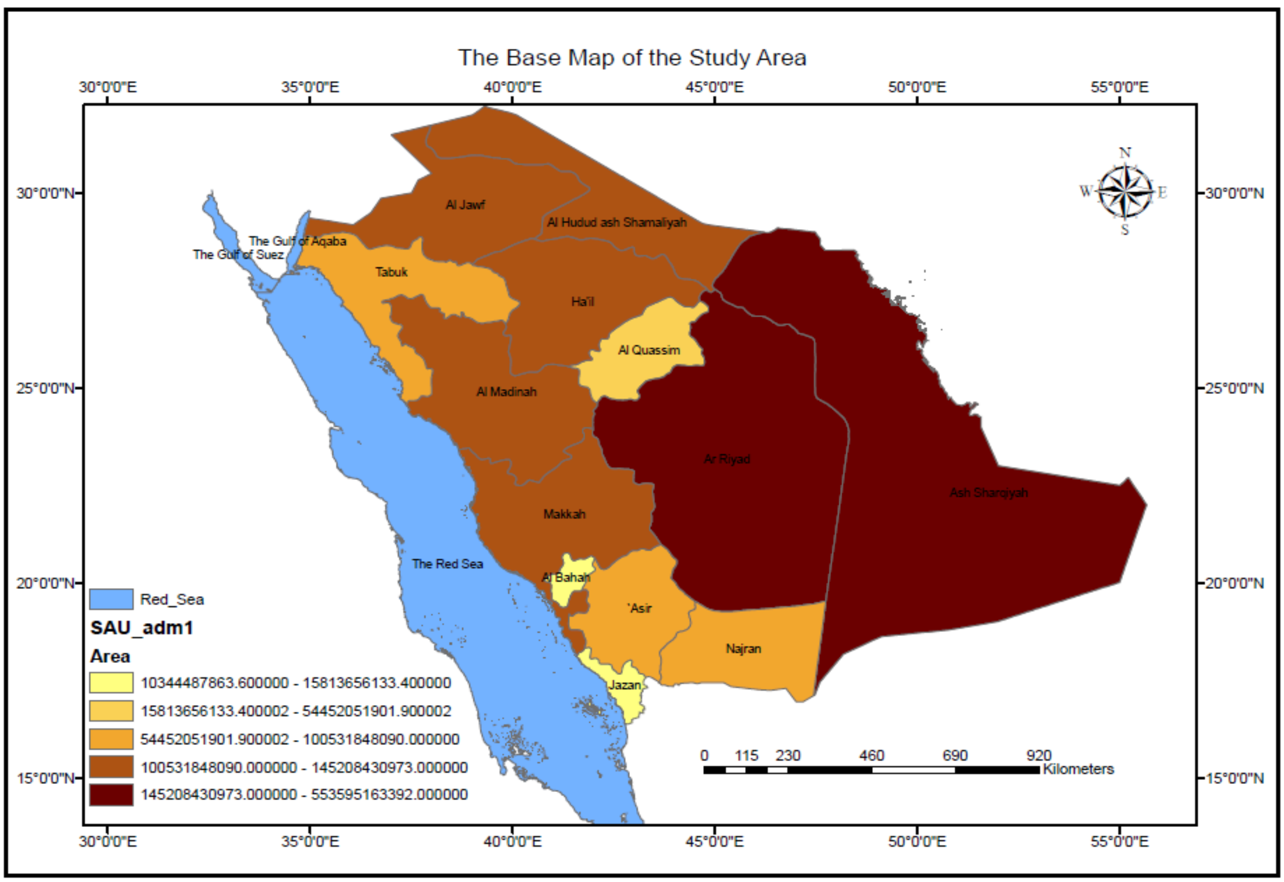


Fig. 1 The base map of the study area (Is derived from ArcGIS 10.4)

Table 1. Shows the area of palm trees planted, the number of palm trees, and the quantity of date production during the period: 1999-2013 [55-57]

S.N	Year	Area planted (Km^2)	Number of palm trees (palm)	Quantity of dates production (tons)
1	1999	1415.70	19,305,188	712,266
2	2000	1424.50	19,779,697	734,844
3	2001	1390.99	20,254,206	817,887
4	2002	1399.79	20,849,602	829,540
5	2003	1414.21	21,324,111	884,088
6	2004	1488.01	22,287,857	941,293
7	2005	1507.44	22,625,983	970,488
8	2006	1524.02	23,085,542	977,036
9	2007	1557.34	23,218,660	982,546
10	2008	1570.74	23,458,299	986,409
11	2009	1619.75	23,634,310	991,660
12	2010	1551.18	23,437,090	991,546
13	2011	1560.23	23,742,593	1,008,105
14	2012	1568.48	25,096,578	1,031,082
15	2013	1569.01	25,104,161	1,095,158

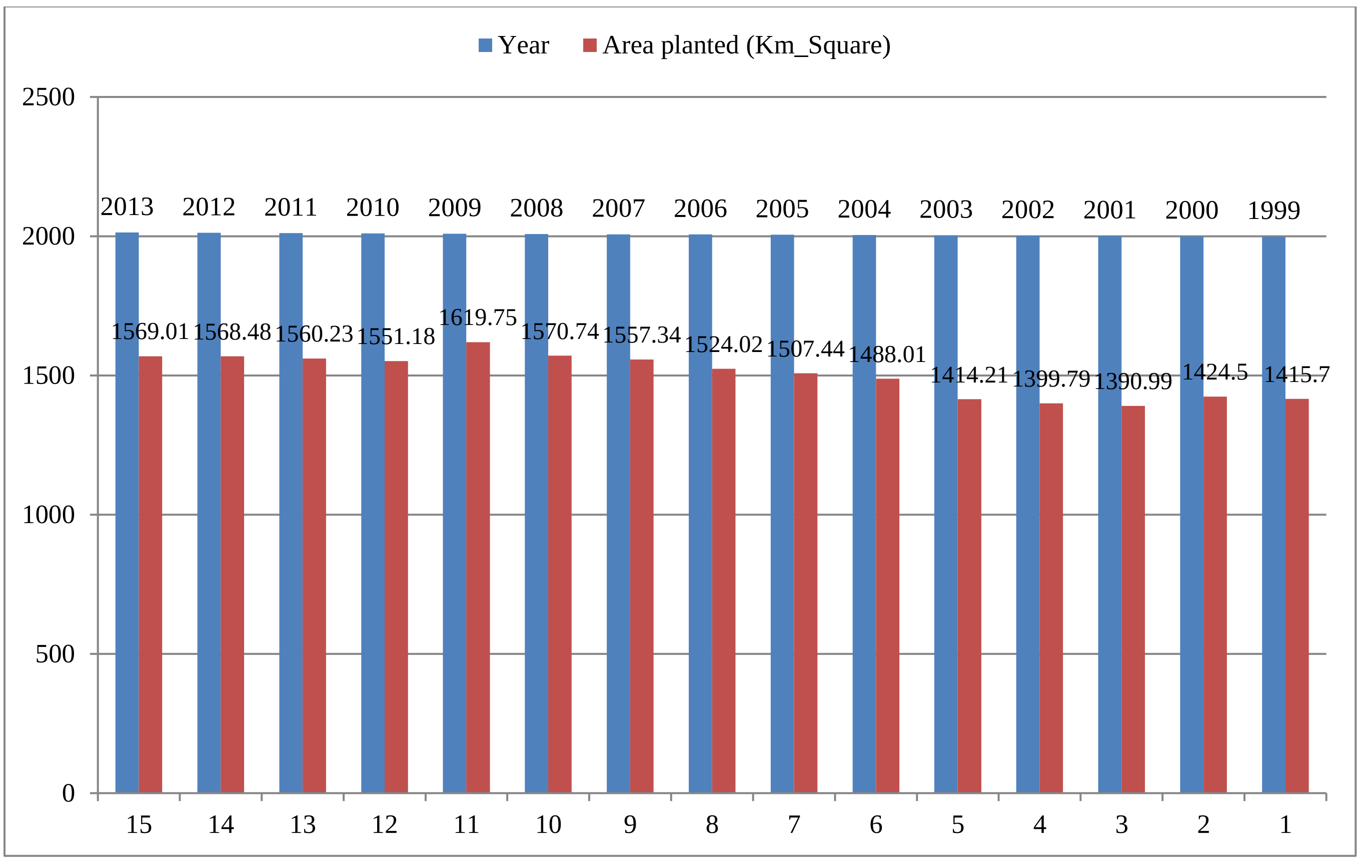


Fig. 2 Palm-planted areas during the period 1999-2013 in KSA

2.3. The Paper Methodology Steps

The actions that will be taken to complete the tasks are depicted in Figure 3. The paper's methodology.

- Add the base map of the Kingdom of Saudi Arabia (KSA) to the ArcGIS 10.4.

- Data collection, such as the base maps and attribute palm trees data from KSA;
- Selecting the test point to guarantee the accuracy of the interpolation procedures.
- Manually compute the MAE, MSE, and RMSE values using ArcGIS 10 and Excel. 4.
- All interpolation strategies' geostatistical findings are compared and explained.
- Validate the prediction results using GIS interpolation and mathematical models to ensure accuracy.
- The best interpolation method is selected to complete the estimation of the missing palm areas data over the following years.
- The digital model is used for palm farm management.
- Building the simulation of Composting of Palm Fronds for the Production of Organic Fertilizer;
- Calculating the Operating Cost.

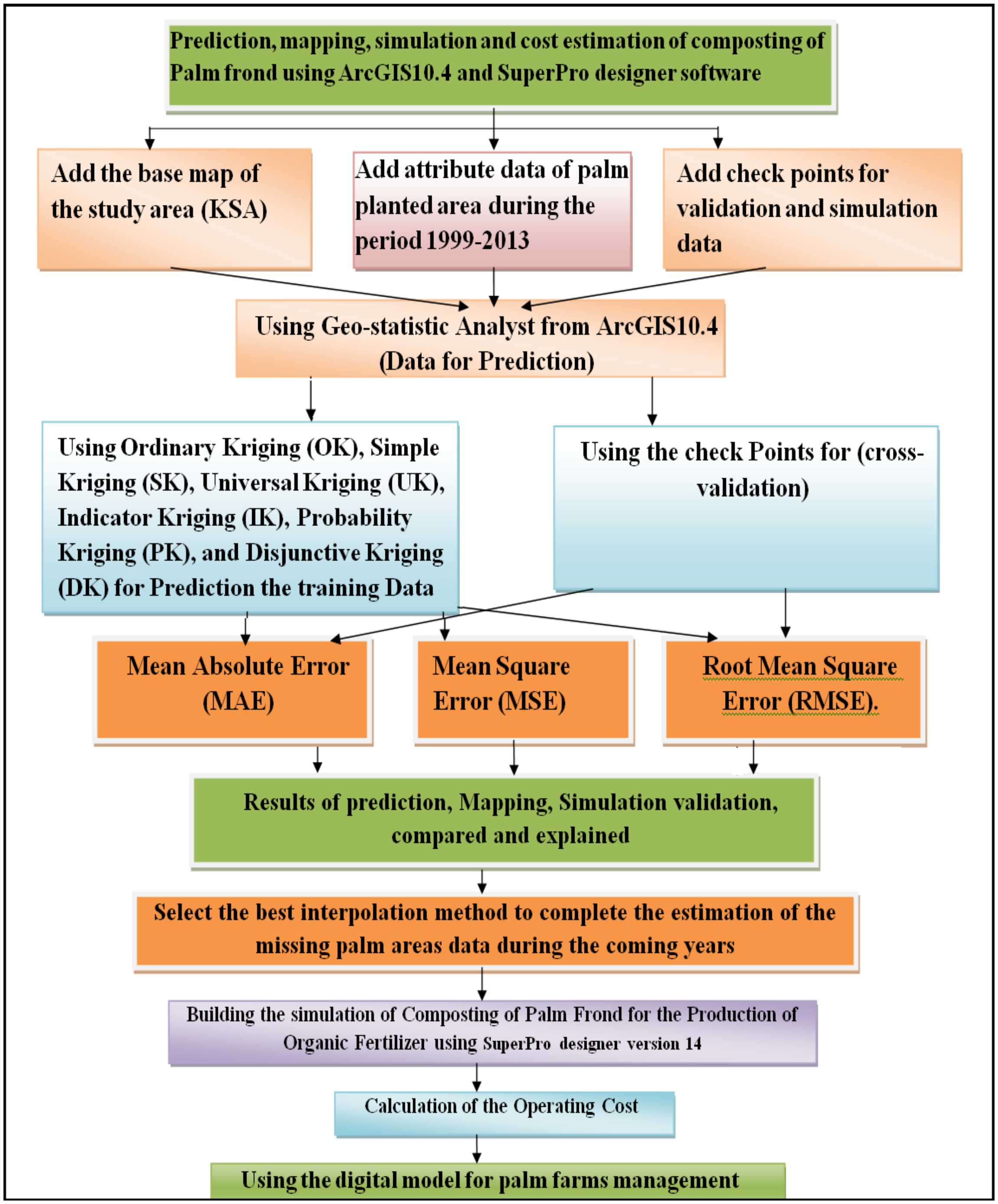


Fig. 3 Research methodology flow chart

2.4. Validation of Prediction using GIS Interpolation and Mathematical Models

Interpolation is a technique used to estimate or predict values. Cross-validation was used to compare the expected value with the observed value, interpolate the value from the remaining observations, and continuously eliminate a data point because of the study's small sample size. The Mean Absolute Error (MAE), Mean Square Error (MSE), and Root Mean Square Error (RMSE) were computed using the interpolated and measured values at each sample point in order to compare the accuracy of the forecasts. The RMSE describes the sample standard deviation of the differences between the expected and actual values.

Many factors, such as sample size, sample design, and spatial distribution, affected prediction errors, which were commonly employed to measure the efficacy of geo-statistical analysis.

[58-61]. This work uses the following mathematical models for geo-statistics and validation:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|x_i - x| \tag{1}$$

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(x_i - x)^2 \tag{2}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}[Z^*(x_i)-Z(x_i)]^2}{n}} \tag{3}$$

$$R^2 = 1 - \frac{\sum(y_i - y^{\sim}_i)^2}{\sum(y_i - y^{*}_i)^2} \tag{4}$$

Where: The variables Z (xi) and Z* (xi) reflect the observed and interpolated solid waste values at sites xi and x, respectively; The sample size, n, the interpolation value obtained from the interpolation method, the actual compressive strength value derived from laboratory test results, and the absolute errors are denoted by |xi – x| in the equations above. R-Square shows the coefficient of determination. $\sum(y_i - y^{\sim}_i)^2$ means sum squared regression $\sum(y_i - y^{*}_i)^2$ deals with the total sum of squares.

2.4.1. Techniques for Verifying Simulation Outcomes

Methods for validating simulation results against experimental data are:

1. Make a direct comparison between the outcomes of physical composting experiments and simulation outputs, such as compost quality, nutrient content, and temperature profiles. This entails evaluating important performance metrics like output characteristics and breakdown rates.
2. To measure the degree of agreement between simulated and observed data, use statistical measures like RMSE (Root Mean Square Error), MAE (Mean Absolute Error), or correlation coefficients. This offers a numerical assessment of the accuracy of the simulation.
3. To ascertain how changes in input parameters impact simulation outputs, perform sensitivity studies. This guarantees that the model is responsive to genuine changes in composting conditions and helps validate its resilience.
4. Examine simulation outcomes against those of related research in the literature. Participating in peer reviews can also reveal information about the model's dependability and suitability for particular uses.

2.5. Palm Fronds

Palm fronds are organic materials consist of lignin, cellulose, hemicellulose, ash, protein, and moisture with the following percentages: 14%, 31.5%, 19.2%, 12.3%, 9.4%, and 13.6%, respectively[3]as shown in Figure 4. In the SuperProdesigner software, the palm fronds were introduced as a mixture consisting of the mentioned components and materials.

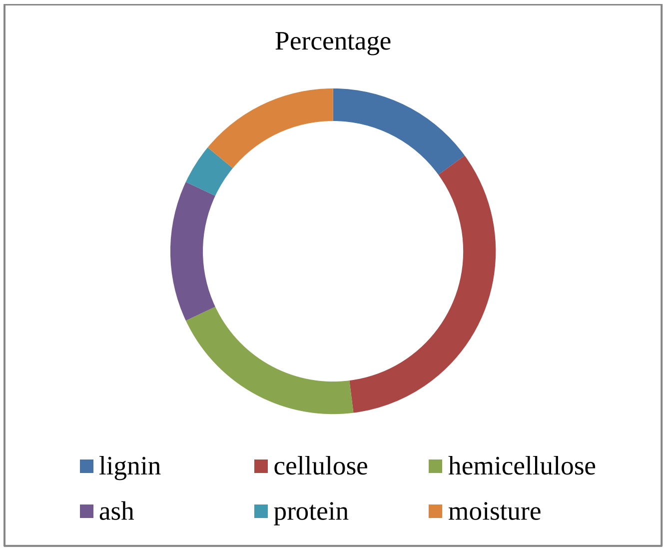


Fig. 4 Content of palm fronds

2.6. Building the Simulation

SuperPro-Designer version 14 is the program utilized [62]. Two aerobic digestion reactors, a dryer, and a crusher make up the suggested process equipment. The following parameters and presumptions were used when creating the flow sheet: the mass of the fronds is 100 kg/batch, and the operation mode is batch. As seen in Figure 5, a pretreatment procedure is performed before the palm fronds go on to the reaction step. The wet biomass from the source is approximated as 48% wet, then it dried to 13.6%. Then, after drying, it was shredded so it could react with a high surface area. The conversion of the reactions in the first reactor was estimated to be around 60%, while in the second reactor, it was estimated to be in a range between 70 to 98% for different reactions. The first reactor acts as an anaerobic stage and the second reactor as a thermophilic stage, as shown in Figure 6.

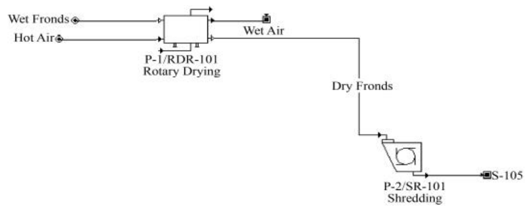


Fig. 5 Pretreatment of palm fronds

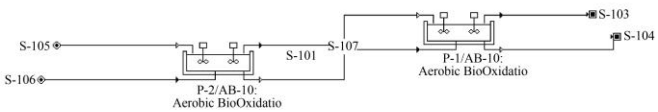


Fig. 6 Aerobic digestion reactors

The dryer used is a rotary dryer, as shown in Figure 7. The purpose of adding this equipment is to dry the fresh-cut biomass to the desired moisture content.

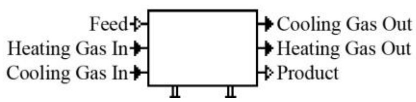


Fig. 7 Rotary dryer [57]

A shredder was added as shown in Figure 8. The purpose of this equipment is to reduce the size of palm fronds, therefore enhancing the bulk surface so that better mass and heat transfer can be performed.

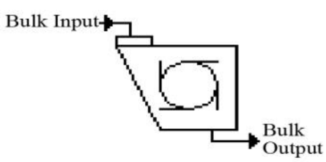


Fig. 8 Shredder

The reactor used is a stoichiometric Well-Mixed (WM) Aerobic bio-oxidation reactor, as shown in Figure 9. This reactor is used to simulate the biodegradation of organic materials in the presence of oxygen. The model calculates Volatile Organic Compounds (VOC) emissions.

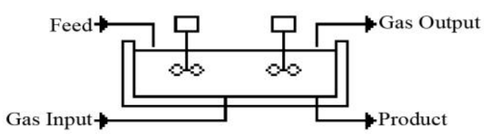


Fig. 9 Stoichiometric Well-Mixed (WM) Aerobic Bio-Oxidation reactor [62]

To design the WM reactor, the following design equations were used:

$$V_W = F\, t_R \tag{5}$$

$$V = V_w / Ratio \tag{6}$$

Where t_R is the hydraulic residence time, V_W is the working liquid volume, V is the vessel volume, and Fis is the feed volumetric flow rate, and Ratio is the working to vessel volume ratio, which is 85%. These equations (Equations 5 and 6) were built in the simulation to calculate the design dimensions required and then the Cost estimated inside the software. To design the dryer, the evaporation rate in (kg evap./m^3.h) was specified, and then the software calculated all the dimensions and the Cost of the dryer. To design the shredder, the throughput was specified, and then the program estimated the sizing and the Cost of the equipment.

2.7. Economic Evaluation

For economic evaluation, firstly, the total capital investment needs to be estimated. Then the operating Cost, revenues, gross margin, return on investment, payback time, the Net Present Value (NPV), total plant direct cost, total plant indirect cost, working capital, Startup and Validation Cost, Up-Front R&D Cost, Operating Cost, Materials Cost, Raw Material and Cleaning Agent Streams, Heat Transfer Agents, Labor-Dependent Cost, Utilities Cost, Depreciation, Laboratory /QC /QA Cost Transportation Cost, Advertising and Selling Costs, and Waste Treatment/Disposal Cost.

2.7.1. Total Capital Investment

It includes five different categories, including Direct Fixed Capital (DFC), Working Capital, Startup and Validation Cost, Up-Front R&D Cost, and up-front royalties.

2.7.2. Operating Cost ($/yr)

The costs required for the project, for example, utilities and raw materials.

2.7.3. Revenues

It is mainly the income from the products and some other things.

2.7.4. Gross Margin

Gross margin is the percentage of gross profit divided by the revenues, as shown in Equation 7.

$$\text{Gross margin} = \frac{\text{Gross Profit}}{\text{Revenues}} x100 \tag{7}$$

2.7.5. Return on Investment (ROI)

ROI is the net profit divided by the total investment, as shown in Equation 8. If it is not positive, then the project will not be considered.

$$\text{ROI} = \frac{\text{Net Profit}}{\text{Total investment}} x100 \tag{8}$$

2.7.6. Payback Time

It is the total investment divided by the net profit, as shown in Equation 9. The shorter the payback time, the better the investment.

$$\text{Payback Time (in years)} = \frac{\text{Total Investment}}{\text{Net profit}} x100 \tag{9}$$

2.7.7. The Net Present Value (NPV)

It is the summation of the net cash flow divided by the interest rate to the power of year k, as shown in Equation 10.

It also has to be positive; if not, then the project will not be considered.

$$\mathrm{NPV} = \sum_{k=1}^{N} \frac{\mathrm{NCF_k}}{(+\mathrm{i})_1^{\mathrm{k}}} \quad (10)$$

2.8. Profitability Analysis

The profitability analysis examines the project's profitability. Gross profit, income taxes, net profit, gross margin, ROI, payback period, cash flow analysis, net cash flow, capital expenses, debt financing, depreciation, taxable income, revenues, operating costs, net present value, and internal rate of return are all calculated.

2.8.1. Gross Profit

Are the revenues excluded from the Annual Operating Cost (AOC) as shown in Equation 11.

$$\text{Gross profit Revenues–AOC} \quad (11)$$

2.8.2. Income Taxes

It is a percentage of the annual gross profit.

2.8.3. Net Profit

Is the annual gross profit minus income tax plus annual depreciation, as shown in Equation 12.

$$NetProfit = Grossprofit - Taxes + Depreciation \quad (12)$$

2.8.4. Gross Margin

Gross margin is calculated according to Equation 13.

$$GrossMargin = \frac{GrossProfit}{Revenues} \times 100 \quad (13)$$

2.8.5. Return on Investment (ROI)

ROI is calculated according to Equation 14.

$$ROI = \frac{NetrProfit}{Totalinvestment} \times 100 \quad (14)$$

2.8.6. Payback Time

Payback time is calculated according to Equation 15.

$$Paybacktime\ (inyears) = \frac{Totalinvestment}{NetrProfit} \quad 15)$$

2.8.7. Cash Flow Analysis

It is a calculation of net cash flow, capital expenses, and debt financing.

2.8.8. Net Cash Flow (NCF)

NCF is calculated according to Equation 16 during construction and startup.

$$NCF = NCF_{con} = DebtFinancing - Capitalexpenses \quad (16)$$

Then the NCF was calculated according to Equation 17.

$$NCF = NCF_{con} + NetProfit + Depreciation \quad (17)$$

2.9. Capital Expenses

Capital expenses are calculated according to Equation 18.

$$Capitalexpenses = f_c\left[(1 - f_s) \times f_p \times DFC\right] + UFRD + UFR + SC + WC \quad (18)$$

UFRD is up-front R&D, UFR is up-front royalties, SC is startup and validation cost, and WC is working capital. While f_p, f_s, and f_c are fractions of the process, salvage fraction, and the fraction added to the year's capital expenses, respectively.

2.10. Debt Financing

Capital expenses are calculated according to Equation 19 up to the 5th year of the project, while Equation 20 applies from the first year of operation.

$$DebtFinancing = DF_{DFC} = f_d \times (f_c \times f_p \times DFC) \quad (19)$$

$$DebtFinancing = DF_{DFC} + f_w \times WC + f_{rd} \times UFRD + f_r \times UFR \quad (20)$$

2.11. Depreciation

The total depreciable amount, d_{tot}, is calculated according to Equation 21:

$$\mathrm{d_{tot}} = \sum_1^N \mathrm{d_k} = B - S \quad (21)$$

Where:

$$\mathrm{B = f_p \times UDFC + C_s} \quad (22)$$

$$\mathrm{S = f_s \times f_p \times UDFC} \quad (23)$$

$$d_k = d_{tot}/N \quad (24)$$

2.12. Taxable Income

Taxable income is calculated according to Equation 25

$$Taxableincome = GrossProfit + LoanPayments \quad (25)$$

2.13. Gross Profit

Gross profit is calculated according to Equation 26

$$GrossProfit = Revenues - AOC \quad (26)$$

2.14. Revenues

Revenues are calculated according to Equation 27

$$\text{Revenues} = \mathrm{f_Q} \times (\mathrm{t}/12) \times \text{Annual Revenues} \quad (27)$$

2.15. Operating Cost

Operating Cost is calculated according to Equation(28).

$$\text{Operating Cost} = \mathrm{f_Q} \times (\mathrm{t}/12) \times \mathrm{AOC_v} + \mathrm{AOC_F} \quad (28)$$

2.16. Direct Fixed Capital (DFC)

2.16.1. Total Plant Direct Cost (TPDC)

Equipment acquisition costs, insulation, electricity, buildings, yard improvement, auxiliary facilities, instrumentation, process piping, and installation are the nine categories that make up this total. Equation (29) illustrates how to calculate the equipment's purchase cost, which is equal to the base cost times the required capacity divided by the base capacity to the power α.

$$PC = C0(\frac{Q}{Q0})^\wedge\alpha \qquad (29)$$

The program's built-in chemical engineering cost index was utilized to account for the year. The expense of building the equipment's foundations and other necessary components is known as installation. The expense of connecting the pipes to all services and equipment is known as process pipe work. The price of control devices and all necessary connections is known as instrumentation—the price of the pants and insulators required for the factory. The Cost of electrical connections and all the equipment required to produce electricity, including an electric generator, is referred to as the Cost of electricity. Buildings: It is the price required to construct the plant buildings, as well as all other construction-related items. Enhancement of the yard requires this expenditure.

This Cost is needed to improve the yard, and it is calculated as a factor from the equipment costs. Auxiliary facilities are also calculated as a factor of the equipment costs.

2.16.2. Total Plant Indirect Cost (TPIC)

The TPIC is the Total Of Engineering And Construction Fees. Engineering is the Cost of preparing the documents related to the design of the equipment, their specifications, and everything similar to construction: this is related to the overall effort made by the organization for the construction.
All nine items of direct costs and the two items of indirect costs were calculated as factors. The sum of TPDC and TPIC is denoted as Total Plant Cost (TPC). There are also the contractor's fees, and the Contingency Fees (CFC) have to be added as factors from the Direct and Indirect Costs (TPC). So TPC and CFC give the DFC.

2.17. Working Capital

The extra money required in addition to fixed capital to launch the plant and run it until revenue is generated is known as Working Capital. The DFC was used to compute the Startup and Validation Cost, Up-Front R&D Cost, Up-Front Royalties, and Capital Investment Charged to This Project.

2.17.1. Operating Cost

Materials expenses, consumables costs, labor-dependent costs, utilities costs, waste treatment/disposal costs, facility-dependent costs, laboratory/QC/QA costs, transportation costs, miscellaneous costs, advertising/selling costs, running royalties, and failed product disposal costs are examples of operating costs.

2.17.2. Labor-Dependent Cost

Labor's Cost is calculated according to Equation (30)

$$DetailedLasbourRate = (basicrate)x(1 + benifits + supervision + supplies + adminstration) \qquad (30)$$

3. Results and Discussions

3.1. Geostatistical Analysis Outcomes with ArcGIS 10.4

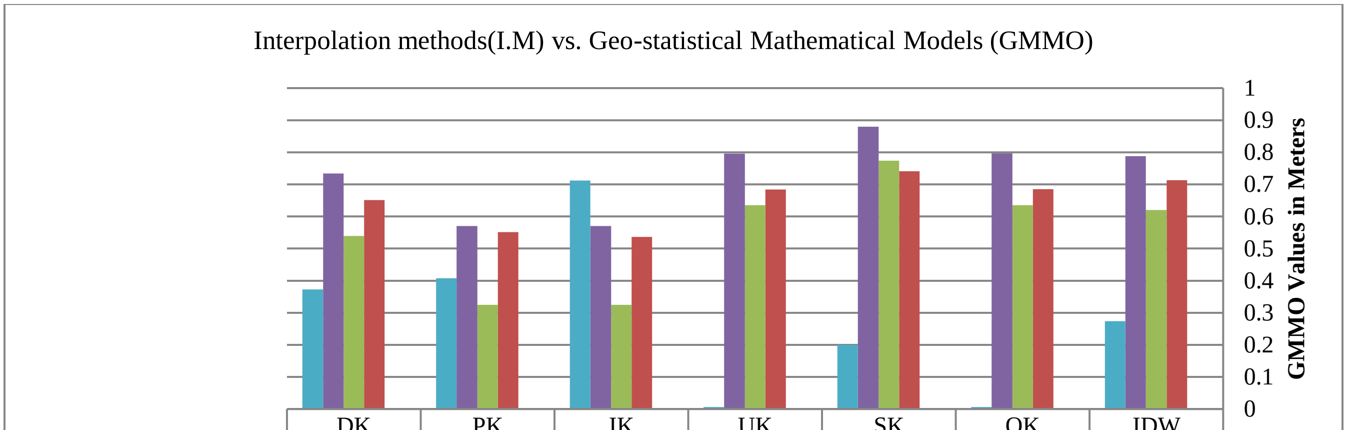
ArcGIS Geo-statistical Analyst is an add-on for ArcGIS Pro and ArcGIS Enterprise. Tools for spatial interpolation and statistical models are included in ArcGIS Geo-statistical Analyst. Its objective is to provide reliable and consistent estimates of events at sites with no measuring resources. One of the geo-statistical interpolation methods offered in ArcGIS Geo-statistical Analyst is Kriging, which may be used to generate a statistically valid prediction surface and evaluate the prediction uncertainties.

ArcGIS Geo-statistical Analyst computed these values using 15 training sites of palm regions in KSA to accomplish the seven interpolation approaches, as shown in Table 2 and Figure 10.

Table 2. Summary of geo-statistical mathematical models (M. Mo) Values of MAE, MSE, RMSE, and R^2 values using interpolation methods (I.M) in the palm-planted area in KSA

I. M. / GMMO	IDW	OK	SK	UK	IK	PK	DK
MAE	0.713	0.685	0.741	0.684	0.536	0.551	0.651
MSE	0.620	0.635	0.774	0.635	0.325	0.325	0.539
RMSE	0.788	0.797	0.880	0.796	0.570	0.570	0.734
R2_ palm Area	0.274	0.006	0.2	0.006	0.712	0.408	0.373
Regression Equation	y = 0.187x + 12.22	y = 0.040x + 14.44	y = -0.154x + 17.31	y = 0.040x + 14.44	y = 0.420x + 8.754	y = 0.338x + 9.906	y = 0.000x + 15.02

I.M: Interpolation Methods, GMMO: Geo-statistical Mathematical Models; MAE: Mean Absolute Error; MSE: Mean Square Error; RMSE: Root Mean Square Error; R^2: Coefficient of Determination ; IDW: Inverse Distance Weighting; OK: Ordinary Kriging, SK: Simple Kriging; UK: Universal Kriging; IK: Indicator Kriging; PK: Probability Kriging; DK: Disjunctive Kriging,



	DK	PK	IK	UK	SK	OK	IDW
GMMO							
MAE	0.651	0.551	0.536	0.684	0.741	0.685	0.713
MSE	0.539	0.325	0.325	0.635	0.774	0.635	0.62
RMSE	0.734	0.57	0.57	0.796	0.88	0.797	0.788
R-square_ palm Area	0.373	0.408	0.712	0.006	0.2	0.006	0.274

Fig. 10 Interpolation methods vs. geostatistical mathematical models, values of (MAE, MSE, and RMSE) are applied in Palm-Planted areas in KSA

3.1.1. Prediction of Palm Numbers During The Period 2014-2030

ArcGIS 10.4 has a number of prediction tools that let users make educated guesses about values at unknown places using data that already exists. To produce forecasts, these tools make use of a variety of regression and geostatistical approaches. Kriging, regression analysis, and spatial statistics models are examples of frequently employed techniques. Decision trees are among the models that have been used for hazard prediction as a result of GIS breakthroughs [63]. In this study, the geostatistical analysis is used to predict the number of palms during the period from 2014 to 2030 according to the real data collected from the study area in the period 1999-2013. Table 3 shows the prediction result of the palm trees during the period 2014 to 2030 using GIS. These numbers of the palm trees are distributed in all the Kingdom of Saudi Arabia (KSA).

Table 3. Prediction result of the palm trees during the period: 2014-2030

Year	Predicted number of palm trees
2014	25924149
2015	26191379
2016	26529410
2017	27035241
2018	27160272
2019	27417142
2020	27756633
2021	27769725
2022	28155756
2023	28223064
2024	28482987
2025	28712417
2026	28812795
2027	29051838
2028	29593279
2029	29933010
2030	30200140

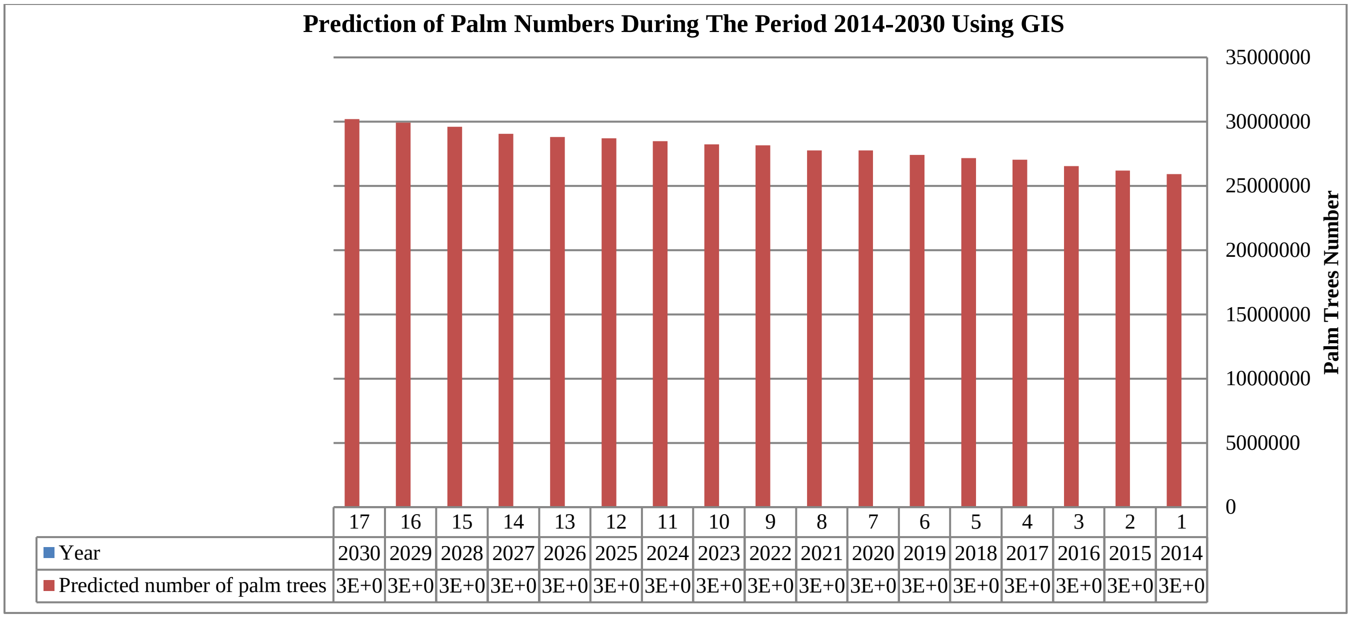


Fig. 11 Prediction of palm numbers during the period 2014-2030 using Indicator Kriging (IK) interpolation method (The best interpolation method was investigated)

In Table 3, the total number of palm trees was estimated based on the real data presented in Table 1. This number was forecasted in the majority of towns in KSA and focused on four of the most important palm-planted regions, such as Qassim, Medina, Riyadh, and Eastern. In the present study, the total number of palm trees in the current year equals 28712417, spread throughout all of the regions of KSA. Figure 12 represents the landuse map of the KSA, with approximately 11.2 million palm trees, or 39% of the total number of palm trees in the Qassim region. The Riyadh region came in second with 28.9%, the Medina region came in third with 26.8%, and the Eastern region came in fourth with 14.2%. This study was compared with 30200140 palm trees in 2030.

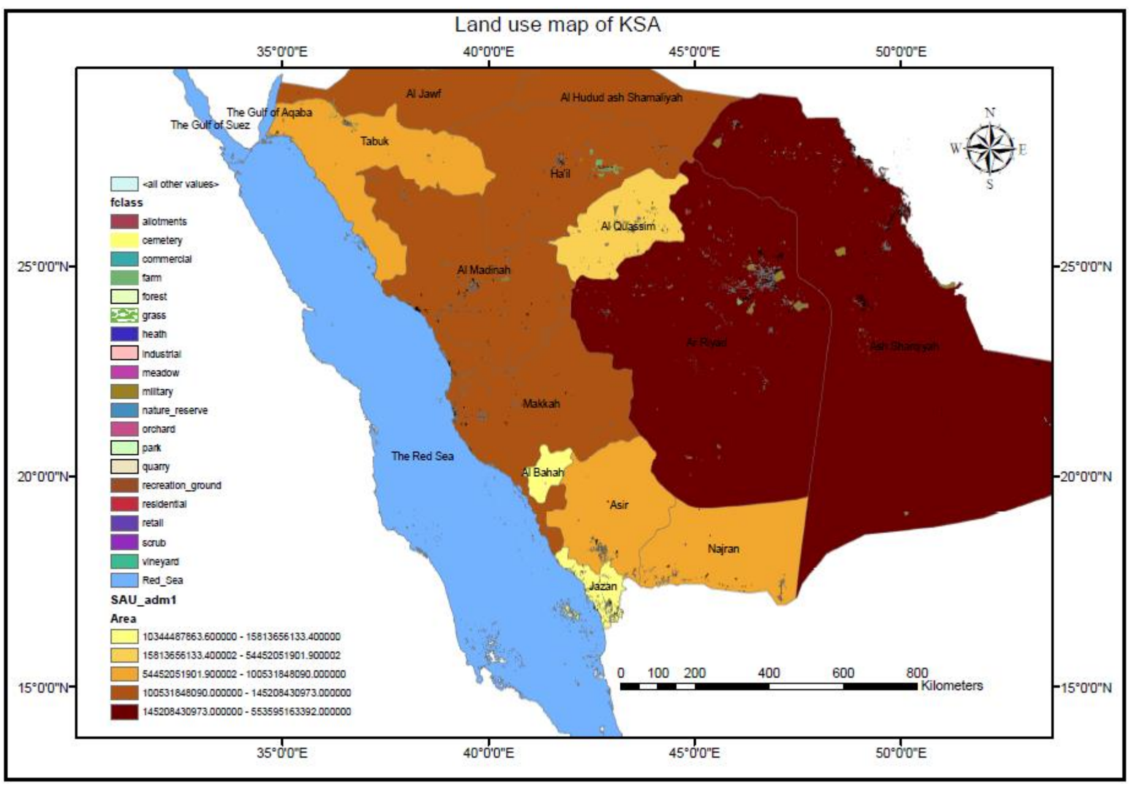


Fig. 12 The land use map of KSA (Is plotted by ArcGIS 10.4)

3.2. Results of Validations and Discussion

3.2.1. Cross-Validation of ArcGIS Prediction Results

Cross-validation estimates the trend and autocorrelation models using all of the data. One by one, each data site is eliminated, and the predicted data value is created. Cross-validation compares the measured and predicted values for each point. By estimating the trend and autocorrelation models using all the data, cross-validation inadvertently commits a slight cheat. Significant errors may cause some data locations to be classified as weird after cross-validation, necessitating a rerun of the trend and autocorrelation models.

To forecast the optimal distribution of elevation data, this study employed several interpolation techniques, including IDW, OK, SK, UK, IK, PK, and DK. Based on training and test data, the spatial analysis is carried out using ArcGIS 10.4 to identify the optimal elevation interpolation methods.

A geostatistical study is performed to assess the effectiveness of the best interpolation techniques. Cross-validation of the palm areas chosen randomly from Table 1 for each of the 10 test periods is shown in Table 4.

Table 4. An example of the real eight test points' cross-validation computation (manually calculated)

Po. No.	Year	Palm area (km_sq.)	Prediction Area(km_sq.)	Δx = xi-x	|xi – x|	$(x_i - x)^2$
1	1999	1415.7	1416.330	0.630	0.63	0.3969
2	2002	1424.5	1424.500	0.000	0	0
3	2003	1390.99	1391.183	0.193	0.193	0.037249
4	2008	1557.34	1557.340	0.000	0	0
5	2009	1570.74	1569.970	-0.770	0.77	0.5929
6	2011	1619.75	1619.660	-0.090	0.09	0.0081
7	2012	1551.18	1551.220	0.040	0.04	0.0016
8	2013	1569.01	1568.640	-0.370	0.37	0.1369
Sum		12099.21	12098.843	-0.367	2.093	1.173649
Geostatistical Mathematical Models values				MAE	MSE	RMSE
Manually calculation				**0.260**	**0.146**	**0.382**
ArcGIS10.4 calculation				**0.260**	**0.146**	**0.382**
Difference				**0.000**	**0.000**	**0.000**

3.2.2. Discussion of Reasons for Choosing GIS Software and the Superpro-Designer over Alternatives for Prediction Data and Simulation

An efficient framework for improving composting operations is created by combining SuperPro Designer for in-depth process analysis with GIS for spatial evaluation, simulations, and forecasting data. GIS software is very useful for prediction problems involving geographic and spatial data because of these benefits. This framework is strengthened by a thorough validation of the selected operational parameters. Several differentiating reasons led to the use of GIS and SuperPro Designer software for forecasting, composting, and simulation:

GIS Software

GIS software is preferred over alternatives for data prediction for the following reasons:

- GIS software is perfect for forecasts that rely on geographic distribution since it offers powerful tools for examining spatial linkages and trends.
- GIS can readily incorporate a variety of data kinds, including topographical, environmental, and demographic data, enabling thorough studies that conventional data tools might find difficult.
- The capacity to produce intricate maps and visual outputs facilitates the efficient interpretation and communication of forecasts to stakeholders and decision-makers.
- GIS provides specific geostatistical techniques, including surface modeling and interpolation, which are essential for producing precise forecasts based on spatial data.
- GIS solutions are scalable, meaning they can accommodate additional data as it becomes available without sacrificing speed.
- A lot of GIS programs have user-friendly interfaces that make data entry, manipulation, and analysis easier, making them usable by people with different levels of technical proficiency.
- In dynamic forecast scenarios where conditions may change quickly, GIS can make use of real-time data streams.
- GIS software frequently includes capabilities that make it simple for users and stakeholders to share data and analysis, improving cooperative efforts in planning and research.

SuperPro Designer

SuperPro Designer software is preferred over other simulation choices for the following reasons:

- SuperPro Designer is very useful for in-depth research because it was created primarily to simulate process activities, especially in sectors like waste management and chemical engineering.
- Sophisticated simulations are made possible by the software's extensive toolkit for simulating intricate processes, such as material and energy balances.
- Regardless of technical proficiency, users may create and visualize workflows with ease thanks to its user-friendly graphic interface, which streamlines the simulation process.
- The integrated economic evaluation tools in SuperPro Designer enable users to evaluate the cost-effectiveness of different procedures and make well-informed financial decisions.
- The platform's changeable parameters provide a great deal of customisation of simulations, making it adaptable to particular project needs.
- It facilitates cross-software cooperation and data management by supporting integration with several data formats and other applications.
- Strong reporting features in the software allow users to provide thorough documentation of their simulations, which is crucial for openness and stakeholder communication.
- Sensitivity analyses can be used by users to comprehend the effects of variable changes, offering insights into risk management and process optimization.

3.2.3. The Determination and Validation of Operational Conditions

Determining and verifying operating conditions include the following:

- Fundamental operational parameters, including moisture levels, temperature, and airflow, were identified from existing industry standards and practices. These are pivotal in determining the efficiency of the composting process.
- Using SuperPro Designer, various operational scenarios were simulated by adjusting the identified parameters, allowing for an analysis of how different settings impact composting performance.
- Validation was performed by comparing the results with historical data from existing composting operations. This approach ensured that simulation results reflected realistic outcomes.
- A sensitivity analysis was conducted to understand the influence of different parameters on composting efficacy. This assessment confirmed the reliability of the selected operational settings.
- Involving local experts and waste management professionals in the validation phase provided crucial insights, ensuring that operational conditions were practical and aligned with regulatory standards.

3.2.4. Relevance of Historical Data on Palm Trees (1999-2013) to Saudi Arabia's 2030 Vision

Stakeholders may better support and align their agriculture strategies with Saudi Arabia's 2030 Vision by utilizing historical palm tree data during the period 1999-2013 and validating simulation results with this experimental data according to the following:

- Historical data on palm trees can offer insights into yield quantification, growth patterns, and environmental requirements, guiding sustainable agricultural practices in line with the 2030 Vision's objectives of raising agricultural productivity and food security.
- Establishing more resilient agricultural techniques can be facilitated by estimating future outcomes under changing climate scenarios by analyzing how palm trees have reacted to climatic conditions over the past few years.
- In order to satisfy the Vision's emphasis on sustainable natural resource management, historical agriculture data are essential for enhancing water usage and soil management techniques.
- In Saudi Arabia, palm trees are significant both culturally and economically. Initiatives to increase the date palm can be supported by historical data.
- By fostering biodiversity through sustainable agriculture methods incorporating traditional crops like palm trees, historical data insights help achieve environmental goals set in the 2030 Vision.

3.2.5. Validations of the Simulation of Composting of Palm Fronds

The study's findings were validated by comparing them to those of [59, 60]. Listed the following ranges of compost quality: pH 6.8–7.3, potassium 0.2–0.5%, phosphorus 0.6–0.9%, and nitrogen 1-2%. Organic Matter: 35–45%, Moisture Content: 45–50% 3/8 of the screen is passed by particle size. According to the same study, thermophilic temperatures range from 41 to 76 degrees Celsius for two weeks, and mesophilic temperatures range from 10 to 40 degrees Celsius for one week, for a total of three weeks (Figure 13).

In this study, the batch duration was set at three weeks. The mesophilic and thermophilic stages were assumed to happen in two reactors, but in reality, it is only one reactor, so the products of the first reactor were fed to the second reactor.

The temperature in the first stage was calculated by the software to be 23.8 °C, and the second stage to be 57.9 °C. So the two-stage temperatures agree with the ranges mentioned by [59]. The product content includes Phosphorus around 0.26% potassium around 2.5%, water 46%, and Organic matter 37.45%. So there is very good agreement with the results of this study and the results of [59].

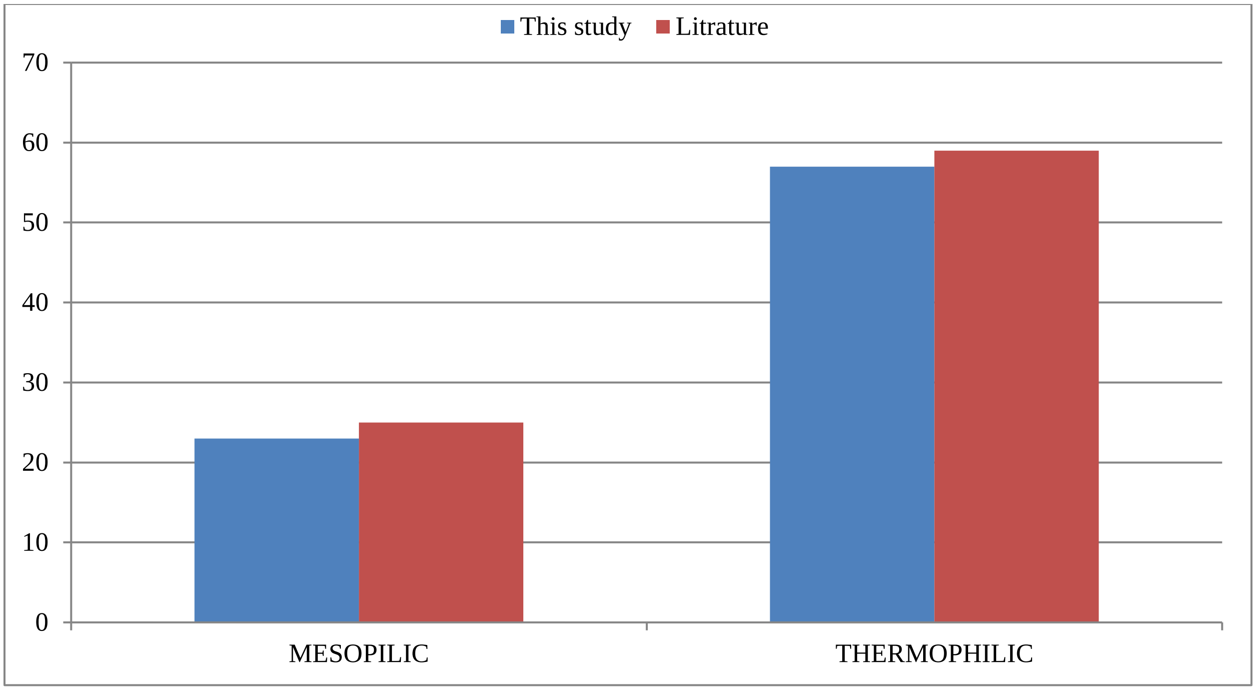


Fig. 13 Validation of the results data

3.3. Operating Conditions

The simulation was configured in batch mode, as indicated in Table 5. There are 22 batches per year, each lasting 15 days. The software determines that the annual operation time is 330 days. The fertilizer product for each batch is displayed by batch size.

Table 5. Overall process data

Annual Operating Time	7,920.00 h
Unit Production Ref. Rate	28,821,358.06kg MP/yr
Batch Size	1,310,061.73kg MP
Recipe Batch Time	360.00 h
Number of Batches per Year	22.00

Table 6 shows the raw materials used per year, per batch, and per Main Product (MP). The raw materials used are air and palm fronds. The amount of palm fronds per batch is around 632 tons. This amount was estimated according to the production of palm fronds all over Saudi Arabia [2]. The amount of air needed for the process was estimated according to [66].

Table 6. Bulk materials (After shredding and drying process)

Material	kg/yr	kg/batch
Air	70,400,000	3,200,000.00
Palm Fronds	13,909,170	632,235.00
TOTAL	84,309,170	3,832,235.00

Table 7 shows all registered components in the current simulation. Also, it included all the components of the mixtures, including ash, wet fronts, and dry fronts. Table 8 shows the composition of the mixtures included in the simulation.

Table 7. Registered components

Full Name	Formula
Aluminum Oxide	Al_2O_3
Calcium Oxide	CaO
Cellulose	$C_6H_{10}O_5$
Carbon Dioxide	CO_2
Iron(III) Oxide	Fe_2O_3
Glucose	$C_6H_{12}O_6$
Glycine	$C_2H_5NO_2$
Hemicellulose	$C_5H_8O_4$
Humic Acid	$C_9H_9NO_6$
Potassium Oxide	K_2O
Lignin	$C_{7.3}H_{13.9}O_{1.3}$
Lysine	$C_6H_{14}N_2O_2$
Magnesium Oxide	MgO
Nitrogen	N_2
Ammonia	NH_3
Oxygen	O_2
Phosphorus Pentoxide	P_2O_5
Phenol	C_6H_5OH
Proteins	$CH_{1.601}O_{0.291}N_{0.286}S_{0.009}$
Silicon Oxide	SiO_2
Vanillic Acid	$C_8H_8O_4$
Vanillin	$C_8H_8O_3$
Water	H_2O

Table 8. Mixture compositions

Air	Ingredient	Mass %
	O_2	23.29
	N_2	76.71
Palm Fronds	Ingredient	Mass %
	Cellulose	31.5
	Lignin	14
	Proteins	9.4
	Hemicellulose	19.2
	Water	13.6
	Ash2	12.3
Ash2	Ingredient	Mass %
	CaO	12.97
	K_2O	23.47
	MgO	3.37
	SiO_2	45.64
	$Al2O_3$	5.57
	$Fe2O_3$	3.43
	P_2O_5	5.55

Table 9 shows the stream details for all streams of the reactors. It shows the pressure, temperature, density, specific enthalpy, total enthalpy, heat capacity, component flow rates, and total for each stream. Also shows the source and destination for each stream. Obviously, it can be seen that the temperature was reduced a little bit in the first reaction stage, then increased in the second stage. This can indicate the presence of thermophilic and mesophilic organisms [31].

Table 9. Stream details

Stream Name	S-105	S-106	S-101	S-102	S-103	S-104
Source	INPUT	INPUT	P-2	P-2	P-1	P-1
Destination	P-2	P-2	P-1	P-1	OUTPUT	OUTPUT
Stream Properties						
Temperature (°C)	25	25	23.84	23.84	57.93	57.93
Pressure (bar)	1.01	1.01	1.01	1.01	1.01	1.01
Density (g/L)	1,213.56	1.18	1.19	49.02	1.1	363.57
Total enthalpy (kW-h)	6,915.62	22,499.18	70,031.28	5,903.14	81,343.25	19,986.92
Specific enthalpy (kcal/kg)	9.41	6.05	18.18	9.81	20.86	36.11
Heat Capacity (kcal/kg-°C)	0.38	0.24	0.24	0.41	0.24	0.62
Component Flowrates (kg/batch)						
Al_2O_3	4,331.51	0	0	4,331.51	0	4,331.51
CaO	10,086.11	0	0	10,086.11	0	10,086.11
Cellulose	199,154.03	0	0	79,661.61	0	7,966.16
CO_2	0	0	221,310.33	174.17	573,886.73	173.56
Fe_2O_3	2,667.34	0	0	2,667.34	0	2,667.34
Glucose	0	0	0	92,834.77	0	4,641.74
Glycine	0	0	0	1,683.40	0	997.41

Hemicellulose	121,389.12	0	0	48,555.65	0	4,855.56
Humic Acid	0	0	0	14,166.26	0	54,500.11
K_2O	18,251.42	0	0	18,251.42	0	18,251.42
Lignin	88,512.90	0	0	84,087.26	0	50,452.35
Lysine	0	0	0	3,278.32	0	1,942.40
MgO	2,620.68	0	0	2,620.68	0	2,620.68
N2	0	2,454,777.20	2,453,125.53	1,651.68	2,454,142.25	634.96
NH3	0	0	0	5,800.66	5,239.87	52.93
O2	0	745,222.80	571,732.88	403.69	284,057.09	77.07
P2O5	4,315.95	0	0	4,315.95	0	4,315.95
Phenol	0	0	0	2,110.50	0	1,250.47
Proteins	59,430.09	0	0	32,835.12	0	16,089.21
SiO_2	35,491.90	0	0	35,491.90	0	35,491.90
Vanillic Acid	0	0	0	1,755.89	0	28,905.42
Vanillin	0	0	0	2,417.85	0	7,256.05
Water	85,983.96	0	68,441.00	68,441.00	38,601.97	218,744.48
TOTAL (kg/batch)	632,235.00	3,200,000.00	3,314,609.74	517,622.71	3,355,927.90	476,304.80
TOTAL (L/batch)	**520,973.86**	**2,713,654,476.55**	**2,784,630,797.68**	**10,559,761.44**	**3,042,038,709.02**	**1,310,061.73**

Table 10. Overall component balance (kg/batch)

COMPONENT	INPUT	OUTPUT	IN-OUT
Al_2O_3	4,331.51	4,331.51	0.00
CaO	10,086.11	10,086.11	0.00
Cellulose	199,154.03	7,966.16	191,187.86
CO_2	0	574,060.29	-574,060.29
Fe_2O_3	2,667.34	2,667.34	0.00
Glucose	0	4,641.74	-4,641.74
Glycine	0	997.41	-997.41
Hemicellulose	121,389.12	4,855.56	116,533.56
Humic Acid	0	54,500.11	-54,500.11
K_2O	18,251.42	18,251.42	0.00
Lignin	88,512.90	50,452.35	38,060.55
Lysine	0	1,942.40	-1,942.40
MgO	2,620.68	2,620.68	0
N_2	2,454,777.20	2,454,777.20	0
NH_3	0.00	5,292.79	-5,292.79
O_2	745,222.80	284,134.17	461,088.63
P_2O_5	4,315.95	4,315.95	0.00
Phenol	0	1,250.47	-1,250.47
Proteins	59,430.09	16,089.21	43,340.88
SiO_2	35,491.90	35,491.90	0.00
Vanillic Acid	0	28,905.42	-28,905.42

Vanillin	0.00	7,256.05	-7,256.05
Water	85,983.96	257,346.44	-171,362.48
TOTAL	3,832,235.00	3,832,232.70	2.30

Table 10 shows the overall material balance of the process. Clearly, it can be seen that some of the components were not affected, for example, the ash and the nitrogen associated with the air. That means these components did not react. However, all other components were affected; some of them were consumed as lignin and oxygen, and some of them were generated as humic acid and glucose, as shown in Figure 14.

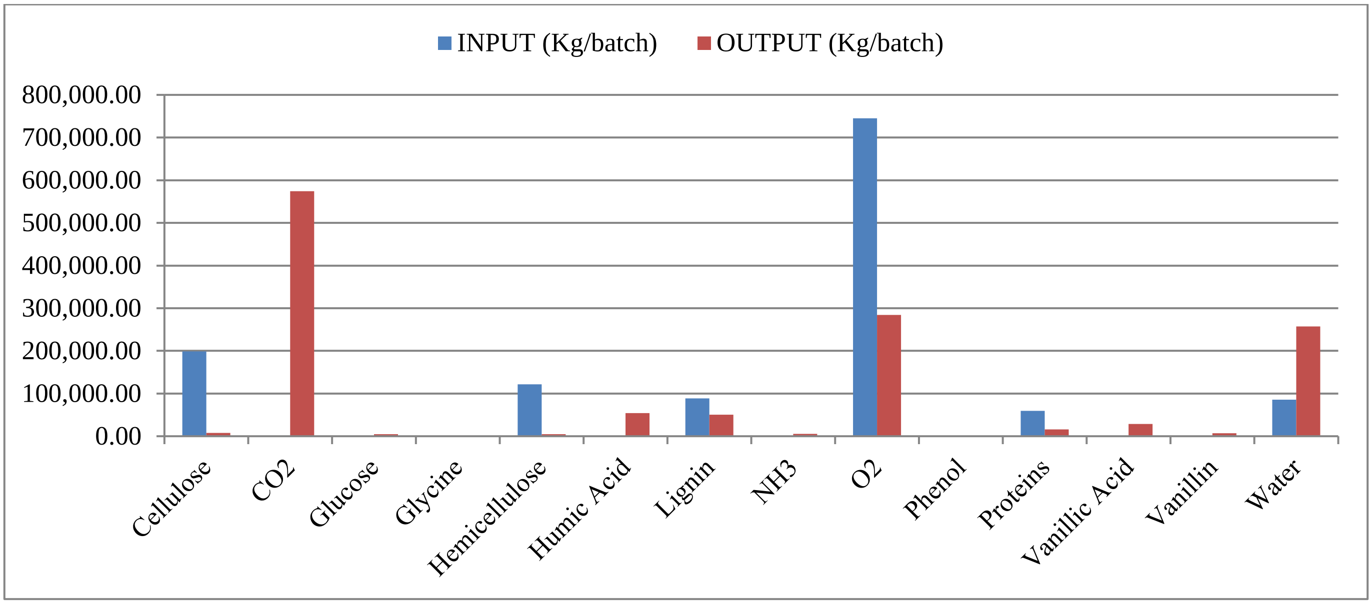


Fig. 14 Component balance in the composting process

Table 11. Executive summary

Total Capital Investment	20,482,696	$
Operating Cost	5,329,105	$/yr
Revenues	4,251,000	$/yr
Batch Size	1,310,061.73	kg MP
Cost Basis Annual Rate	8,501,473	kg MP/yr
Unit Production Cost	0.63	$/kg MP
Unit Production Revenue	0.5	$/kg MP
Gross Margin	34.63	%
Return On Investment	14.63	%
Payback Time	6.83	Years
IRR (After Taxes)	8.3	%
NPV (at 7.0% Interest)	1,156,000	$

Using SuperPro Designer and GIS software, the design, simulation, operating conditions, prediction, and mapping of Saudi Arabia's palm frond composting process greatly enhance the region's overall waste management and organic fertilizer production. The design, simulation, and mapping of the palm frond composting process may be customized to meet Saudi Arabia's unique waste management and agricultural needs by combining SuperPro Designer and GIS software, fostering sustainable development and a circular economy in waste management.

3.4. Cost Analysis

Total capital investment, operational costs, revenues, batch size, cost base annual rate, unit production cost, unit production revenue, gross margin, return on investment, payback period, and Net Present Value (NPV) (at 7.0% interest) are all included in Table 11's executive summary of the project. The software was used to estimate each of these expenses. The methodology section provided more information on how to calculate these expenses. Equipment specifications were illustrated in the Table 11. Table 12 shows the equipment descriptions, the unit cost, and the total Cost of equipment. The equipment used was a well-mixed aeration basin, shredder, and rotary dryer. The total Cost of the equipment is calculated to be 3,530,000$. In the software, there are listed equipment items with fixed costs, but for unlisted equipment, there is 20 percent added to the equipment cost.

Table 12. The equipment descriptions

Quantity	Name	Description	Unit Cost ($)	Cost ($)
1	AB-102	Well-Mixed Aeration Basin. Vessel Volume = 609125.14 L	1,996,000	1,996,000
		Unlisted Equipment		499,000
1	SR-101	Shredder (Rated Throughput = 1475.21 kg/h)	111,000	111,000
1	RDR-101	Rotary Dryer (Drying Area = 84.70 m2)	717,000	717,000
		Unlisted Equipment		207,000
TOTAL				3,530,000

3.4.1. Fixed Capital Estimate Summary

Total Plant Cost (TPC) is the sum of TPDC and TPIC. In addition, the contractor's fees and Contingency Fees (CFC) must be included in the Direct And Indirect Costs (TPC). Thus, the DFC is obtained by adding TPC to CFC.

3.4.2. Total Plant Direct Cost (TPDC) (Physical Cost)

The equipment purchase cost, installation, process piping, instrumentation, insulation, electrical, buildings, yard improvement, and auxiliary facilities make up the nine components of the total plant direct cost. The methodology section included illustrations for these nine items. The TPDC, which is displayed in Table 13, is the total of these elements, which were computed as a factor from the equipment purchase cost.

Table 13. Total plant direct cost (TPDC) ($) (physical cost)

1. Equipment Purchase Cost	3,530,000	100%
2. Installation	353,000	10%
3. Process Piping	1,235,500	35%
4. Instrumentation	1,412,000	40%
5. Insulation	105,900	3%
6. Electrical	353,000	10%
7. Buildings	1,588,500	45%
8. Yard Improvement	529,500	15%
9. Auxiliary Facilities	1,412,000	40%
TPDC	10,519,400	

Table 14 Shows the Total Plant Indirect Cost (TPIC). The TIPC includes the summation of engineering cost and construction cost. The engineering cost is 25% from the TPDC, while the construction cost is 35% from the TPDC.

Table 14. Plant indirect cost ($) (TPIC)

10. Engineering	2,629,850	25% from TPDC
11. Construction	3,681,790	35% From TPDC
TPIC	6,311,640	

The Total Plant Cost (TPC) is the sum of the TPDC and TPIC. The amount was calculated to be 16,831,040 $. The contractor's fee is 5% of the TPC, and contingency is 10% of the TPC. CFC is adding these two items. Adding TPC and CFC gives a direct Fixed Capital Cost (DFC), which was calculated to be 19,355,696 $. Table 15 shows the facility-dependent Cost, while Table 11 shows the annual operating cost, which is calculated to be 5,329,105$, and Figure 15 shows the breakdown of operating costs.

Table 15. Facility-dependent cost

Cost Item	Annual Cost($)
Depreciation	1,912,000
Maintenance	283,000
Insurance	201,000
Local Taxes	403,000
Factory Expense	1,006,000
TOTAL	**3,805,000**

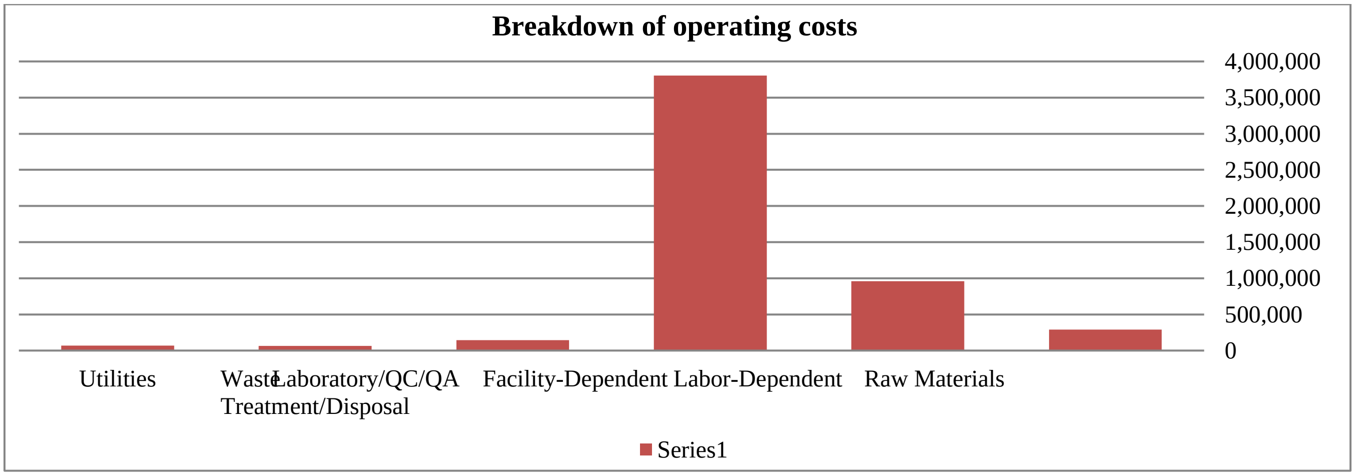


Fig. 15 Breakdown of operating costs ($)

Table 16. Annual operating cost

Cost Item	$
Raw Materials	291,000
Labor-Dependent	957,720
Facility-Dependent	3,805,000
Laboratory/QC/QA	143,000
Waste Treatment/Disposal	66,000
Utilities	66,385
TOTAL	**5,329,105**

The profitability analysis is presented in Table 12. Table 17 shows the total investment charged to this project, which is 20,482,696 $, the main revenue, which is 4,250,736$/yr, the total revenues, which is 6,801,177.6, AOC, which is 5,329,105$/yr, and the net profit, which is 2,996,959$/yeas, as shown in Figure 16. Also, Table 12 shows the gross margin, return on investment, and payback time, which are 34.63%, 14.63%, and 6.83years, respectively.

Table 17. Profitability analysis

A.	Direct Fixed Capital	19,355,696	$
B.	Working Capital	121,000	$
C.	Startup Cost	1,006,000	$
D.	Up-Front R&D	0	$
E.	Up-Front Royalties	0	$
F.	Total Investment (A+B+C+D+E)	20,482,696	$
G.	Investment Charged to This Project	20,482,696	$
H.	Revenue/Savings Rates		
S-104 (Main Revenue)	28,821,358.06	kg/yr	
I.	Revenue/Savings Price		
S-104 (Main Revenue)	0.5	$/kg	
J.	Revenues/Savings		
S-104 (Main Revenue)	14,410,679.03	$/yr	
1	Total Revenues	14,410,679.03	$/yr
2	Total Savings	0	$/yr
K.	Annual Operating Cost (AOC)		
1	Actual AOC	5,329,105	$/yr
2	Net AOC (K1-J2)	5,329,105	$/yr
L.	Unit Production Cost /Revenue		
Unit Production Cost	0.63	$/kg MP	
Net Unit Production Cost	0.63	$/kg MP	
Unit Production Revenue	0.5	$/kg MP	
M.	Gross Profit (J-K)	9,081,574.03	$/yr
N.	Taxes (2%)	387,113.92	$/yr
O.	Net Profit (M-N + Depreciation)	6,782,460.11	$/yr
Gross Margin	63	%	
Return On Investment	33.11	%	
Payback Time	3	years	

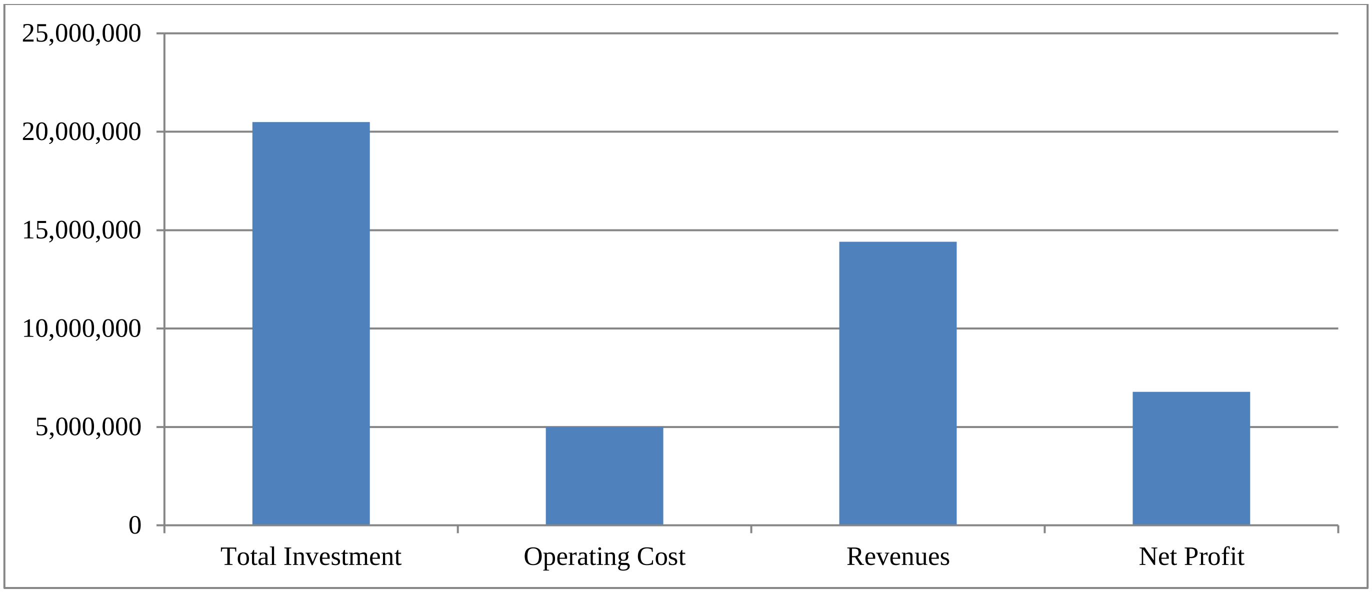


Fig. 16 Economic summary of the project

This study focused on the Design, Simulation, and Mapping of the Palm Fronds Composting Process in Saudi Arabia. The design, simulation, prediction, and mapping of the palm fronds composting process in Saudi Arabia using SuperPro Designer and GIS software is a significant advancement over cutting-edge methods and previously published research in a number of important areas. This study played an important role in improving the modeling capabilities, validation processes with real data, prediction depends on the surveyed data, site selection optimization of the waste management, Process Effectiveness and Quality Enhancement, Sustainability, the Economic Impact, and Decision Support Systems.

4. Conclusion

An important development in waste management and the creation of organic fertilizer is provided by the design, simulation, prediction, and mapping of the Palm Fronds Composting Process in Saudi Arabia by integrating SuperPro Designer and GIS software. This study contributes to a more sustainable agricultural framework, corresponds with national objectives, and establishes a precedent for similar research activities in other locations by tackling both the operational inefficiencies in composting and the environmental difficulties faced by agricultural waste.

IDW, OK, SK, UK, IK, PK, and DK are the seven interpolation techniques that were employed in the study. Even though the statistical analysis of the palm data was done using data from actual measured data, the interpolation techniques are arranged in a particular sequence. Accurate altitude employment was the primary goal of implementing these technologies. The six alternative interpolation techniques yielded results that were acceptable and were ranked in decreasing order of accuracy, with the IK producing the best interpolation results.

SuperProdesigner software was used to simulate composting of palm fronds. The software was very useful in conducting this kind of simulation because it uses specialized built-in equipment for this purpose. The simulation results showed very good details in mass and energy balances and cost analyses. The capital cost was estimated. The product composition was compared with the literature for validation purposes. The profitability analysis was performed. The total investment required for this plant is 20,482,696dollars, the main revenue is 14,410,679.03 dollars/year, the total revenue is 6,801,177.6, AOC is 5,329,105dollars/year, and the net profit is 6,782,460.11dollars/year. Also, the gross margin, return on investment, and payback time were estimated to be 63.00%, 33.11%, and 3 years, respectively.

4.1. Suggestion for Future Work

1. The preservation of palm tree-planted areas and the expansion of KSA's agricultural area should be prioritized.
2. A statistical census of the proportion of productive to non-productive palm plants should be prioritized.
3. The significance of implementing contemporary techniques for counting palm trees in censuses, especially those that utilize satellites, drones, Global Positioning System (GPS), and Geographic Information Systems (GIS).

Availability of Data Materials

The dataset used during the current study is available from the corresponding author on reasonable request.

The Paper's Highlighting

- The present research focuses on the positive benefits of using palm frond waste as a feedstock for the production of organic fertilizer, as well as the benefits of organic fertilizers in general.
- Sheds light on how managing a significant amount of palm frond waste can enhance Saudi Arabia's (KSA) environment.
- Applying the powerful simulation application SuperPro-Designer, which is considered capable of modelling the aerobic composting process.
- Validation of interpolation and experimental data with simulation data acquired, combined with ArcGIS 10.4 and SuperPro Designer.

Abbreviations

t_R:	Hydraulic residence time, GIS: Geographic Information Systems, IDW: Inverse Distance Weighting
OK:	Ordinary Kriging, SK: Simple Kriging, UK: Universal Kriging, IK: Indicator Kriging
PK:	Probability Kriging, DK: Disjunctive Kriging, V_W: Working liquid volume, V: Vessel volume
F:	Feed volumetric flow rate, NPV: Net Present Value, NCF: Net cash flow, i: Interest rate, k: Year.
AOC:	Annual Operating Cost: ROI: Return on investment, UFRD: Up-front R&D, UFR: Up-front royalties
SC	Startup and validation cost, WC: Working capital, f_p: Fractions of the process, f_S: Salvage fraction
F_C:	Fraction added to the year's capital expenses, d_{tot}: Total depreciable amount,
d_k :	Depreciable amount of a section's assets in year k, N: Depreciation (recovery) period
B	Cost basis of a section's assets (the Cost right before the project starts)
S	Salvage value of the section's assets at the end of the depreciation period
f_p	Fraction of a section's DFC that is assigned to this project,
UDFC	Undercoated DFC of a section (i.e., the fraction of a section's DFC that has not been depreciated already).
C_s	Startup & validation Cost of a section, f_s: Salvage fraction of the entire DFC
AOC_V:	Annual variable operating Cost, f_Q: Fraction of operating capacity for that year
t:	Months of operation for that year (if it is the first year of operation), AOC_F: Annual fixed operating cost
TPIC:	Total Plant Indirect Cost, TPC: Total Plant Cost, CFC: Contactor's fees, and the contingency fees
PC:	Purchase cost of the equipment, C0: Base cost, Q: Required capacity, Q0: Base capacity, α: Power

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