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Journal of Technology and Innovation

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Support the international scientific community in its written production Science, Technology and Innovation in the Field of Engineering and Technology, in Subdisciplines of technology and technology in telecommunications, food technology, computer technology, technology in transport systems, technology in motor vehicles, energy technology, naval technology, nuclear technology, textile technology, systems engineering, electronics engineering, energy engineering, innovation.

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Presentation of content

In the first article we present, *Machine-Learning model for estimating sugarcane production at crop level*, by Lárraga-Altamirano, Hugo René, Hernández-López, Dalia Rosario, Piedad-Rubio, Ana María and Blanco-Martínez, José Ramón, with adscription in the Tecnológico Nacional de México - Instituto Tecnológico de Ciudad Valles, in the next article we present, *Tax colletion and the use of ICT through the referenced payment: the perspective of taxpayers in Texcoco, State of Mexico, in 2019*, by Teja-Gutiérrez, Rebeca, López-Lira, Nidia and Loera-Suárez, Verónica, with adscription in the UAEM Texcoco, UAEM Valle de Chalco, in the next article we present, *Analysis of the use of the cell phone in the learning process of the students of The Superior Technique in Industrial Processes of the UTNA*, by VAZQUEZ-GUTIERREZ, Rosa Inés, with adscription in the Universidad Tecnológica del Norte de Aguascalientes, in the next article we present, *Attenuation of the effect of salinity on redwood (Caesalpinia platyloba) by saline compost*, by Roblero-Roblero, Elier Rutilo, Ruelas-Ayala, Rey David, Sañudo-Torres, Rosario Raudel and Félix-Herrán, Jaime Alberto, with adscription in the Universidad Autónoma Indígena de México.

Content

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Article

Machine-Learning model for estimating sugarcane production at crop level

Modelo Machine-Learning para estimación de índice de producción de caña de azúcar a nivel de cultivo

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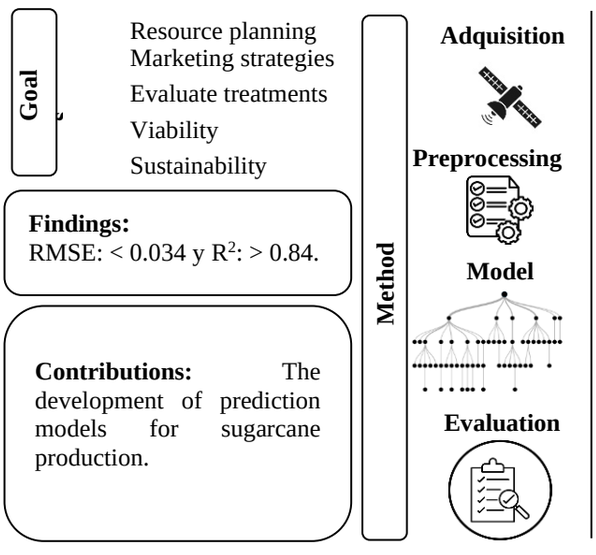
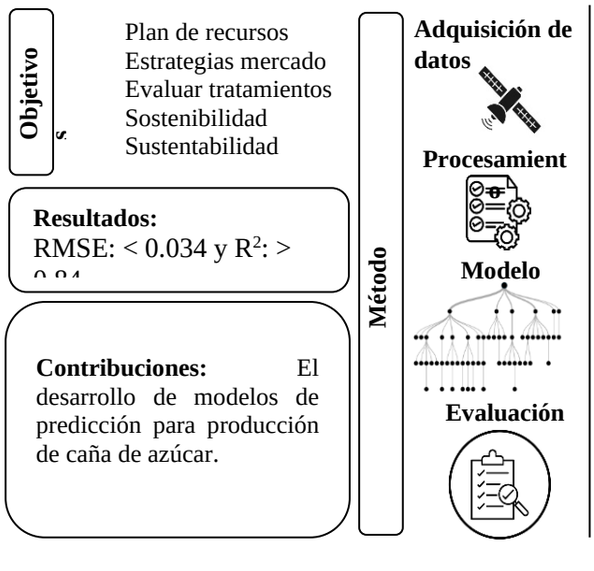
Abstract

Yield maps provide essential information for those who manage the field. The anticipated production data will be able to make better decisions on how resources should be used in harvesting, define market strategies and, above all, it will help evaluate treatments used on the crop. Sugar cane is the predominant crop in Huasteca Potosina, Mexico. The proposed Machine Learning model based on Random Forest Regressor integrates time series of vegetation indices extracted from Sentinel-2 images and meteorological data. The R^2 and RMSE metrics (0.84 y 0.034) show the effectiveness of the model for prediction.

Resumen

Los mapas de producción de cultivo proveen información esencial para quienes administran el campo. El dato anticipado de la producción permitirá tomar mejores decisiones sobre los recursos a ocupar en la cosecha, definir estrategias de mercado y, sobre todo, servirá para evaluar tratamientos utilizados sobre el cultivo. La caña de azúcar es el cultivo predominante en la Huasteca Potosina, México. El modelo Machine Learning propuesto basado en un Random Forest Regressor integra series de tiempo de índices de vegetación extraídas de imágenes Sentinel-2, y datos meteorológicos. Las métricas R^2 y RMSE (0.84 y 0.034) muestran la efectividad del modelo para la predicción.





Yield estimation, sugarcane, random forest regressor

Estimacion de la producción, caña de azúcar, random forest regressor

Citation: Lárraga-Altamirano, Hugo René, Hernández-López, Dalia Rosario, Piedad-Rubio, Ana María and Blanco-Martínez, José Ramón.Machine-Learning model for estimating sugarcane production at crop level. Journal of Technology and Innovation. 2024. 11-28:1-13.

Introduction

Crop production maps provide essential information for field managers, providing indicators to guide decisions towards best practice in agriculture. The importance of knowing the production rate in advance of harvest lies in better understanding the variability of each part of the crop over a complete cycle, and thus zoning plots and improving the application of site-specific strategies (Xu et al., 2020).

Sugarcane is the crop with the highest production worldwide; in Mexico alone, 772,003 hectares were harvested in 2017, which produced 56,954,993 tonnes of this grass, mostly used by the sugar industry (FAO, 2019). The Huasteca Potosina is the regional context where the present project is developed, the cultivation of sugar cane predominates over others, contributing significantly to the national production of this grass. The national production index per hectare from 2007 to 2016 decreased by 4.2%, showing very marked ups and downs and closing at approximately 70 ton/ha (SIAP, 2019).

Therefore, in the particular case of sugar cane in the Huasteca Potosina region, Mexico, the trend is to better manage resources under a sustainability scheme. The efficient and sustainable production of sugar cane is an important issue, since on the one hand there is a tendency to better manage the field with fewer resources, and on the other, to reduce the negative impact of agricultural activities on the environment (Said Mohamed et al., 2021).

Information and communication technologies play a central role in building smart farm models that provide the farmer with information acquired from different media, allowing real-time monitoring of plots to plan their activities in response to changing circumstances (O'Grady & O'Hare, 2017).

The study of agricultural fields through Remote Sensing (RP) techniques has empowered Smart Agriculture, being the basis for the development of technological solutions that favour the implementation of activities such as crop monitoring. RP methods that provide satellite images as a basis for statistical analysis are potentially suitable for producing data of good accuracy on some biophysical variables, from which reliable, efficient and timely estimates of crop condition can be obtained.

This potential is largely due to the information that is generated on a frequent basis from revisits of satellite platforms (Tovar Blanco et al., 2020).

From satellite images it is possible to construct time series based on the calculation of vegetation indices (VI), another important component that adds value to crop characterisation. IVs correlate with crop development, examples of these are: Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Normalized Difference Water Index (NDWI), Green-Red Vegetation Index (GRVI), Leaf Area Index (LAI), among others (K.C. et al., 2021).

Machine Learning (ML) methods, either supervised or unsupervised, have been used to transform the large amount of spectral time series data into information useful to the producer, through classification or regression models that can estimate crop production. The ML method integrates a learning process from a set of examples (training), each example describing crop attributes also known as variables or characteristics. In other words, the ML method has the ability to relate each input characteristic to a corresponding output value. Of the techniques that have demonstrated greater accuracy in prediction compared to traditional statistical methods are Radom Forest (RF), Artificial Neural Network (ANN) and Support Vector Machine (SVM). Highlighting that RF in agricultural data analysis applications has proven to be one of the best non-parametric statistical methods for classification and regression due to its high estimation accuracy, high computational speed, robustness and ability to predict important variables (Felipe Maldaner et al., 2021).

The importance of knowing the production index in advance of harvest lies in better understanding the variability of each part of the crop during a complete cycle, and thus zoning plots and improving the application of site-specific strategies. There are several methods of estimating crop production rate: 1) using growth models (CGMs) that simulate the physical process of the crop; 2) through high and low resolution satellite imagery with which it is possible to cover larger areas; 3) through light detection and ranging (LiDAR) data with which height information is obtained due to its very high spatial resolution (Xu et al., 2020).

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Lárraga-Altamirano, Hugo René, Hernández-López, Dalia Rosario, Piedad-Rubio, Ana María and Blanco-Martínez, José Ramón.Machine-Learning model for estimating sugarcane production at crop level. Journal of Technology and Innovation. 2024. 11-28:1-12. https://doi.org/10.35429/JTI.2024.28.11.1.13

The present research project is focused on the development of a technological solution that supports the decision making of sugarcane producers in the region, in other words, producers must make decisions based on a greater amount of information that gives certainty to the economic viability without leaving aside the environmental friendliness. To this end, it is proposed to design a sugar cane production estimation model based on Machine Learning (ML) algorithms to predict the number of tonnes per hectare expected to be harvested during the season. The anticipated production data will allow better decisions to be made about the resources to be used in the harvest, define market strategies and, above all, serve as a parameter for evaluating the chemical or organic treatments used in the season.

Background

The estimation of the sugar cane production index has been a subject addressed in different research studies around the world, which show the diversity of methods applied for its calculation. Of the methods applied, those that use remote sensing for the study of agricultural surfaces stand out, and currently, in conjunction with machine learning techniques, have managed to improve the estimation models. This section mentions work carried out by different authors who contributed to this project.

The production prediction model presented in (Arab et al., 2021), oriented to grape cultivation, exposes the importance of the crop phases in the production season, as well as the usefulness of production maps for the producer, showing the variability along the field to determine the best harvesting time and market strategies. An ML model was implemented together with time series satellite imagery based on NDVI, LAI and NDWI. Statistical methods were used to determine the different crop growth stages, particularly in the study of NDVI behaviour, this seasonality was treated by a representative mean for each crop. A regression model was implemented through an artificial neural network (ANN). The prediction results were compared against field data, finding that the model can be applied to estimate yield indices.Meanwhile (Canata et al., 2021), highlights the importance of the use of production maps in decision making in the context of Precision Agriculture (PA). Using multi-temporal orbital imagery and ML techniques, a sugar cane production estimation model was proposed.

The satellite platform used was Sentinel 2, obtaining images from sowing to harvesting of the crops studied. The model based on RF (Random Forest) and MLR (Multiple Linear Regression) used the dataset of satellite images and crop data filtered and interpolated to the same spatial resolution as the images, was divided into a training and test set. The near infrared band showed a large contribution to the yield estimate.

In (Singla et al., 2020), the use of ML algorithms and the use of remote sensing to extract agricultural information was proposed for the construction of sugarcane prediction models. As a first attempt, the parameters to be used as model input were determined through the Mean Decline Accuracy and Mean Gini Decline metrics of the Random Forest (RF) algorithm. It was noted that GNDVI, NDVI and Land Surface Water Index obtained the best results among other indices. The objective of the proposed work focused on machine learning methods to optimise the correlation of historical crop yield values with spectral information. The RF method shows significant performance compared to other methods such as classification and regression tree, support vector regression and nearest neighbour.

In (Jeena Jacob et al., 2021, Chapter 58) a crop yield estimation model was implemented using a multilayer Perceptron neural network and Random Forest Regression, trained with data from 4 crops, weather information and yield data. Climatological information included maximum, minimum and average values of temperature, humidity and pressure. The metrics used to evaluate the models were: absolute error (MAE), mean square error (MSE) and root mean square error (RMSE). For real-time prediction, a web application was created using Python, Flask where the user accesses the trained model to predict performance.

Methodology

Study area

The study area is a commercial crop with an area of 100 ha of which 80 ha are used for production, divided into 17 plantations, Figure 1. Located in the municipality of Ciudad Valles, San Luis Potosi, Mexico (22.0038508° N -99.0496236° W 78.0256153 m), whose climate is warm sub-humid with summer rains.

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Box 1

Figure 1
Study crop, "El Tuzo" ranch, Ciudad Valles, S.L.P., México

Source: Google Earth
https://earth.google.com/web/@22.00020428,-99.05020569,78.37226312a,4280.28218377d,30y,0h,0t,0r

All fields within the crop have the same cane variety CP 722086, the production season lasts 12 months, the harvest months are from October to December each year.

Data acquisition

The data collection includes variables that affect the sugar cane production rate, such as spectral information from satellite images, climatological data measured by weather stations and the production data of the studied crop. The multispectral images are obtained from the Sentinel-2 platform, whose constellation consists of two satellites (A and B), equipped with an MSI (MultiSpectral Instrument) sensor with 13 spectral resolution bands, with spatial resolutions of 10 m, 20 m and 60 m and a revisit frequency of 10 days for each satellite with a difference of 5 days between them. The images are downloaded through the free Copernicus Hub repository for the period 2018-2023, each image covers an area of 110 km x 110 km with a UTM/WGS84 projection system (Canata et al., 2021).

The climatological data collected must coincide with the period of the image download, so that the variables of precipitation, evapotranspiration, average, maximum and minimum temperatures of each production cycle are known (Yu et al., 2020). In Mexico, there are weather stations administered by CONAGUA (National Water Commission), which makes this information available on its official website. The stations located near the study crop are the following (Government of Mexico, 2023):

- 24076 Santa Rosa.
- 24012 Ciudad Valles.
- 24043 Micos.

Once the data have been homogenised they must be geospatially interpolated within the crop area, considering as reference the known locations of the meteorological stations, applying the kriging and IDW interpolation algorithms (Shukla et al., 2020). On the other hand, production measurements for each crop fraction (block) are collected through the sugarcane producer in tonnes/hectare (ton/ha). Additionally, data related to the supply of fertilisers, herbicides and pesticides, as well as irrigation management and timing, crop age and finally sowing and harvesting dates are obtained for each block (Hammer et al., 2020).

Data adequacy

Feature extraction

The vegetation indices known as NDVI, GNDVI, LAI and NDWI are calculated, these characterise the sugar cane crop in its different phenological phases through the production cycles, making it possible to extract statistical data from each image over time. The mean, maximum and minimum value, standard deviation, quartiles 2 and 3 are obtained. Through the NDVI statistics and extracting only the cultivated surface area (segmentation), the time series is visualised over the period 2019-2023, thus, the behaviour of production with respect to the mentioned index is observed. Based on the NDVI time series, phenological characteristics related to the crop cycle are calculated, taking advantage of the advantages of this index in identifying the density of the vegetation with high values. Phenological characteristics such as (Dimov et al., 2022):

- Start of season (SOS).
- Date of highest NVDI peak of the season (POS).
- End of Season (EOS)
- Maximum NDVI value POS
- Average sum of NDVI values
- Average sum of maximum NDVI values POS
- Length of season in days
- First half of the season, days between SOS and POS
- Second half of the season, day between POS and EOS

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The yield dataset was obtained from the transformation of EVI (Enhanced Vegetation Index) values to the yield index reported by the crop manager (Ji et al., 2021).

Selection of characteristics

The number of features infers in the estimation process, variables with a low correlation with respect to the sugarcane yield index cause an unreliable prediction, also, the computation time is increased due to the high dimensionality of the model. This is why feature selection is desirable for better interpretation and increased estimation efficiency. The study of correlation between independent and dependent variables is of importance for feature selection, alternatively there are models such as PCA (Principal Component Analysis) and EFA (Exploratory Factor Analysis) to identify those independent variables with a high correlation with respect to the dependent variable (Singla et al., 2020).

Model design

In this study, the Random Forest Regressor (RFR) algorithm is proposed to analyse the non-linearity of the predictor variables in relation to the dependent variable (production index), the model can be tested using a varied set of input data. For each characteristic, the RFR identifies the degree of importance of all selected predictor variables. The RFR is comprised of multiple independent decision trees, which average their estimates to minimise absolute error and handle a high dimensionality data set such as time series. The tuning of the algorithm considers the adjustment of hyperparameters to achieve a higher degree of prediction efficiency. The number of decision trees, the depth of the tree and the maximum number of features to be analysed are the parameters to be tuned. The model training estimates that 70% of the data is used for the learning process, while the remaining 30% is used for validation (Everingham et al., 2016).

Model evaluation

To measure acceptable model accuracy, the evaluation metrics Rr2, root mean square error RMSE and mean absolute deviation MAE are applied, using equations 01, 02 and 03.

$$R^2 = 1 - \frac{\Sigma_{i=1}^{n}(y_i - \hat{y}_i)^2}{\Sigma_{i=1}^{n}(y_i - \overline{y_i})^2} \quad [1]$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \quad [2]$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i| \quad [3]$$

Where n is the number of samples and yi and ^y the observed and estimated values by the model respectively and ---y the means of all observations. The higher the R2 value, the lower the RMSE and MAE, which can be concluded as an effective prediction of the model (Wang et al., 2022).

Results

Data acquisition

The images were acquired from the Copernicus platform managed by the European Space Agency (ESA). The search configuration specified the study crop, the query period, the 2A and 2B satellites that form the Sentinel-2 constellation, see Figure 2.

Box 2

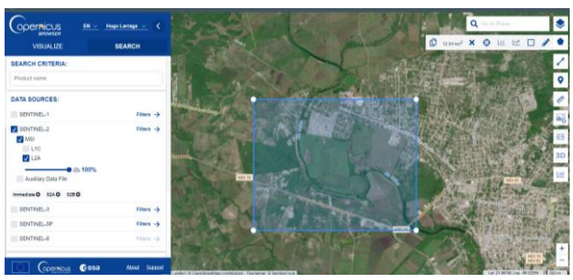

Figure 2
Copernicus Hub Platform

Source: ESA https://dataspace.copernicus.eu

Also, the product level was determined as L2A, i.e. orthorectified images with reflectance levels below the atmosphere. The cloud cover percentage was kept at 100%, as it is not known with certainty whether the crop surface will be covered by clouds. Table 1 shows the number of images downloaded from the above-mentioned platform.

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Box 3

Table 1

Sentinel-2 images downloaded

Year	S2 scenes
2019	71
2020	64
2021	46
2022	47
2023	62

Source: Own elaboration

The pre-processing of this image gallery was carried out in 3 stages:

1) Image cropping using a vector format mask to obtain only the area where the study crop is located, as presented in Figure 3. It is worth remembering that the Sentinel-2 images have an extension of 110 x 110 km, therefore, it is necessary to extract only the crop image. The download package consists of a set of images in different regions of the electrogenic spectrum with different spatial resolutions, the average data weight is 1Gb.

Box 4

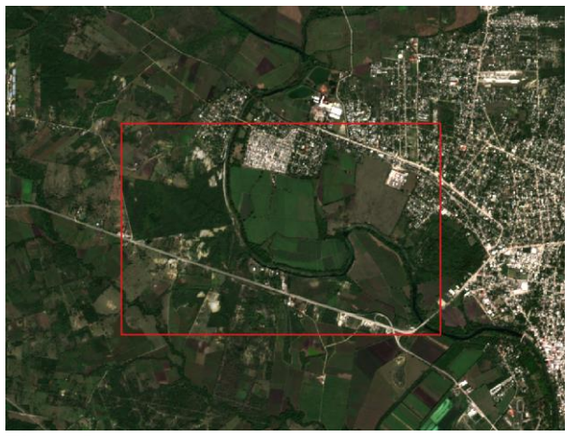

Figure 3

Sentinel-2 image crop

Source: Own elaboration

2) Increase the resolution of bands 5, 6, 7, corresponding to the Red Edge region; band 12 shortwave infrared and the SCL (Scene Classification Map) product. These images are used for the calculation of vegetation indices and cloud masking operations. It is desirable to work with the highest resolution spectral information, therefore, the aforementioned bands are transformed from 20m to 10m resolution. The operations implemented for this purpose, occupy a bilinear interpolation, taking band 4 (visible red) as the basis of transformation.

3) Calculation of the vegetation indices NDVI, GNDVI, LAI and NDWI. These combinations of spectral bands allow the study of crop conditions of interest to the grower. An example of the NDVI index is shown in Figure 4.

Box 5

Figure 4

Example of NDVI vegetation index

Source: Own elaboration

Time series

The time series that were analysed are 2, according to the type of data they contain: the vegetation index series and the climatological data series.

The information of the latter was provided by the CONAGUA agency of the state of San Luis Potosí, comprised the period 2018-2022, with the following variables:

- Monthly average temperature
- Date of the extreme minimum temperature
- Date of the extreme minimum temperature
- Maximum daily precipitation in the month
- Date of the maximum daily precipitation in the month
- Date of the maximum daily precipitation in the month

Total monthly evaporation

From the above list, only two meteorological characteristics were considered for study, those that have the greatest influence on crop development, namely temperature and precipitation.

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The providers of this information were 5 meteorological stations distributed in the municipality of Ciudad Valles, S.L.P., identified by key and name according to the following list:

- 24076 Santa Rosa.
- 24012 Ciudad Valles.
- 24043 Micos.
- 24065 San Felipe.
- 24028 El Tigre.

The homogenisation of the climatological information was carried out by means of the CLIMATOL software. The cleaning of the data foresees that there are values affected by instrumentation failures, omission, human error, etc. Stations 24065 and 24028 were discarded due to lack of information on the variables of interest.

The Kriging and IDW algorithms and the QGIS geographic information system were used to interpolate the temperature and precipitation values over the crop space, see Figure 5.

Box 6

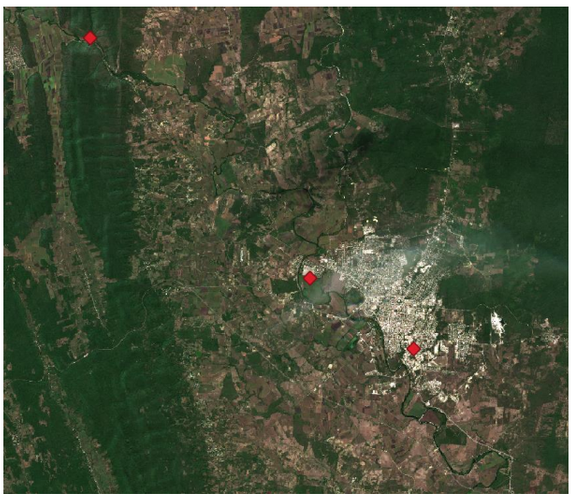

Figure 5
Weather stations near the study crop
Source: Own elaboration

The result of this operation was 12 files in raster format with interpolated monthly temperature values and 12 with monthly precipitation values. In total 96 rasters were processed for the seasons 2019-2022.

For the vegetation index time series we first calculated the overall statistics for each image, selecting only the pixels belonging to the crop by means of a binary mask presented in Figure 6.

Box 7

Figure 6
Binary mask of the study crop
Source: Own elaboration

The statistics calculated from the pixel collection were:

- Number of crop pixels.
- Percentage of the crop classified as vegetation according to the SCL.
- Minimum value.
- First quartile ['25%'].
- Minimum value.
- Mean.
- Third quartile ['75%'].
- Maximum value.
- Standard deviation.
- Histogram of pixels in the ranges -1 to 1.

Statistical values were stored in CSV format for quick retrieval. The graphical representation of the NDVI time series using the general statistics is shown in Figure 7. Cloud occlusion is a common phenomenon in satellite images, for this case the SCL product was used to filter out classes 4 and 5 corresponding to vegetation and classes 8, 9 to low and high probability of clouds. The scenes affected in a percentage greater than 30% of the crop surface by the cloud masking operation were recalculated by cubic interpolation. Subsequently, to plot the time series, the lowest, average and maximum values were smoothed by applying a moving average and spline interpolation to minimize the overall curvature of the plot, see Figure 8.

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Box 8

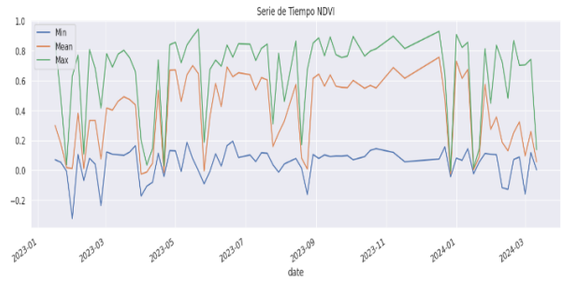

Figure 7

NDVI time series plot with statistical values (2023-2024)

Source: Own elaboration

Box 9

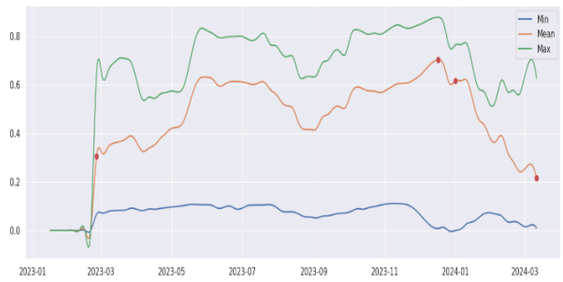

Figure 8

NDVI time series plot with smoothing and phenological data (2023-2024)

Source: Own elaboration

Once the time series has been processed it is possible to identify phenological variables. In Figure 8 the beginning of the season, the maximum NDVI value in the season and the end of the season are marked with red dots. Table 2 contains the details of the phenological information.

Box 10

Table 2

Phenological variables of the NDVI time series

CICLO	SOS	SOS_VAL	POS	POS_VAL	EOS
2019	2019-02-06	0.219916	2019-11-08	0.719613	2020-03-17
2020	2020-03-17	0.302193	2020-10-08	0.654029	2021-02-15
2021	2021-02-15	0.265945	2021-08-19	0.652035	2022-03-02
2022	2022-03-02	0.307735	2022-10-28	0.681958	2023-02-25
2023	2023-02-25	0.302675	2023-12-17	0.703349	-

Source: Own elaboration

Input data

The input data consisted of six sets of characteristics for each season. Each set is composed of the seasonal production index as the dependent variable and the features or independent variables that are hypothesised to be related to production.

The spectral and climatic data were transformed to CSV format along with the coordinates (x,y) so as not to lose the location of each element on the 2D image. These sets were labelled for control as follows:

DS1: time series of vegetation indices between SOS and EOS period.

DS2: 4 randomly selected scenes of the growth phase, between the SOS and POS period.

DS3: 4 randomly selected scenes from the senescence phase, between the POS and EOS period.

DS4: DS3 + Sentinel-2 bands 10m resolution (2, 3, 4, 5, 6, 7, 8, 12).

DS5: DS3 smoothed by sliding window averaging operation with 3x3 kernel.

DS6: DS3 + weather variables January-December.

The production index for each season is provided by the crop manager, based on the record of the sugar mill where the sugar cane enters. Table 3 shows the production for each season.

Box 11

Table 3

Seasonal production rates

Year	ton/ha
2019	89
2020	70
2021	70
2022	78

Source: Own elaboration

To estimate the production index at crop image level, the spatial resolution and the EVI vegetation index were considered. The process starts with the selection of a pre-harvest scene to estimate the EVI index, Figure 9 presents the histogram which like NDVI index the range of values is from -1 to 1.

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Box 12

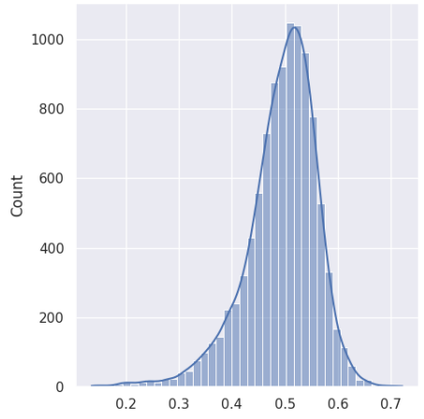

Figure 9
EVI vegetation index histogram
Source: Own elaboration

Outliers were identified as shown in Figure 10, which were removed from the set.

Box 13

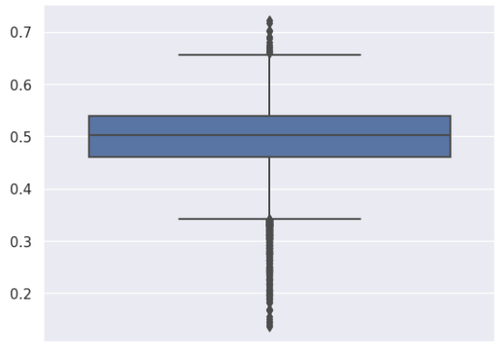

Figure 10
Box plot of EVI values
Source: Own elaboration

After data cleaning, a scaling operation was performed for each of the EVI values and the range determined by the minimum and maximum value of the set, so that the mean of the new set is the expected production index.

Training and evaluation

Hyperparameter tuning of the RFR model was achieved using the Cross Validation technique implemented in a Grid Search.

The number of subsets tested was k = 5, the result is shown in Table 4.

Box 14

Table 3
Best hyperparameters, crossvalidation

Hyperparameters	Value
Number of trees	500
Branch depth	50
Maximum Characteristics	sqrt
Random_State	18
RMSE	-0.01667882

Source: Own elaboration

A significance analysis of the spectral variables was carried out to determine their relationship with the production index and to determine the most appropriate time frame for estimation.

Figure 11 shows the most suitable period for estimation, the dotted line represents the POS of the season. The months of November and December show a higher importance, therefore, it is the time where the prediction will have a higher accuracy.

Box 15

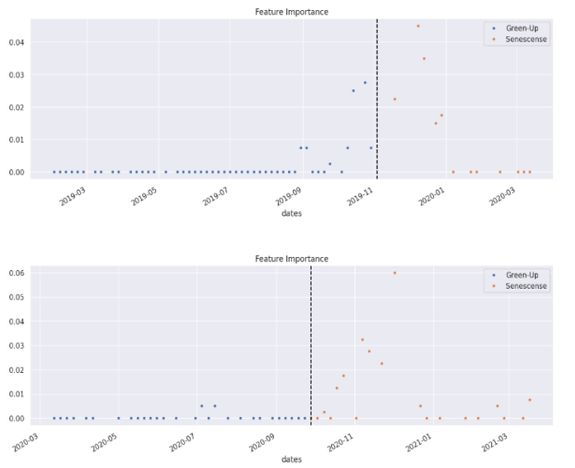

Figure 11
Spectral scene importance analysis
Source: Own elaboration

The RFR training was implemented through Google Colab and the Python programming language.

The 6 input datasets were evaluated for the 2019, 2020 and 2021 seasons. The data are cleaned of outliers, the pixels for each crop that were trained are shown in Table 5.

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Box 16

Table 5
Data available for training

Training	Test	Total
6422	2753	9175
6722	2881	9603
6483	2779	9262

Source: Own elaboration

The results of the RFR model are shown in Table 6, metrics such as R^2 and RMSE are considered to be the most effective indicators of model performance.

Box 17

Table 6
RFR model results

Ciclo	Input	Variables	MAE	MAPE	RMSE	R^2
2019	1	240	0.02	97.21	0.03345754	0.85
2019	2	16	0.04	95.02	0.05588784	0.59
2019	3	16	0.03	96.72	0.03892498	0.8
2019	4	48	0.02	97.66	0.02675273	0.91
2019	5	16	0.03	96.23	0.04462116	0.74
2019	6	40	0.03	97.07	0.03486532	0.84
2020	1	192	0.02	97.21	0.02617325	0.89
2020	2	16	0.03	94.92	0.04768077	0.65
2020	3	16	0.02	96.34	0.03397908	0.82
2020	4	48	0.02	97.53	0.02298952	0.92
2020	5	16	0.03	96.24	0.03617964	0.8
2020	6	40	0.02	97.16	0.02671924	0.89
2021	1	140	0.01	98.23	0.01865486	0.92
2021	2	16	0.03	95.54	0.04167443	0.61
2021	3	16	0.02	96.87	0.03212605	0.77
2021	4	48	0.01	98.06	0.01864354	0.92
2021	5	16	0.02	96.66	0.03353144	0.75
2021	6	40	0.02	97.65	0.02365406	0.87

Source: Own elaboration

Discussion of results

Table 6 shows that set 4, integrated by the vegetation indices of the senescence phase plus the Sentinel-2 bands with resolution at 10m obtained an R2 of 0.91, 0.92 and 0.92 for the studied seasons, at the same time they present the lowest RMSE errors, being 0.0267, 0.0229 and 0.0186 respectively. 0267, 0.0229 and 0.0186 respectively, however, there are other sets with encouraging results such as 1 and 6. Considering that these are the 3 data sets with the highest number of variables, they explain more effectively the relationship with the production index.

The analysis of the importance of the characteristics of set 1 can be seen in Figure 12 for the 2019 season.

Box 18

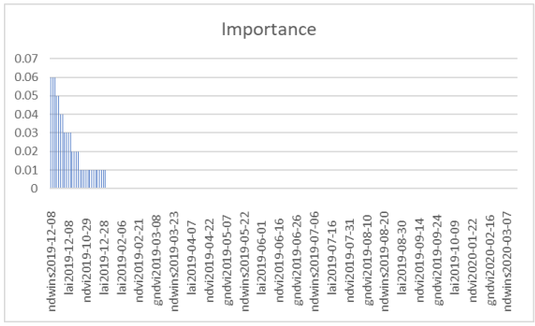

Figure 12
Importance of characteristics set 1 2019 season
Source: Own elaboration

This behaviour is the same for the remaining seasons, so that even when the model performs well, not all variables contribute value, making unnecessary computation with risk of failure. 80% of the characteristics of model 6 were important in the calculation of the estimate (Figure 13).

Box 19

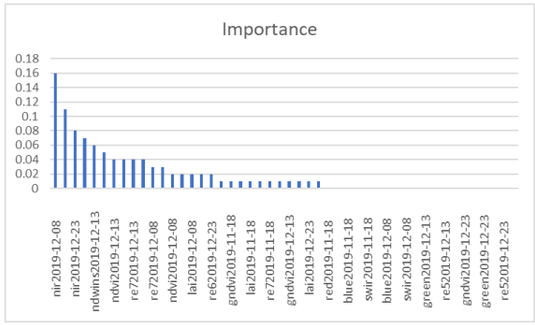

Figure 13
Importance of characteristics set 6 2019 season
Source: Own elaboration

Box 20

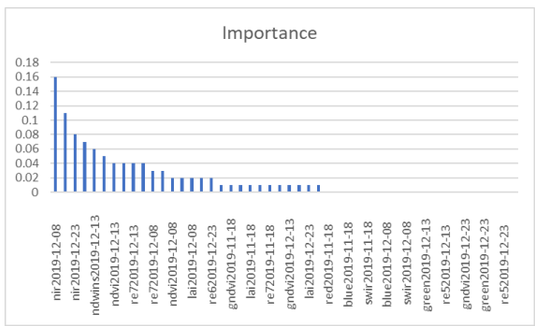

Figure 14
Importance of characteristics set 4 2019 season
Source: Own elaboration

Model 4 registers importance for only 58% of its characteristics (Figure 14). This behaviour is the same for the 2020 and 2021 seasons. The prediction behaviour of the models can be studied in Figure 15.

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Box 21

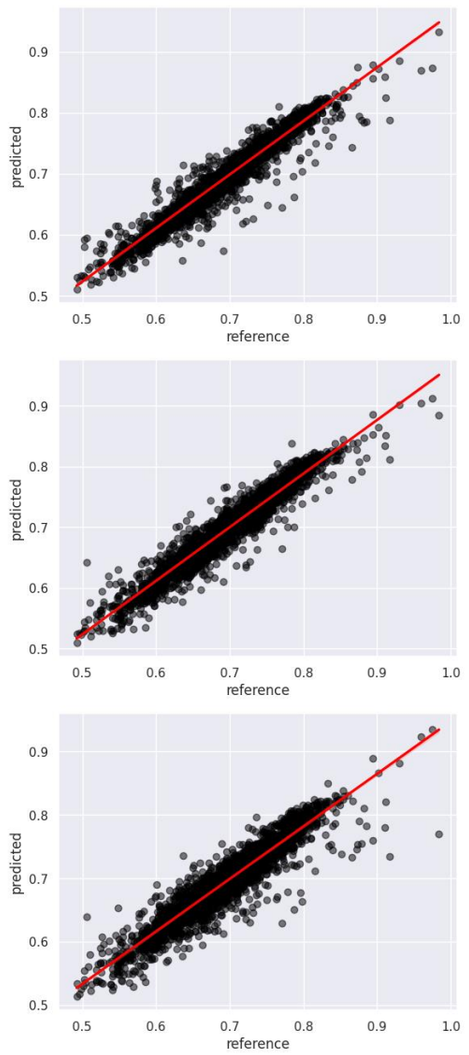

Figure 15

15 2021 season forecast performance graphs

Source: Own elaboration

The previous figure shows in red the estimation function that the model has built to predict the sugar cane production index. Corresponding to the 2021 season, set 1, 4 and 6 appear in first place.

Conclusions

This study demonstrates the potential of time series formed by Sentinel-2 multispectral satellite images with a spatial resolution of 10m in the development of predictive models for sugar cane production.

The Random Forest Regressor is a Machine Learning algorithm that has demonstrated efficiency in regression tasks, reaching in this particular case, metrics $R^2 > 0.84$ and RMSE < 0.034, when working with spectral samples of the phenological cycle of the crop included in the senescence stage. It also highlights the importance of identifying the appropriate time frame to carry out the prediction exercise, which for the crop under study is the months of November and December. The selection of features proves the importance of spectral information such as vegetation indices to characterise crops, however, the intervention of other factors such as Sentinel-2 bands or climatological data can enhance the accuracy of the prediction.

Future work includes the possibility of exploring techniques other than cloud masking by SCL, as this product is inaccurate in class classification. Therefore, the processing of the time series and the identification of phenological variables could be improved. With the prediction of the sugar cane production index, it is possible to plan the harvest and optimise resources.

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' Contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

Lárraga-Altamirano, Hugo René: Contributed to the project idea, research method and technique. He supported the design of the field instrument. He carried out the data analysis and systematisation of results, as well as writing the article.

Hernández-López, Dalia Rosario: Carried out the systematisation of the background for the state of the art. She supported the design of the field instrument. She also contributed to the writing of the article.

Piedad-Rubio, Ana María: contributed to the research design, the type of research, the approach, the method and the writing of the article.

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Blanco-Martínez, José Ramón: worked on the application of the field instrument, data collection and systematisation of the results. He also worked on the writing of the paper.

Availability of data and materials

The satellite images for the integration of the time series were obtained from the free Copernicus platform managed by the European Space Agency. Climatological data measured by the EMAS were requested from the National Water Commission of the State of SLP.

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The research did not receive any funding.

Abbreviations

ANN	Artificial Neural Network
AP	Precision agriculture
CONAGUA	National Water Commission
EMAS	Automatic Weather Stations
EOS	End of season
ESA	European Space Agency
EVI	Enhanced Vegetation Index
GNDVI	Green Normalised Difference Vegetation Green
GRVI	Green-Red Vegetation Index
IV	Vegetation Indices
LAI	Leaf Area Index
MAE	Absolute Error
ML	Machine Learning
MSE	Mean square error
NDVI	Normalised Difference Green Vegetation Index
NDWI	Normalized Difference Water Index
POS	Highest peak of the season
PR	Remote Sensing
R2	Completion Coefficient
RF	Random Trees
RFR	Random Forest Regressor
RMSE	Root Mean Square Error
SCL	Scene classification map
SCV	Comma Separated Values
SOS	Season Start

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Article

Tax colletion and the use of ICT through the referenced payment: the perspective of taxpayers in Texcoco, State of Mexico, in 2019

La recaudación fiscal y el uso de las TIC a través del pago referenciado: la perspectiva de los contribuyentes en Texcoco, Estado de México, en 2019

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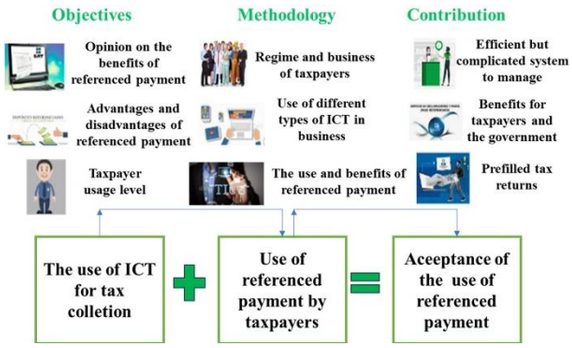
Abstract

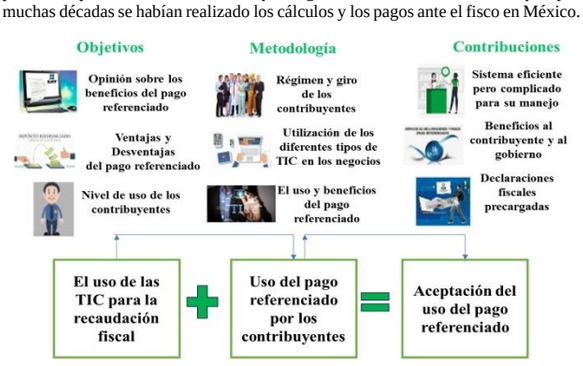
In Mexico, the Tax Administration has committed to the use of Information and Communication Technologies (ICT) to avoid tax evasion and avoidance, which is why the Mexican government has proposed an information system to comply with tax obligations. This work aimed to evaluate the advantages and disadvantages of a new system called Referenced Payment. 110 taxpayers in the municipality of Texcoco, State of Mexico, were surveyed through directed sampling. The type of research was basic and the research approach was mixed and descriptive. SPSS software version 15.0 for Windows was used to systematize and analyze the data collected in the surveys. The results show a positive acceptance by taxpayers despite being a system that changed the way in which, for many decades, calculations and payments had been made to the treasury in Mexico.



Evasion, Technologies, Referenced

Resumen

En México, la Administración Tributaria ha apostado al uso de las Tecnologías de la Información y Comunicación (TIC) para evitar la evasión y la elusión fiscal, por ello el gobierno mexicano ha propuesto un sistema de información para cumplir con las obligaciones fiscales. Este trabajo tuvo el objetivo de evaluar las ventajas y desventajas de un nuevo sistema denominado Pago Referenciado. Se encuestaron a 110 contribuyentes en el municipio de Texcoco, Estado de México, mediante un muestreo dirigido. El tipo de investigación fué básica y el enfoque de la investigación fue mixta y descriptiva. Para sistematizar y analizar los datos recabados en las encuestas se utilizó el software SPSS versión 15.0 para Windows. Los resultados muestran una aceptación por parte de los contribuyentes de manera positiva a pesar de ser un sistema que llegó a modificar la manera en que, por muchas décadas se habían realizado los cálculos y los pagos ante el fisco en México.



Evasión, Tecnologías, Referenciado

Citation: Teja-Gutiérrez, Rebeca, López-Lira, Nidia and Loera-Suárez, Verónica. Tax colletion and the use of ICT through the Referenced Payment: The perspective of taxpayers in Texcoco, State of Mexico, in 2019. 2024. 11-28:14-25.

Introduction

Mexico is one of the countries with a high rate of tax evasion and avoidance in Latin America (Licona Vite, 2011). (Licona Vite, 2011), which has led to a low level of tax revenue collection at the federal, state and municipal levels. The Mexican government has proven to be a changing agent according to the times and fiscal needs, and has therefore adopted new models and strategies for tax collection in order to avoid or reduce tax evasion and avoidance.

Therefore, the Mexican government has adopted technology as a tool to carry out its functions, including tax collection. It is known that the accelerated development of telecommunications and information technology has influenced practically all fields of human endeavour, so the technological revolution that humanity is currently experiencing is largely due to the significant advances in ICT and its application in all fields of society (Díaz Lazo, Pérez Gutiérrez, & Florido Bacallao, 2011). Some examples of the use of ICT have been in the management of Social Security (Romero Coronado, 2024), in stock market operations and financial management (Pardo Bernal, 2023) and (Espinosa Loor et al., 2023). As well as in the digital transformation in the era of a so-called 5.0 society (Maldonado Molina, 2024).

In this context, Mexico has implemented an information system called "Referenced Payment", which aims to increase efficiency, transparency, accessibility and responsiveness to the demands of taxpayers and organisations, as well as to achieve a competitive government that enables the achievement of economic and social development goals. However, this new form of collection has brought confusion and conflict for taxpayers, as for a long time they used to make their tax payments through the windows of the Tax Administration Service (SAT) modules. Therefore, the purpose of this paper is to analyse the viability, acceptance, use and efficiency of the system called "Pago Referenciado", from the users' point of view.

On the other hand, the reasons for implementing this new system for the calculation and payment of taxes in Mexico are analysed. The issue is relevant in the current Mexican context, as the Referenced Payment is part of a whole process of using Information and Communication Technologies (ICT) in the Mexican tax administration, which has been developing for several decades.

This highlights the fact that the digital era has taken off sporadically as changes in the way tax contributions are collected. In this context, ICT has been an instrument of cost reduction and information improvement for Mexican government management, as it is changing the nature of products and services (Macau, 2004).

It is worth mentioning that the study was carried out in the city of Texcoco, State of Mexico, a commercial and agricultural region, where the companies are in the range of micro and medium-sized enterprises. The type of research is basic and the approach is qualitative and descriptive, which made it possible to measure the level of use, the use and benefits of ICTs in tax collection, as well as to have a broad view of the acceptance or denial by taxpayers of the emergence of the "Referenced Payment" modality.

The document is structured as follows: first, a theoretical review of the Mexican tax system and technological progress is presented. Secondly, the level of tax collection in Mexico is presented. Thirdly, it discusses the "Referenced Payment" as a technological strategy for tax collection. In the fourth point, the methods and materials of the research are discussed, followed by the presentation of the results and then the discussion. Finally, the conclusions and recommendations are presented.

Bibliographic Review

According to Cajigas R., Ramírez, & Granados (2007), two of the most serious problems worldwide in terms of tax collection are tax evasion and tax avoidance. These authors mention that tax avoidance is understood as a lower payment of the tax payable by the taxpayer, as opposed to tax evasion, where the economic agent obliged to declare and pay a tax simply does not pay.

On the other hand, Tapia Tovar (2000) defines tax evasion as defrauding the tax administration by concealing or simulating income or expense accounts in order to pay lower amounts of tax. For this reason, Jiménez (2003) points out the importance of having an administrative control scheme that facilitates spontaneous and timely compliance in the payment of taxes.

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Of course, the phenomenon of tax evasion is explained by a number of factors, among which the following stand out: broad tax exemptions, insufficient quality and quantity in the provision of public goods and services, the growing informal economy, excessive dependence on oil revenues, government administrative failures, legal loopholes in tax laws and, finally, political factors (Ayala Espino, 2000), all of which contribute to the Mexican government's tax administration problems.

As a result of the problems faced by the tax administration in Mexico, there is a need to create new strategies and methods to calculate the taxpayers' ability to pay, thus employing the use of new Information and Communication Technologies (ICT), in order to provide the tax administration with timely and reliable information (Cajigas R., Ramírez, & Granados, 2007). Hence, the tax administration needs to have information systems to reduce fraud rates and improve the proper functioning of the tax system. A tax information system is a strategic instrument for the collection, processing and distribution of information, and are also conditioning factors for the success and competitiveness of a government administration (Armas A. & Colmenares de Eizaga, 2007) and (Martín Granados & Valdés Hernández, 2003). On the other hand, it is recognised that the financial system is important for Mexico's economic development, together with the level of tax collection (Bonilla López, 2002). On the other hand, globalisation has led to the use of information and communication technologies in the economic, social, cultural and political life of society. Something similar happens with the technological revolution that conditions developed and developing countries to be at the forefront, and Mexico is no exception.

One example is that of Latin America, where the cases of Chile, Colombia and Venezuela stand out, which have been the main pioneers in adopting the use of ICTs for tax purposes. Meanwhile, countries such as Spain, Ireland and England have taken the strategic decision to give greater priority to the use of the Internet for tax purposes (Armas A. & Colmenares de Eizaga, 2007); (Abelló Silva, 2003) and (Rovira Ferrer, 2011).There are, however, advantages in the implementation and use of ICT in the audit process, some of them are: reduction of the cost of the data procedure, reduction in the use of paper and printouts, amendments of errors, change of schedules, administrative simplification.

Reduction in the hours-visits to the tax offices, transparency in the collection of taxes, provides information to the taxpayer, tax refunds via Internet, it has even reached the point that the tax administration directly sends drafts of the pre-calculated returns so that taxpayers can simply confirm them, as mentioned by Abelló Silva (2003), Armas A. & Colmenares de Eizaga (2007), Ríos Granados (2003) and Rovira Ferrer (2011).

Consequently, Téllez Valdés (2008) comments that information systems are part of the daily life of citizens around the world and play a fundamental role in the success of the universal economy. This brings advantages for governments, but also brings with it risks of malicious attacks against information systems, as attacks against information systems are a threat to the creation of a more secure information society and a space of freedom, security and justice. Therefore, the Mexican government should implement strategies to safeguard taxpayers' information.

In the case of Mexico, the tax administration has found itself in a new facet in the tax collection strategy since the beginning of the 21st century (Ríos Granados, 2003). On the one hand, it is presented as a welfare tax administration, i.e., as a tax collection agency that controls tax obligations, verifies and verifies compliance with tax obligations, and, finally, as a welfare or auxiliary agency (Hallivis Pelayo, 2000).Consequently, the Mexican tax system has a complex structure, which implies a growing role for social security contributions, the general sales tax, as well as a lower share of customs taxes (Vargas Téllez, 2010). Its complex structure makes the Mexican government implement some strategies for taxpayers. Thus, it establishes as an obligation for them to verify all their tax obligations through the Internet. Therefore, in a certain way, it becomes a tax administration friendly for taxpayers, in the sense that it offers through electronic media all the possibilities of assistance to taxpayers, but in another sense, it increases tax obligations via Internet in favour of a good management of the tax administration (Ríos Granados, 2003).Regarding the implementation of new technologies in tax collection, a transition period should be considered, where information on a documentary and electronic regulation is provided, in which a period of time should elapse before the new trends in electronic auditing come into force.

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The Tax Administration System (SAT) has implemented electronic accounting, electronic invoicing and referenced payment. The latter is the subject of study in this research.

Tax collection in Mexico

The Mexican tax collection system is not considered progressive, especially for the Tax Incorporation Regime (RIF), considered as small taxpayers, since the tax charged to this sector of the population is not proportional to the economic capacity of taxpayers. This regime is preparatory for the obligations they will acquire when they finally join the single regime that will prevail for business and professional activities.

Consequently, they will acquire greater fiscal responsibilities and increase their taxes. This sector of the population has a low economic capacity and may not have access to the use and application of information and communication technologies to keep accounts, register their receipts, file their tax returns, among others (Portillo Villalpando, López Lira, & Rivera Huerta, 2016). As a result, many taxpayers, far from paying taxes, will remain in informality.

According to World Bank data, Mexico has very low tax collection compared to other economies, due to its high rate of tax evasion and avoidance. Mexico's problem is that a significant proportion of the population does not pay taxes or pays symbolic amounts. The situation described above is confirmed by the World Bank in its Yearbook of Public Finance Statistics on tax collection as a percentage of GDP in Mexico. Hence, in 1972 tax collection was 7.61% of GDP, by 2017 it was 13.04% of GDP as shown in Figure 1.

Box 1

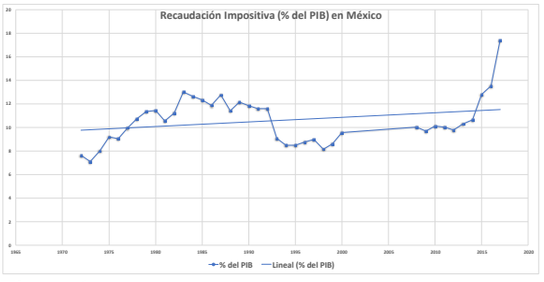

Figure 1

Tax collection (% of GDP) in Mexico

Source: (World Bank Group, 2019)

Consequently, due to the low tax collection, the Mexican tax administration has bet on the use of the Internet and information and communication technologies, so they have emphasised on having a database of taxpayers, trying to organise an "information system" in which all the taxpayer's information is stored regarding their tax obligations, such as having a record of all their transactions, payments, deposits, purchases, sales, place, date, in short, all the information concerning the payment and management of contributions, with the aim of increasing tax collection.

It is worth mentioning that tax collection in Mexico has been characterised throughout its history by multiple partial reforms, which have failed to increase tax collection, and have often only hindered and confused taxpayers.

Currently, the Mexican government has modernised its tax collection system by introducing and using Information Technologies (ICT) to automate its processes, to provide its services online, to implement communication with society, i.e. the government wants to consolidate itself as an electronic and cutting-edge government that can be competitive at a global level, so it has implemented the "Pago Referenciado" (referenced payment).

The referenced payment

The Referenced Payment is a new service for filing returns and payments through which taxpayers must make the payment of their federal tax obligations, by means of a capture line (reference). With this system, the Tax Administration Service (SAT) modernises the payment of taxes, as it uses dynamic electronic forms to facilitate the filling out, which also contain the option to automatically calculate the tax based on the direct filing of the returns with the SAT: Provisional and Definitive. This new declaration and payment system or Referenced Payment becomes one more tool for the tax authority, as every month it will know the amount of income, expenses or creditable taxes that the taxpayer has considered or generated for the determination of its tax obligations, which implies a greater internal and administrative control to avoid making mistakes that lead, for example, to the filing of complementary declarations. In the event that a tax payment is required, the taxpayer may make the payment in authorised banks, using the Referenced Payment service, i.e., through the following capture line.

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Before the implementation of the "Pago Referenciado" in August 2002, the payment of federal taxes was made quarterly and with printed tax forms. In September 2002, the electronic payment scheme was introduced. This electronic payment scheme implied profound transformations in the SAT and in its interaction with the taxpayer, since it implied the use of 100% electronic formats, which include validations and arithmetic operations, as well as functionalities to select the tax, the concept, the periodicity, the period, the fiscal year and the type of declaration, which avoids the capture of this information, that is, it no longer has to be captured, since the tax declaration is recalculated with the data and transactions crossed by banks, suppliers, clients and creditors.

Undoubtedly, in recent years, the SAT has continued to strengthen its technological platform and develop new applications with the aim of making it easier for taxpayers to comply with their tax obligations.

With the Referenced Payment service, taxpayers file their returns on the SAT's Internet portal and pay their taxes in authorised banks, using the referenced deposit banking service, i.e., through a capture line. With this service, dynamic electronic forms are used with aids to facilitate filling out, which have the option of automatic calculation of the tax. In addition, the taxpayer only goes to the authorised bank if he/she has to pay tax.

The Referenced Payment allows, eventually, to have more points to make the payment of taxes such as self-service shops or other commercial establishments, which facilitates compliance, so taxpayers can make their payment with other options.

It should be noted that nowadays, practically all services offered by the SAT can be done online, at any time, without queues, without paper, and in an easier and faster way. Taxpayers no longer have to travel to do their paperwork; they can even receive guidance remotely, via telephone, chat, social networks or directly on the SAT's website.

Using online services saves time and resources for the benefit of citizens, and also reduces the number of visits to SAT offices, benefiting taxpayers who come for guidance, as they find greater availability of appointments and are provided with a better and more effective service.

To carry out the procedures from the Internet, taxpayers only need an Advanced Electronic Signature (e.firma or FIEL) or their Confidential Electronic Identification Code (CIEC), enter the SAT's Internet portal and make the Referenced Payment.

It should be noted that according to Mexican tax laws (LISR, 2019; LIVA 2019 and the CFF, 2019), taxpayers subject to file their returns and payments through the Referenced Payment system are the following:

a) Those who carry out business and professional activities and have the obligation to pay ISR (Income Tax), VAT (Value Added Tax), and IEPS (Special Tax on Production and Services).

b) Those who are registered in the Tax Incorporation Regime and are obliged to pay ISR and VAT.

c) Taxpayers who provide professional services for medical fees and who are obliged to pay ISR.

d) Those who obtain income from renting a house and commercial premises. They have the obligation to pay ISR and VAT.

Methods and Materials

The theoretical postulates that support the research are the Mexican tax laws, which indicate the guidelines for the calculation and payment of taxes, such as: the Income Tax Law (LISR), the Value Added Tax Law (VAT) and the Federal Fiscal Code (CFF).

Study region

The study region is located in the Municipality of Texcoco, State of Mexico, which is located in the eastern part of the State of Mexico. The general map of the Mexican Republic indicates that the geographical location of the municipality of Texcoco according to its territorial extension is located at 19° 23' 40" and 19° 33' 41" north latitude and between 98° 39' 28" and 99° 01' 45" west latitude. Texcoco has an altitude of 2,250 metres above sea level. It has a total territorial extension of 418.69 square kilometres.

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The municipality of Texcoco is bordered to the north by the municipalities of Tepetlaoxtoc, Papalotla, Chiautla and Chinconcuac; to the south by Chimalhuacán, Ixtapaluca, and Chicoloapan; to the west by Atenco and Nezahualcóyotl; and to the east by the states of Tlaxcala and Puebla, as shown in Illustration 1.

The National Institute of Statistics and Geography (INEGI) carried out the population count in 2020 at the national level, and reported that the municipality of Texcoco has a population of 277,562 inhabitants. It should be noted that 2020 was the last population census in Mexico.

Box 1

Figure 2

Map of the location of the Municipality of Texcoco, State of Mexico

Source: Own elaboration

Object of study and unit of analysis

The object of study is Information and Communication Technologies (ICT) and the unit of analysis is the use of ICT for the payment of taxes through the "Referenced Payment" system.

Type and focus of the research

The type of research is basic, and the research approach was qualitative descriptive as well as quantitative, as the surveys were systematised in SPSS software version 15.0 for Windows.

Method and techniques used

The method used was analytical with the content analysis technique. Survey and interview techniques were used for data collection. For the analysis of the surveys, the statistical method was used in order to calculate descriptive statistics. SPSS (Statistical Product and Service Solution) software version 15.0 for Windows was used to collect, count, present, synthesise and analyse the survey data. This facilitated data capture, data analysis and systematisation.

Research sample

The type of sampling was non-probabilistic. Due to the fact that we did not have access to the complete list of companies and taxpayers registered in the Confederation of National Chambers of Commerce, Services and Tourism of Mexico (CONCANACO-SERVYTUR Mexico), this registry forms the total population of the universe of the sampling frame, and therefore, it was not possible to know the probability that each individual and/or company would be selected to have a statistical sample. Therefore, it was decided to select a convenience sample, i.e. from the population that was available and agreed to answer the survey. In this sense, only 110 taxpayers agreed to answer the survey, it is worth mentioning that the survey was carried out during three days and during working hours outside the offices of the module of the SAT offices in Texcoco, and they were randomly invited to participate by answering the questionnaire. Therefore, the research approach is considered mixed and does not introduce biases with respect to the population, since it is not possible to infer about the total population, however, the study provides empirical elements and an exploratory approach on the use and opinions about the Referenced Payment.

The field instrument

The survey was designed to measure the following variables and categories: a) the taxpayer's profile, where he/she was classified according to his/her branch of activity; b) the regime and line of business according to Mexican tax legislation; c) the different tax obligations he/she is subject to comply with; d) the type of ICT used to comply with his/her tax obligations; e) the use of the Pago Referenciado to comply with the tax authorities.

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Results

Based on the survey, the following results were obtained.

Economic activity carried out by taxpayers

88.5% of the taxpayers interviewed carry out activities in the tertiary sector, 8.85% carry out activities in the secondary sector and 2.65% are in the primary sector, so it is inferred that most of the taxpayers interviewed are service providers, such as transport, health, and traders, among other activities.

Tax regime under which taxpayers are taxed according to their economic activity

Most of the taxpayers surveyed are classified in the "Tax Incorporation Regime" (RIF), which amounts to 66.67%; most of the taxpayers in this regime are individuals providing services such as printing, restaurants, among others. This regime applies to taxpayers who only carry out business activities, sell goods or provide services, as long as they obtain income from salaries, wages, leasing or interest. One condition that must be met by this type of taxpayers is that their combined income does not exceed 2 million pesos per year, i.e., approximately $100,000 dollars per year. On the other hand, 26.13% of the taxpayers surveyed are under the regime of legal entities. It is worth mentioning that the regime of legal entities includes for-profit companies such as commercial companies, financial leasing companies, among others (LISR, 2019).

6.31% of the respondents are taxed under the business and professional activity regime, such as veterinary and dental clinics and offices, also known as individuals with business activity, which includes hardware stores, hardware stores, kindergartens, kindergartens, schools, mini-supermarkets, grocery shops, bars, canteens, economic kitchens, cafeterias, restaurants, mechanic shops, among others. Finally, 0.9% are taxed under the regime of income similar to salaries, this regime is for individuals who decide to provide their professional services to companies or other individuals, sporadically or temporarily.

Type of taxes they are subject to pay

Taxes such as Value Added Tax (VAT) and Income Tax (ISR) are at the top of the list, with 34.04% and 36.14% respectively. Thus, most of the taxpayers surveyed are registered in the Tax Incorporation Regime (RIF); the third tax with the highest tax collection is the Flat Tax (IETU) with 22.48% and lastly, the Special Tax on Production and Services (IEPS) with 4.26%.

How they paid their taxes

According to the surveys conducted, 58.77% already pay their taxes by funds transfer and 41.23% still go to the bank window, but more and more taxpayers are finding it necessary to adapt to the new change in the payment of their taxes, since this new form of payment by funds transfer is no longer a payment option, but an obligation as a taxpayer.

What type of technology (ICT) do taxpayers use?

28.57% of the people surveyed have mobile phone technology, in second place, the Internet with 26.46%, followed by e-mail with 20.9%, 13.76% have wireless communication technology (Bluetooth and Wi-Fi) and lastly, cutting-edge technology (IoT applications), representing 10.32%.

Use of the Internet for tax returns and payments

Regarding the use of the Internet to pay their tax returns, the results obtained in the survey show that 88.29% of the taxpayers surveyed use the Internet to pay their taxes, while 10.81% do not use it and the remaining 0.9% do not apply.

Benefits of using technology in tax obligations

An important point to analyse is the factors by which taxpayers have benefited from the use of the Internet to pay their taxes; 34.6% save time, 32.7% consider that they save money, 30.04% think that it saves paper and space, and 2.66% do not apply.

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Security and safeguarding of information

We sought to find out what taxpayers use as a security system to protect their information. It was found that 48.57% of taxpayers protect their information on the company's server, 31.43% protect their information on their PC and external disk, 16.43% protect their information online and in an Internet cloud, and 3.57% do not apply this question.

Knowledge of the referenced payment system

62.16% of taxpayers surveyed say that they do know about the Referenced Payment System, 36.04% not enough and 1.8% have not heard anything about it, so it can be inferred that most taxpayers are already familiar with this platform in the calculation and payment of their taxes under this platform implemented by the Mexican government.Taxpayers obliged to file their tax returns and pay their taxes through the Sistema Pago ReferenciadoAccording to the taxpayers obliged to file their returns and payments through the Referenced Payment System, 81.08% of taxpayers are obliged to file their returns through the new Referenced Payment Service, while 18.92% of taxpayers do not yet apply this modality due to lack of knowledge.

Is the Referenced Payment System useful and timely? 50.45% of taxpayers consider that the use of the Referenced Payment System has been useful and timely for the filing of their tax returns and payment of taxes, compared to the way of filing previously used. However, 41.44% of taxpayers consider that the use of the Referenced Payment service is not sufficient, because they consider it is deficient and sometimes slow to use, while 8.11% consider it is not useful and even stated that the previous way of filing tax returns was more practical.

Capacity for handling the Referenced Payment System

According to the implementation of the new Referenced Payment Service, 66.67% of the taxpayers have not found it necessary to train or become trained in the handling of this new system; although 33. 33% of taxpayers have needed to be trained in the use of this new system, because they consider that it is a bit more complicated to use and difficult to understand, so they have had to seek some kind of advice either from a Public Accountant or from one of the SAT offices to obtain better advice on the use and management of the system.

Reasons to consider when implementing the Sistema de Pago Referenciado (Referenced Payment System)

Some of the main objectives considered by taxpayers to be covered by the implementation of the new Referenced Payment system by SAT is savings, since 28.08% of the taxpayers surveyed consider that saving paper, time and money has been the main objective covered by the implementation of the Referenced Payment. Taxpayers no longer have to go to SAT offices or bank branches, thus saving time and money, and most taxpayers used to spend a large part of their time in carrying out their formalities to comply with their obligations in due time and form. Consequently, the use of so much paper is avoided, as information can now be stored on electronic devices such as USB sticks, hard disks, or mobile phones.

According to the study, 25.77% of respondents believe that the use of this system will reduce tax evasion currently registered in Mexico, while 27.69% mentioned that it will increase tax collection, and 15.88% of taxpayers believe that it is a measure to stay ahead as an electronic government in order to streamline certain bureaucratic procedures.

Finally, 3.08% of taxpayers did not generate an opinion because they have not used this system.

Efficiency rating of the Referenced Payment System

The results show the acceptance of the system among taxpayers, where it can be seen that 45.05% consider the efficiency level to be good, while 23.42% indicate that the efficiency level has been excellent, allowing to speed up the fulfilment of their obligations, while the other 20.72% indicate that the efficiency level has been regular. 72% indicate that the performance of this system has been fair and that there is still much room for improvement to provide a better service, which suggests that taxpayers have a different perspective on the referenced payment system and that the sole purpose is to have a quality, efficient and effective system that facilitates the submission of their obligations. Finally, 10.81% did not express an opinion because they have not used it.

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Discussion

From the results obtained from this research, it can be inferred that there are different sectors in which taxpayers in the municipality of Texcoco pay taxes, being the main generator of tax revenues the tertiary sector, and according to the field results, 60.36% of taxpayers are in the Tax Incorporation Regime (RIF), being these the main subjects that contribute to public spending through the payment of VAT, ISR and IETU in the municipality of Texcoco, State of Mexico. It can be said that the taxes that finance the public expenditure of this municipality come from taxpayers who pay taxes in the RIF, in such a way that the government has resources to meet its obligations to society, as mentioned by Bonilla López (2002).

On the other hand, as mentioned by Díaz Lazo, Pérez Gutiérrez, & Florido Bacallao (2011), we are currently living in an era of booming digital technologies, characterised by constant scientific and technological changes and innovations. These findings are congruent with the results of the research, since 100% of the respondents make use of some type of ICT, such as the Internet, wifi, local servers, mobile telephony, email, among others. In such a way that the Mexican Government is using ICTs that are nowadays in vogue as a mechanism for the calculation and payment of tax contributions. As is happening in other countries in Latin America and Europe, this is in agreement with Armas A. & Colmenares de Eizaga (2007).

In the above context, the results show that more and more taxpayers are using information technologies to comply with their tax obligations. In this respect, the survey showed that 58.77% of taxpayers use the transfer of funds to make tax payments, which agrees with Jiménez (2003) in mentioning that ICTs have been a tool that facilitates timely compliance in the payment of taxes. Therefore, 88.29% of the respondents use the Internet to make their tax returns and payments, due to the multiple benefits as mentioned by Macau (2004) when stating that the use of ICTs reduces costs and improves management information, which is consistent with the statement of a taxpayer with more than 20 years in his company when saying:

> *"…Since the implementation of the online payment of taxes and returns through the Internet as the Referenced Payment system, he considered that many of the businesses in Texcoco have felt a noticeable change since we save time going to the bank or dealing with the people at the bank and the SAT, and the process is faster".* (Anonymous taxpayer, 2019).

This research allowed us to understand that the Referenced Payment system, far from being a headache for taxpayers, has been a friendly system, since 66.67% of the respondents did not need to undergo training, 50.45% said that the platform is simple and easy to use, 45.5% said that the system is good. However, there are those who believe otherwise, as one taxpayer who refuses to use the system commented:

> "It is annoying to be dealing with accessing the page and even more so when I know that it is a service that is supposed to be available 24 hours a day and that if I do not do it on the date stipulated by the SAT, I have to pay more in surcharges" (Anonymous taxpayer, 2018).

In this regard, Rovira Ferrer (2011) mentions that despite the most advanced technologies, the tax administration still has deficiencies, since the rate of attention to all taxpayers' demands is still not one hundred percent, especially during tax payment periods, when the Referenced Payment platform is saturated.

Conclusions and recommendations

In addressing the research on Federal Tax Collection through ICTs, it is worth mentioning that the methodology designed has proved useful to conclude that the Referenced Payment is an efficient system that benefits the taxpayer and the government, the success is justified by the savings in paper, time, money and highlighting the flexibility of management at all times of the information. In addition, it allows to obtain guidance and advice via telephone or online, which speeds up the development of certain procedures. The results show a positive acceptance by taxpayers, despite being a system that came to modify and revolutionize the custom that had been in place for many decades, now it remains to measure its effectiveness for tax collection at the national level.

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However, the improvement of this system does not meet all the government's expectations, since it must be improved so that the tax administration can verify that the information captured by the taxpayer is true, since it is often the taxpayer who feeds and manipulates the system. Therefore, it is concluded that a limitation of the Referenced Payment system is that it is only focused on efficiency and not on effectiveness, therefore, tax evasion is still present.

In general, it is considered important to highlight that there is no 100% improvement in the implementation of this system, since there is no virtual surveillance to attack the threats, dangers and problems faced by taxpayers with the confidentiality of their information.

In addition, it is recommended to continue with the research and to evaluate the Referenced Payment system, its effectiveness in increasing tax collection and decreasing tax evasion in Mexico, starting with the government with the fourth transformation of President López Obrador.

Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Author contribution

Teja-Gutierrez, Rebeca: Contributed with the project idea, research design, research type, approach, method, technique, field instrument design and application. She carried out the data analysis and the writing of the article.

Nidia-López,Lira: Supported the research design, data collection and systematization of the results. She also helped in the writing of the paper.

Loera-Suarez Verónica: She carried out the systematization of the background for the development of the state of the art. She also collaborated in the collection of data and the writing of the article.

Availability of data and materials

The measurement instrument is available. As well as the data.

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Abbreviations

CFF. Federal tax code

CIEC.Confidential electronic identification code

CONCANACO-SERVYTUR. Confederation of National Chambers of Commerce, Services and Tourism of Mexico

e.Signature. Electronic signature

FIEL. Advanced electronic signature

IEPS. Special tax on production and services
IETU. Flat rate business tax

INEGI. National Institute of Statistics and Geography

ISR. Income tax

VAT. Value added tax

LISR. Income tax law

LIVA. Value added tax law

GDP. Gross Domestic Product

RIF. Tax incorporation regime

SAT. Tax Administration Service

ICT. Information and Communication Technologies

USB. Universal Serial Bus

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Graphical Interface in MATLAB for design and analysis of reflectors for lighting systems or solar collectors on parabolic surfaces

Interfaz gráfica en MATLAB para el diseño y análisis de reflectores para los sistemas de iluminación o colectores solares en superficies parabólicas

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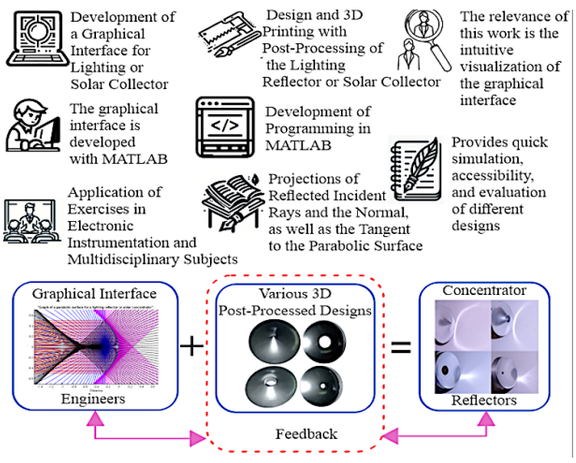
Abstract

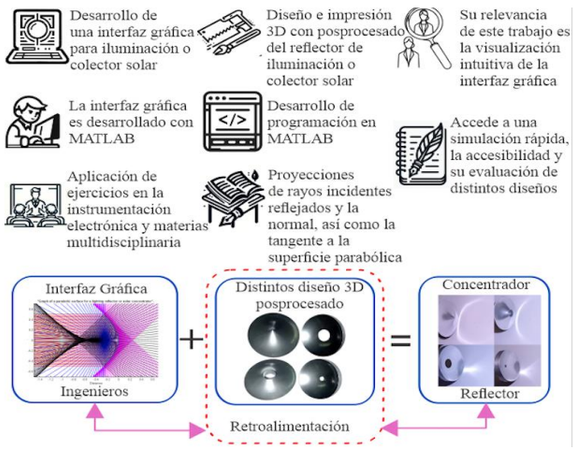
This project introduces the successful development of a MATLAB graphical interface for the design and analysis of reflectors and solar concentrators on parabolic surfaces. The integration of spline techniques for precise modeling of these surfaces has been implemented, along with the capability to generate STL files for 3D printing. The interface not only enables detailed and adaptable design of reflectors but also includes an advanced simulator for projecting incident rays and analyzing their reflection on the parabolic surface, focusing specifically on the focal point location. This has led to a significant increase in the efficiency of solar concentrators and lighting systems by enabling the precise placement of absorbers to maximize energy transfer. The obtained results confirm the initial hypothesis, demonstrating that the interface enhances the precision and efficiency in the design of these systems, thereby offering a valuable tool in both educational and professional realms in the fields of solar energy and lighting



Interface, Graphical, Concentrator

Resumen

Este proyecto presenta el desarrollo exitoso de una interfaz gráfica en MATLAB para el diseño y análisis de reflectores y concentradores solares en superficies parabólicas. Se ha integrado el uso de técnicas de spline para el modelado preciso de estas superficies, así como la capacidad de generar archivos STL para su impresión en 3D. La interfaz no solo permite un diseño detallado y adaptable de reflectores, sino que también incluye un simulador avanzado para proyectar rayos incidentes y analizar su reflexión en la superficie parabólica, enfocándose específicamente en la localización del punto focal. Esto ha permitido un incremento significativo en la eficiencia de los concentradores solares y sistemas de iluminación al posibilitar la colocación precisa de absorbedores para maximizar la transferencia de energía. Los resultados obtenidos confirman la hipótesis inicial, demostrando que la interfaz mejora la precisión y eficiencia en el diseño de estos sistemas, ofreciendo así una herramienta valiosa tanto en el ámbito educativo como profesional en los campos de la energía solar y la iluminación.



Interfaz, Gráfica, Concentrador

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Introduction

The transition to renewable energy sources is a crucial step in the fight against climate change and environmental pollution. In this context, solar reflectors and collectors emerge as key components, allowing an optimised capture of solar energy, which is essential to reduce our dependence on fossil fuels and reduce greenhouse gas emissions (Valdés, 2020). These advances not only aim to combat global warming, but also promote sustainability and innovation in the field of energy technologies. Solar resource assessment is the first critical step for the effective utilisation of this natural energy, which implies a detailed study of the temporal and spatial distribution of solar radiation. For Mexico, which is among the five countries with the highest solar energy generation potential, this assessment is even more relevant. With an average of 5 kilowatt hours per square metre per day, Mexico has a gross solar energy potential that is 50 times greater than the energy currently generated in the country, a figure that highlights the paradox of its current dependence on fossil fuels for electricity generation. Aware of this reality and the fact that fossil fuel power generation will not be economically sustainable or environmentally friendly in the long term, Mexico has focused on the development of renewable technologies. Photovoltaic panels, for example, are presented as a promising solution thanks to their durability, low maintenance and an initial investment that becomes more competitive every year, facilitating their adoption (Velázquez et al, 2020). Research on solar energy use in Mexico stands out for its focus on sustainable and efficient solutions, such as bioclimatic architecture, water heating and photovoltaic systems. Flores et al. (2020) highlight the importance of Mexico's geographical location for solar irradiation, emphasising advanced technologies such as parabolic dish systems. These systems, optimised through ray-tracing software, allow for higher solar absorption and reduced losses by adjusting key parameters such as geometry and optical properties. In parallel, Mexico's role on the global stage in the fight against climate change is reinforced by its participation in international agreements such as the Montreal and Kyoto Protocols. Juárez (2008) analyses how these commitments underline the need for global policies and joint actions to mitigate the effects of climate change and move towards sustainable development. Mexico's ratification of these treaties demonstrates its commitment to protecting the atmosphere and the ozone layer.

However, Escalona (2020) warns of the challenges facing global warming mitigation due to neoliberal policies that favour transnational corporations. The influence of these entities on global policy decisions has exacerbated environmental problems by prioritising corporate profits over sustainability. This analysis suggests the need to reform public policies to incorporate environmental solutions not only in rural but also in urban areas by promoting technologies such as solar concentrators and floodlighting. The implementation of these systems in urban areas can significantly contribute to raising awareness of carbon emissions reduction and the use of renewable energy sources, as has been observed with the increasing adoption of solar heaters. This sequence of ideas illustrates the complexity of the energy and environmental landscape in Mexico, highlighting the interplay between technological innovation, international commitments and public policies. The transition to a more sustainable and efficient energy model is imperative to address climate change, and will require a combination of technological advances, international cooperation and policy reforms aimed at sustainability and environmental protection. Solar thermal energy represents an innovative and sustainable solution to meet heat needs in various sectors by efficiently harnessing solar radiation. This technology, which transforms the sun's energy into heat, is emerging as an economically viable alternative to fossil fuels, contributing significantly to reducing pollutant emissions and combating climate change. Osornio et al. (2022) highlight the versatility of solar thermal devices, which adapt to different temperature ranges according to specific heat demands, from residential to industrial applications. The positive impact of solar thermal on quality of life is remarkable, especially in urban centres where its use can decrease the prevalence of respiratory diseases linked to air pollution. Although the deployment of this technology in the industrial sector is still limited compared to the residential sector, the trend shows an accelerated growth in the implementation of new solar thermal plants globally. These systems are classified into non-concentrating, such as flat-plate collectors, and concentrating, which include technologies such as the compound parabolic concentrator and the central tower receiver, and are differentiated by the temperatures they can reach. Solar concentrators, in particular, have gained ground in the harnessing of solar energy for electricity and heat generation.

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As a renewable and non-conventional source, solar energy opens up a range of possibilities for immediate application in conventional uses, including food cooking, highlighting its potential to generate income and offer sustainable alternatives in different fields (Linares et al., 2020). This scenario reflects the growing relevance of solar thermal energy and solar concentrators in the global energy matrix, underlining the importance of moving towards clean energy sources that favour sustainability and competitiveness in various sectors. Solar energy is positioning itself as a viable and sustainable alternative to non-renewable energy sources such as fossil fuels. The International Renewable Energy Agency IEA, 2020ª, highlights that investment in solar photovoltaic energy has experienced significant growth, with 2018 being the year with the highest implementation of projects. Despite a slight decline in subsequent years, solar energy is projected to continue its expansion in the near future. This growth is driven by a reduction of up to 82% in the cost of solar system components, such as photovoltaic cells, and a decline in the price of solar power to $0.063 cents per kWh. These trends have motivated numerous companies to switch from fuels such as coal to solar power, achieving significant savings in CO2 emissions and considerable economic benefits in 2019 IEA, 2020b. In addition to electricity generation, solar energy is also harnessed for heat production through heat exchanger systems that use plates or tubes through which a fluid circulates. This thermal approach, which can reach temperatures above 150°C, has the potential to be used in turbines to generate electricity, although its most frequent use is domestic and industrial. In 2019, the global installed capacity of these systems reached 6,289 GW, demonstrating the broad spectrum of solar energy applications, from photovoltaic and thermoelectric generation to water heating and food cooking (Acosta et al., 2023). Solar thermal energy, captured through various technologies, has the potential to meet a wide range of residential and industrial needs. This technology converts sunlight into heat, a process known as solar heating, and transfers this heat to a working fluid for use in a variety of applications. Common applications include domestic hot water supply, space heating, product drying, and steam generation for industrial processes. Continued research and innovation promise to further reduce the production and sales costs of these technologies, encouraging their adoption through policy incentives.

Finally, solar thermal energy used in the industrial sector has advanced significantly, making it possible to reach temperatures suitable for specific industrial processes, ranging from 60°C to 400°C. This range of temperatures opens the door to the adoption of solar thermal technologies. This temperature range opens the door to complex applications, including electricity generation, demonstrating the versatile potential of solar thermal to contribute to a cleaner and more sustainable energy future (González et al., 2020). Solar energy emerges as a promising solution to the global energy crisis and climate change, standing out for its ability to generate energy efficiently and sustainably. Clemente y Espinoza **(**2021**)** highlight the importance of concentrated solar power technologies, such as parabolic and central tower concentrators, for their efficiency in producing heat at high temperature, which optimises solar absorption and minimises heat losses. In the research field, Panaroni et al. (2021) explore the optical efficiency of a prototype parabolic solar concentrator, employing methodologies such as the constant mass calorimeter and the modified Hartmann optical scanning test. Validation of these methods reveals comparable optical efficiencies, highlighting their practical and economic value for the design and evaluation of solar technologies in renewable applications. Given the complexity and high cost associated with solar concentrator fabrication, optical simulations represent an invaluable tool. Narvaez (2021) discusses how these simulations facilitate the precise definition of critical characteristics, such as focus and heat flux distribution, thus enabling efficient optimisation that can avoid costly remanufacturing. Simulation software such as Solar Trace and Tonatiuh offer advanced optical modelling capabilities for applications in concentrated solar power systems.

On the other hand, research on solar cookers by Echazú et al. (2000) analyses the spectral reflectance of different materials, including aluminium and stainless steel. This study provides important insights into heat balance and economic feasibility, offering guidelines for the design of more efficient solar cookers. These advances and studies demonstrate the continued commitment to the improvement and application of solar energy, from high-tech solar concentrators to practical applications such as solar cookers, highlighting solar energy as a fundamental building block for a sustainable and efficient energy future.

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While it is true that methods other than post-processing can be used, according to Lanfranchi, and Comoretto (2024) conducted a groundbreaking study, published in Chemical Engineering Science, they have designed and fabricated dielectric mirrors, called aegides, capable of reflecting near-infrared radiation using various polymer pairs, from common to specialised polymers. Using a quantitative approach, they predicted the heat-reducing efficiency of these aegides, allowing the design of optimised reflectors for various practical applications. They used spin-coating techniques to create the aegides, alternating layers of polymers with different refractive indices on glass substrates.

The programming of graphical interfaces in environments such as MATLAB has undergone a significant evolution, offering tools such as GUIDE and App Designer that facilitate the creation of user interfaces using drag-and-drop techniques. These tools not only allow seamless integration of graphical components such as buttons and text fields, but also enable the incorporation of complex programming logic, optimising user interaction with the application. This approach greatly improves accessibility and efficiency in the development of advanced graphical applications. In the academic and professional environment, several works have been developed using computer-aided tools for the programming of graphical interfaces. Espinoza et al. (2023) illustrate this trend by developing a graphical user interface (GUI) in Python for a thermohaline convection simulator, demonstrating the importance of efficient pre- and post-processing tools in numerical analysis. Such developments emphasise the relevance of GUIs in visualising results and setting simulation parameters, highlighting their value as educational resources in fields such as computational science. Digital graphical interfaces have also found innovative applications outside the traditional domain, such as in cinema, where they facilitate a more dynamic and enriching interaction of the viewer with the film content. Villegas (2023) explores how these technologies contribute to the construction of interactive narratives, marking a move towards formats that integrate digital technology to create immersive viewing experiences. In the construction sector, solar energy is emerging as a sustainable alternative, thanks to technological advances in active and passive systems and cost reductions.

This transition is supported by computational tools that make it possible to assess the feasibility of implementing solar systems, optimising comfort and energy efficiency in buildings. Fondoso et al. **(**2021**)** highlight the use of CAD programs and software such as DesignBuilder to calculate solar radiation on different urban geometries, while noting challenges in compatibility between different programs. This overview reflects how the intersection of GUI programming, simulation and numerical analysis, and practical applications in sectors such as film and construction are driving significant innovations. The integration of these technologies not only facilitates the development of advanced solutions, but also promotes deeper understanding and broader applications in solar energy and other areas of interest. The integration of the graphical interface in the analysis and simulation of complex phenomena, such as quantum states of light, represents a significant advance in scientific research. Fernandez (2022) highlights the implementation of an accessible graphical interface to facilitate quantum tomography, which underlines the relevance of intuitive interfaces in the handling of experimental and simulated data.

This practical and theoretical approach not only improves the understanding of optics and quantum information, but also demonstrates how programming tools can be crucial in the advancement of science. In education, Kariadinata et al. (2023) developed a graphical user interface (GUI) in MATLAB focused on teaching statistics. Using the 4D research and development methodology, this study facilitates the learning of statistical concepts through a user-friendly GUI, demonstrating the effectiveness of graphical interfaces in mathematics education. MATLAB programming has also been applied in the evaluation of parabolic surfaces, as illustrated by the work of Santamaria (2019).

This study presents the use of the Razor's Edge Interferometer in the 2f array to evaluate the optical quality of lenses and reflecting surfaces, offering a cost-effective and versatile alternative to traditional methods.

The ability to generate and analyse interferograms using commercial software emphasises the importance of programming graphical interfaces in optimising experimental results.

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In several works where concentrators implement ray traces in order to analyse radiation behaviour such as Chen and Khosa (2024) both carried out a comprehensive analysis on a photovoltaic/thermal (PV/T) concentrator system employing nanofluid spectral splitting with a triangular receiver, as detailed in their publication in Applied Thermal Engineering. This study proposes a linear Fresnel CPV/T system combined with a triangular cooling duct and an Ag@SiO2/ethylene glycol (EG) nanofluid filter with the aim of boosting the overall system performance. Using an integrated approach combining the Monte Carlo ray tracing method (MCRT) with the Finite Volume Method (FVM), they modelled and evaluated the thermal, electrical and overall efficiency of the system under various operating conditions.

Knowledge of conic curves, from their historical applications in optics to their relevance in modern lighting engineering and design, has been fundamental to technological development. The history of conic curves, as described in Britannica (2023), and their application in Kepler's law of planetary motion, Galileo's projectile trajectory, and architectural and technological innovations, demonstrates their lasting impact on multiple disciplines.

Recently, Kishine and Maeda (2023) explored how the visual perception of parabolas varies with viewpoint, a study relevant to the design of reflectors and solar collectors. This analysis provides a mathematical basis for understanding how geometry affects the distribution and perception of light, optimising the efficiency of these practical applications. These papers illustrate the interconnection between graphical interface programming, quantum theory, educational statistics, experimental optics and geometry, highlighting the essential role of the graphical interface in simplifying and advancing complex research and applications. The paper examines John Wallis' contributions to the rectification of the parabola through the use of numerical series, illustrating a landmark mathematical approach to tackling complex geometric problems. Wallis applied innovative techniques for his time, highlighting the relevance of rectifying curves and generating solids of revolution from curves, which is fundamental to various scientific applications such as ballistics, optics and astronomy (Florio,2022).

Objective

To develop a graphical interface in MATLAB, specialised in the design, analysis and simulation of reflectors and solar collectors with parabolic surfaces. This advanced tool will allow the generation of graphs and coordinate points for use in advanced surface modelling programs, such as the spline method. In addition, it will facilitate the creation of 3D files of revolution, to generate files in formats such as *.stl or *.gcode. The graphical interface will provide the solution to store graphs and coordinate points of surfaces, making it ideal for application in educational and professional contexts. This will provide an essential tool for teaching and realisation of projects in the field of solar energy and lighting. Additionally, a validation process will be carried out to ensure the physical feasibility and constructive efficiency of the generated 3D models.

Hypothesis

If a graphical interface is implemented in MATLAB for the design and analysis of parabolic surfaces, together with the generation of STL files for 3D printing, then the accuracy and efficiency in the design and development of reflectors and/or solar concentrators will be significantly improved. This tool will make it easier for the user to visualise and simulate incident and reflected rays, optimising the location of the effective focal length and thus improving energy harvesting in practical applications. In addition, the ability to define specific upper and lower limits on the designer's surface of these systems will offer greater flexibility and adaptability, making it ideal for application in educational contexts of teaching-learning and will result in a significant improvement of the performance of solar concentrators and/or reflectors under various environmental and design conditions with post-processing.

Methodology and development

The graphical interface was developed in the Measurement and Instrumentation Laboratory of the Centro Tecnológico de la Facultad de Estudios Superiores Aragón, with the objective of designing solar concentrators or lighting reflectors. The design process was started using the parabolic equation, then a 90-degree clockwise rotation around the origin was performed.

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This rotation modifies the x and y coordinates, interchanging them and inverting the sign of one of them. The rotation of a point (x, y) around the origin at an angle θ clockwise is executed using Equations 1 and Equation 2, as described in the following formulae:

$$x' = xcos(\theta) + ysin(\theta) \quad [1]$$

$$y' = -xsin(\theta) + ycos(\theta) \quad [2]$$

For a rotation of 90 degrees (θ=90^°), both Equations 3 and 4 simplify to:

$$x'=y \quad [3]$$

$$y'=-x \quad [4]$$

Applying these transformations to the equation $y=ax^2$, we exchange x for y and y for -x. This gives us the following Equation 5 and Equation 6:

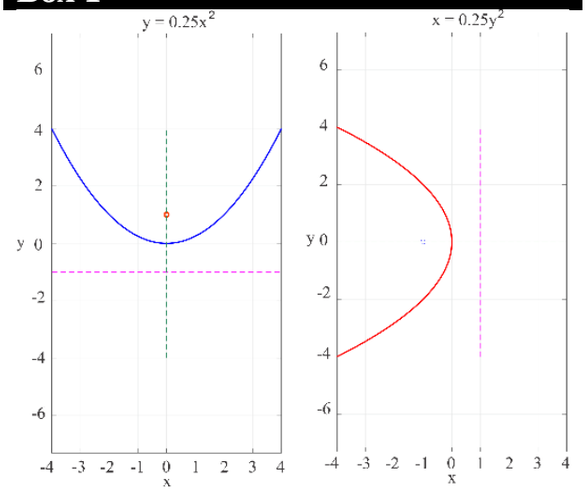
$$-x = ay^2 \quad [5]$$

Reordering:

$$x = -ay^2 \quad [6]$$

Now, Figure 1 shows both parabolic functions $y = -ayx^2$ y $x = -ay^2$ for a specific value of a, e.g., $a = 0.25$.

Box 1



(a) (b)

Figure 1

a) Graph of the parabola. b) Rotation of the parabola

Now, both parabolic functions will be plotted. $y = ax^2$ y $x = -ay^2$ par at a specific value of a, with intervals from 0.2 to 1 as shown in Figure 2, opens up as the value a=1

Box 2

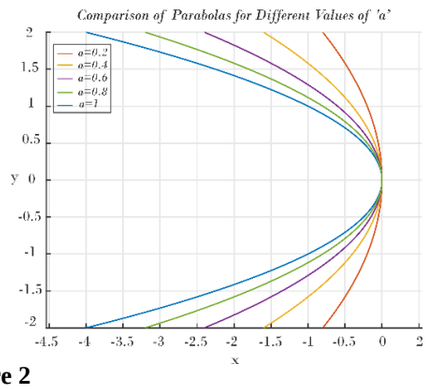


Figure 2

It can be seen that the value does vary or the parabola opens up or becomes narrower when it has the value a=1

The parabola is defined as the set of all points that are at the same distance from a fixed point, called the focus, and a fixed line, called the directrix. For simplicity, let us assume that the focus is at the point F (0, p) and the directrix is the horizontal line y=-p, where p is a positive distance. The vertex of the parabola is at the origin V (0,0) and is the midpoint between the focus and the directrix. We take a generic point P(x,y) on the parabola and by definition, the distance from P to the focus F is equal to the distance from P to the directrix. The distance is described in Equation 7, which is the same equation used in the formula for the distance of P of F:

$$PF = \sqrt{(x-0)^2 + (y-p)^2} = \sqrt{x^2 + (y-p)^2} \quad [7]$$

The distance from P to the directrix is given in Equation 8:

$$PD = | y - (-p) | = | y + p | \quad [8]$$

Equating the two distances in Equation 7 and Equation 8, since PF=PD, and eliminating the square root and the absolute value by squaring both sides of the equality gives Equation 9:

$$x^2 + (y-p)^2 = (y-p)^2 \quad [9]$$

We expand both equations on both sides and simplify and get Equation 10:

$$x^2 + y^2 - 2yp + p^2 = y^2 + 2yp + p^2 \quad [10]$$

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The terms are cancelled y^2 and p^2 on both sides and divide by 4p to keep it unchanged to obtain Equation 11.:

$$x^2 = 4py \quad [11]$$

Divide on both sides by 4p to isolate y, giving Equation 12:

$$y = \frac{1}{4p}x^2 \quad [12]$$

The deduction of the upward-opening parabola with the vertex at the origin was made earlier.. Where $a = \frac{1}{4p}$, For Equation $x = ay^2$, S Following a similar process, if the focus is at (p,0) and the directrix is the vertical line x=-p, it is shown in Equation 13:

$$x = \frac{1}{4p}y^2 \quad [13]$$

In this case, the parabola opens to the right. The constant a in the equation of the parabola $x = -ay^2$ afects the "width" or "aperture" of the parabola. To calculate the value of a, the information needed would be the distance from the vertex to the focus or a specific point through which the parabola passes. The focus of a parabola that opens horizontally is at a distance of $\frac{1}{4a}$ from the vertex, along the axis of symmetry of the parabola. Since the focus has been given at the position (-0.25,0), this means that $\frac{1}{4a}$ =0.25. Then, to find a, a is removed from Equation 14 and thus the value of a is calculated:

$$\frac{1}{4a} = 0.25 \quad [14]$$

To solve for the constant a we have its value of 0.25 as shown in Equation 15:

$$a = \frac{1}{4\times 0.25} \quad [15]$$
$$a = 1$$

This means that the value of a is 1 for the given parabola, which was already mentioned in the initial description. This confirms that the parabola is quite "narrow", since a value of a equal to 1 indicates that it opens at a faster rate than if a were less than 1. If a is based on the geometric definition of the parabola which is the set of all points that are equidistant from a fixed point called the "focus" and a fixed line called the "directrix". If we know the distance from the vertex to the focus (denoted as f), then $a = \frac{1}{4f}$.

The directrix is the same distance from the vertex, but in the opposite direction to the focus. If we have a specific point through which the parabola passes, say (x_0,y_0), we can substitute it into the equation $x=ay^2$ and solve for a: as shown in Equation 16:

$$a = \frac{x_0}{{y_0}^2} \quad [16]$$

The parameter a is called the "parabola parameter" and is directly related to the "focal length", which is the distance from the focus to the vertex of the parabola. The focal length f and the parameter a are related by the equation $f = \frac{1}{4a}$ pa a is a parabola whose vertex is at the origin and which is open along the x-axis. In short, a is an indicator of the curvature of the parabola: the larger the absolute value of a, the steeper the curvature, and the smaller it is, the flatter or more open the curve, the description of the graphical interface we worked with is shown in Figure 3.

Box 3

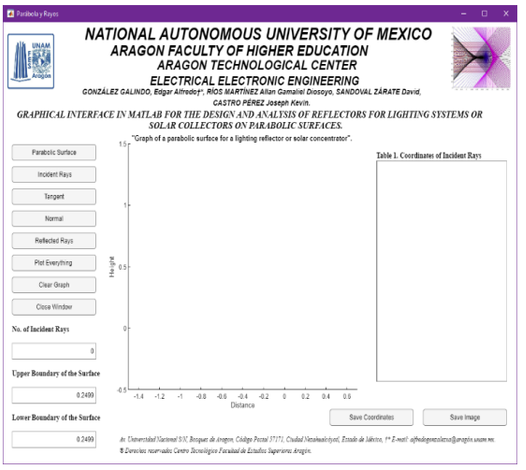

Figure 3
Graphical interface that simulates ray traces for a parabolic surface

The interface allows us to design parabolic surfaces, for this particular case the generated graph is shown, Figure 4a, the parabolic surface is generated where it will be the region of interest where the incident rays will be projected, as shown in Figure 4b.

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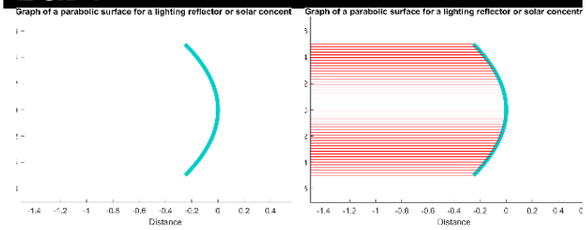
Box 4



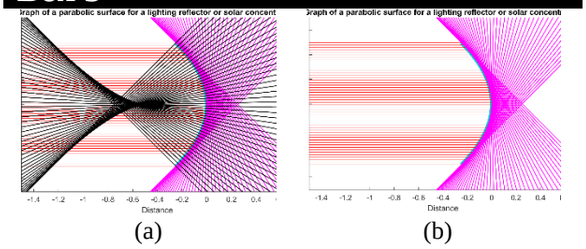
(a) (b)

Figure 4

a) Surface of interest. b) Surface ray tracing

In the same region, the interface allows the projection of lines tangent to the surface at each coordinate point where each incident ray touches the surface, as shown in Figure 5a. Knowing that the normal is perpendicular to each of the lines tangent to the surface, the interface also allows the projection of normal lines at each of the coordinates, as shown in Figure 5.

Box 5



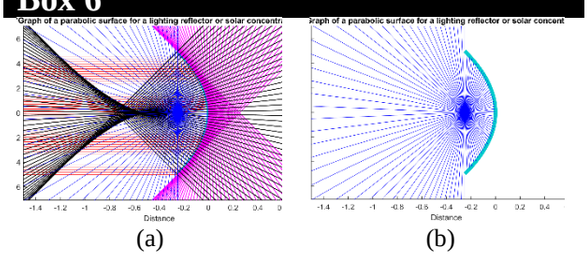
(a) (b)

Figure 5

a) Tangent at each coordinate point of the incident rays. b) Plot of the Normal which is perpendicular at each tangent point

In addition, the interface allows the projection of the reflected rays, shown in Figure 6a. If it is of interest to the user, the different types of rays to be observed in the simulation can be selected. Either incident rays, tangent rays, normal rays or reflected rays. The example in Figure 6b shows the projection of reflected rays without showing the projections of tangents and normals.

Box 6



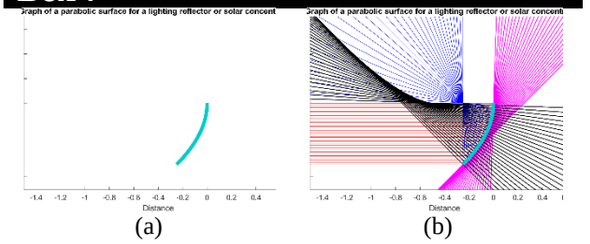
(a) (b)

Figure 6

a) Simulation of the rays, tangents, normals and reflected rays. b) Projection of the parabolic surface and the reflected rays

Another benefit of the graphical interface is that it allows selection of the region of interest on the parabolic surface. Boundaries can be set to delimit where the ray trace is to be projected as shown in Figure 7a. Similarly, the rays of interest that are required to be projected independently in the region of interest can be selected as shown in Figure 7b.

Box 7



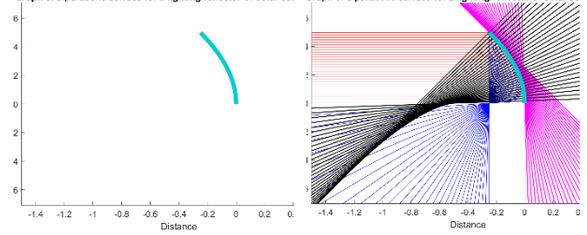
(a) (b)

Figure 7

a) Bounded surface in the negative region of y. b) Incident, tangent, normal and reflected rays from the bounded surface

This delimitation can also be performed on the positive side, as shown in Figure 8a. Applying also the required ray tracing on that delimited surface, showing the projection of all traces as shown in Figure 8b.

Box 8



(a) (b)

Figure 8

a) Bounded surface in the positive region of y. b) Incident, tangent, normal and reflected rays from the bounded surface.

The graphical interface can take the unconstrained values to generate surfaces in the regions of interest to the user, the region can be positive or negative or both regions.

As shown in Figure 9a, the surface is now fragmented into a central area bounded by its coordinates (-0.11, 0.3449) in the positive region of the y-axis and the coordinates (-0.11, -0.3449) of the negative region. The ray traces can be projected as required by the user, as shown in Figure 9b.

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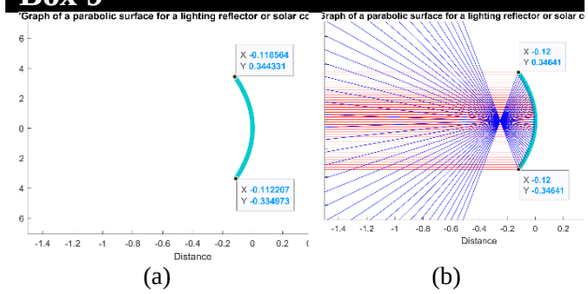
Box 9



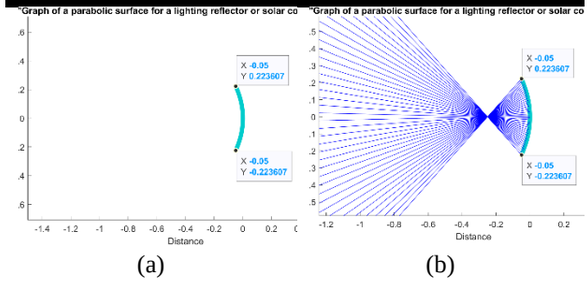
(a) (b)

Figure 9

a) Surface bounded at coordinates (-0.12, 0.3449) and (-0.12, -0.3449). b) Plotting of incident and reflected rays on this surface

The surface of interest, by extension, can be analysed in a smaller section by modifying the boundaries given by the coordinates shown in Figure 10.

Box 10



(a) (b)

Figure 10

a) Delimited minor surface of interest. b) Reflected beams on that surface

In its entirety, the graphical interface allows to delimit any section of the parabolic surface to be analysed.

Results

For the design of a parabolic surface in the graphical interface can facilitate a simulation of the behaviour of the ray traces and at the same time to be able to reconstruct from the graphical expressions the program allows us to store them, as well as the points of coordinates, with base to some techniques can be obtained the equation that satisfies to this surface in Figure 11 is appreciated that the graphical interface is very intuitive and easy to handle.

Box 11

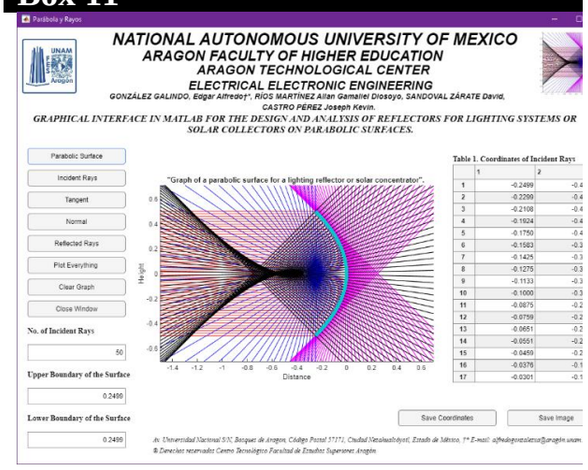


Figure 11

Simulation of a parabolic surface of interest with the projection of the incident, reflected, tangent and normal rays and the coordinate points where the incident rays intersect the surface

In Figure 12 we can see the folder where the generated files are stored, and inside are the coordinate points of the incident rays intersecting the parabolic surface for each design that was simulated, these coordinates can be used to reconstruct the surface.

Box 12

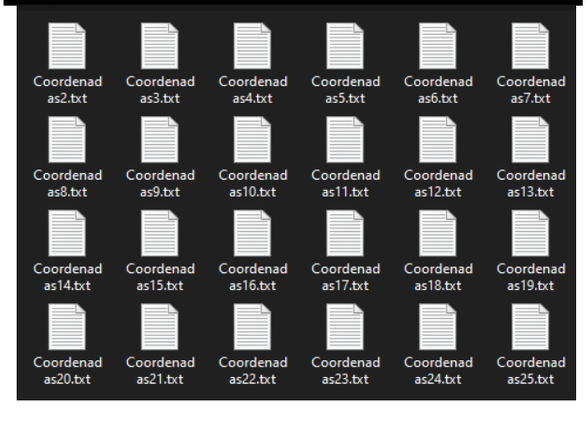


Figure 12

Files from incident lightning coordinates

There are techniques such as Lagrange, Polynomial Interpolation, Splines and B-Splines, Bezier Surfaces and NURBS (Non-Uniform Rational B-Splines) to use coordinate points to reconstruct surfaces, the graphical interface helps to generate the surface as shown in Figure 13 and at the same time generates the coordinate points, these could be used to apply any method mentioned above and obtain its equation that satisfies the surface to be analysed or reconstructed.

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Box 13

Figure 13

Simulation of a parabolic surface of interest with the projection of the incident and reflected rays, the tangent and normal and the coordinate points where the incident rays intersect the surface

In this particular case, the Splines technique was used to reconstruct the surface of the parabola and its region of interest and generate the *.stl file using a computer aided program (CAD), as shown in Figure 14.

Box 14

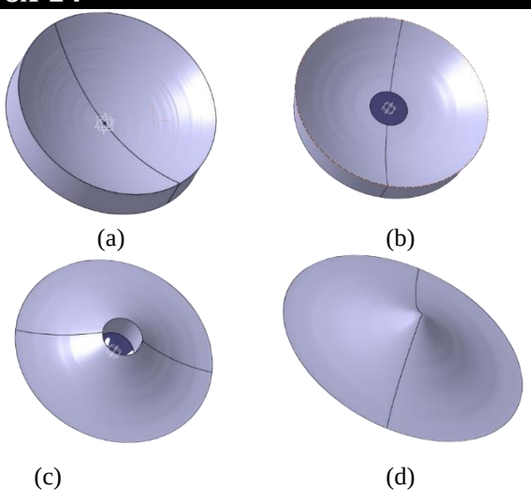

Figure 14

a) 3D design of concave plane revolution, b) concave plane surface with central perforation c) sectioned surface obtaining its mirror at a distance to generate the revolution d) surface without central perforation space to generate a reflection either for lighting or solar collector its shape is toroidal

Figure 15 presents 3D prints using PLA filament. To carry out the chrome plating process for the surface is placed a paste to polish it using sandpaper of the following: 60, 180, 220, 540 and 1000, after sanding it with each calibre 2 layers of resonator is applied subsequently 2 layers of primer is placed, and then the chrome plating is applied to the 3D part.

Box 15

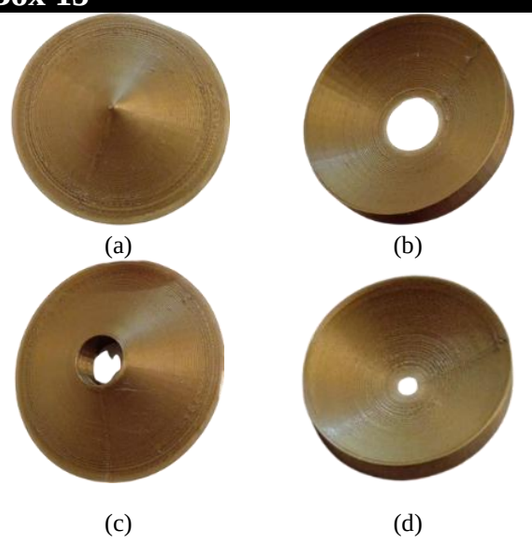

Figure 15

Designing reflective surfaces in 3D printing using PLA filament

The post-process chrome plating stage refers to a technique and procedure applied after 3D printing that helps the surface to be plated with chrome. This process improves the surface properties of the part such as corrosion resistance, as well as durability and aesthetic appearance. The term "post-processing" indicates that chrome plating is performed after the part has been manufactured and after other surface treatments have been carried out. Post-processing includes several stages, such as surface preparation (cleaning, degreasing, and polishing), the chromium plating process itself, and post-chromium plating treatments such as polishing to improve the surface finish as shown in Figure 16.

Box 16

Figure 16

Images shown of the 3D parts with post-processing applied to improve surface reflection

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It is worth mentioning that post-process chromium plating offers several advantages, it also presents environmental and health challenges, particularly related to the handling and disposal of the chromium plating baths used in post-process chromium plating applications, in particular, in Figure 17 only four parts were chromed does not present a significant impact compared to the various industries that use this chromium plating technique (e.g. automotive, decoration and furniture, machinery, armament, aviation, bicycles, tools, etc.).

Box 17

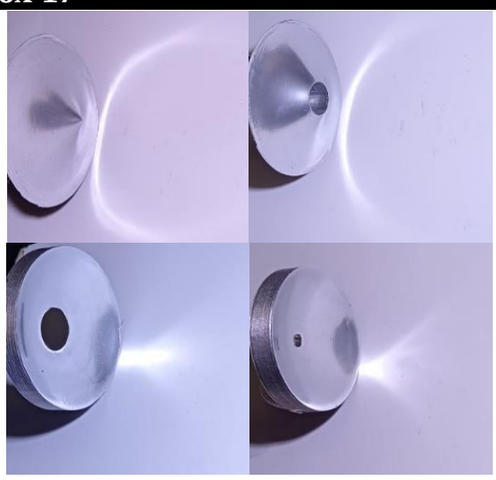

Figure 17
Reflective surfaces after post-processing, the reflection of incident rays to the parabolic surface is visualised

Figure 17 shows the result of the beam projection by visualising that the four chrome-plated parabolic surface shunts reflect and concentrate the light at the effective focal length, two of them generate a toroid and concentrate the illumination at a focal point.

Conclusions

The project has successfully achieved the design and development of parabolic surfaces developed using MATLAB making use of Spline techniques in Computer Aided Programs. The approaches allow accurate and adaptable modelling of these surfaces for specific applications in lighting and solar concentrators. The ability to generate STL files and take these designs to 3D printing has been a significant breakthrough. This not only demonstrated the feasibility of the theoretical designs, but also enabled the physical creation of models that could be used in practical applications and have the advantage of being scalable. A notable contribution has been the ability to modify and adapt parabolic surfaces beyond their traditional shapes.

This flexibility in design allows portions of the parabolic surface to be taken or the original design to be altered to meet specific needs, thus extending the scope for different applications. The results have confirmed that the designed surfaces are effective in concentrating light and illumination and the ray traces demonstrate that the concentration is carried at the effective focal length as shown in the interface graph and two of them concentrate the illumination in a toroidal shape. The project has also laid the foundation for future research and applications.

The developed interface can be a valuable tool for teaching-learning and research in the field of solar energy and lighting, providing an effective means to explore and develop new technologies in these fields.

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Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Authors' contribution

Gonzalez-Galindo Edgar Alfredo: His contribution Graphical User Interface design: He was in charge of designing the graphical user interface (GUI) in MATLAB. This includes planning and creating the layout, buttons, sliders and input fields that will allow the user to interact with the application. This area required a meticulous approach to user experience to ensure that the tool is easy and accessible to manipulate.

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Diosoyo Ríos-Martínez Allan Gamaliel: His contribution to the development of the simulation and analysis logic: he was responsible for the development of algorithms that simulate the reflection of light on reflectors and the analysis of solar collectors or lighting systems. This required a solid understanding of the areas of physics and mathematics involving the parabolic surface and reflection as a light concentrator or solar concentrator to model them correctly in MATLAB.

Sandoval-Zarate David: His contribution was in Integration and Testing: In charge of integrating the different modules developed by the team, ensuring that the graphical interface works easily with the simulation and analysis algorithms. In addition, he is in charge of testing to identify and correct errors in post-processing.

It is essential for the GUI to be reliable and error-free prior to 3D printing.

*Castro-Perez Joseph Kevin:*His contribution was in documentation and physical testing: Responsible for documenting the development process of 3D printing using the spline technique, creating a user guide for the handling of the graphical interface. He will also develop use cases and laboratory practices to demonstrate the application of the tool in real engineering contexts where multidisciplinary subjects are taught. This will help to understand how to use the tool effectively.

Availability of data and materials

The data for this research is available according to the sources consulted.

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Abbreviations

GUI
MCRT
FVM
NURBS
STL

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Attenuation of the effect of salinity on redwood (*Caesalpinia platyloba*) by saline compost

Atenuación del efecto de la salinidad en palo colorado (*Caesalpinia platyloba*) por composta salina

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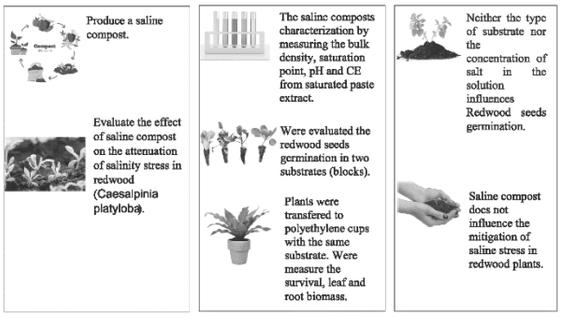
Abstract

The objective of this research is to evaluate the effect of saline compost on the attenuation of salinity stress in palo colorado (Caesalpinia platyloba). A representative sample of saline soil was taken at Ciudad Universitaria Intercultural, sieved (mesh < 5mm) and composted with cattle manure and Cynodon dactylon garden grass pruning, in a 3:1:1 ratio (stubble: manure: saline soil), for 120 days, the characterization consisted of measuring the bulk density (DA), saturation point, pH and EC of the saturated paste extract. The effect of different concentrations of NaCl on the in vitro germination of palo colorado seeds was evaluated in a randomized complete block design with two substrates (blocks), B1) sand-perlite; B2) sand-perlite-salt compost, five treatments 0 M, 0.3 M, 0.4 M, 0.5 M and 0.6 M of NaCl, eight replicates per treatment. The control irrigation was with distilled water. The plants transference to polyethylene cups was fifteen days after sowing; the cups had the same substrate mixture. The variables measured were survival, leaf biomass and dry root biomass. The EC decreased during composting, from 9.45 dS/m low to 2.4 dS/m; the pH of the samples did not show a significant difference. It is concluded that neither the substrate nor the NaCl concentration significantly influenced the germination of palo colorado seeds, and that the saline compost had no effect on the mitigation of salt stress in palo colorado plants.



Foliar and root biomass, soil bioremediation, saline stress, plant development

Resumen

La presente investigación tiene por objetivo evaluar el efecto de la composta salina en la atenuación del estrés por salinidad en palo colorado (Caesalpinia platyloba). Se tomó una muestra representativa del suelo salino en Ciudad Universitaria Intercultural, se tamizó (malla < 5mm) y composteo con estiércol de bovino y poda de pasto de jardín Cynodon dactylon, en relación 3:1:1 (rastrojo: estiércol: suelo salino), por 120 días, la caracterización consistió en medir la densidad aparente (DA), punto de saturación, el pH y la CE del extracto de pasta saturada. Se evaluó el efecto de diferentes concentraciones de NaCl en la germinación in vitro de semillas de palo colorado en un diseño de bloques completos al azar con dos sustratos (bloques), B1) arena-perlita; B2) arena-perlita-composta salina, cinco tratamientos 0 M, 0.3 M, 0.4 M, 0.5 M y 0.6 M de NaCl, ocho repeticiones por tratamiento. El riego del testigo fue con agua destilada. Las plantas se transfirieron a vasos de polietileno a los 15 días de la siembra; los vasos tenían la misma mezcla de sustrato. Las variables medidas fueron sobrevivencia, biomasa foliar y radicular seca. La CE disminuyó durante el compostaje, de 9.45 dS/m bajo a 2.4 dS/m; el pH de las muestras no presentó diferencia significativa. Se concluye que ni el sustrato ni la concentración de NaCl influyen significativamente en la germinación de las semillas de palo colorado, y que la composta salina no tuvo efecto en la mitigación del estrés salino en plantas de palo colorado.

Biomasa foliar y radicular, bioremediación de suelo, estrés salino, desarrollo de planta

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Introduction

Redwood Caesalpinia platyloba S. Watson is a tree species of the Fabaceae family, distributed from Mexico to tropical South America (Rendón-Sosa and Sagayo-Lorenzana, 2017). It is one of the most rustic and versatile legume species (Díaz-Gustavo et al. 2015). In Mexico, the Comisión Nacional Forestal (CONAFOR) has used it in its reforestation programs, as well as to produce pulp for the pulp industry (Prieto et al. 2016). In addition, in the State of Sinaloa there is a high demand for C. platyloba sticks, used it in vegetable crop production market (CONAFOR, 2018).

Globally, soil salinity affects the environmental services that the ecosystem provides, including decreasing soil productivity, water quality, soil biodiversity and increasing soil erosion, degrades soil structure and reduces soil fertility by affecting the availability of micronutrients (FAO, 2021).

In Mexico, by 2022, approximately 64% of soils showed some degree of physical degradation (soil compaction, water or wind erosion) or chemical degradation (salinity, misuse of fertilizers); however, biological degradation (carbon loss) is higher (SADER, 2022). As for salinity, this can reach up to 3.2% of the territory with the states of Sonora, Sinaloa, Tamaulipas, San Luis Potosí, Chiapas, Nuevo León, Oaxaca, Veracruz and Zacatecas being the most affected (Trejo-González, et al., 2019).

Salinity in soil affects seed germination and plant development, causes changes in enzyme activity, suppression of chlorophyll biosynthesis, decreases electron flow from photosystem II (PSII) to photosystem I (PSI), and reduces CO_2 flux due to stomata closure (Nikolić et al., 2023).

In Sinaloa there is enormous potential for reforestation projects, especially when are established in degraded soil conditions where vegetation is scarce (Camejo and Torres, 2000; Rojo et al., 2006; Martínez-Villavicencio et al., 2011). *C. platyloba* is a species that has emerged as a legume of great interest for reforestation in the state, and for the establishment of agroforestry systems (Castillo-Morales et al., 2010). An option to reduce soil salinity is land drainage that allows washing the soils (FAO, 2023).

Also phytoremediation using soil reconversion to a stable ecosystem by introducing native forest species with potential to bioremediate the soil, such as mesquite, catclaw, huizache, among others (Trejo-González et al., 2019). Through redox reactions during the saline soil composting process, to reduce Na^+ ions and other ions present in saline soil to non-toxic forms for plants, e.g. compost and vermicompost (Ait-El-Mokhtar et al., 2022).

Compost and vermicompost, besides favoring the reduction of Na^+ ions in saline soil, can contribute to plant development, favoring the development of stem and root tissue, that is, they contribute to plant vigor; in soils disturbed by salinity, compost could attenuate the impact of salt on redwood plants.

Materials and methods

The representative samples of soil were from four sites with different degrees of salinity disturbance within Ciudad Universitaria Intercultural: 1) soil behind the greenhouse; 2) soil next to the lagoon; 3) soil under mesquite canopy; and 4) soil under tabachín canopy. The sites selection depends on the visible signs of salinity. The variables considered for soil characterization, dried and sieved (> 5 mm), were bulk density, pH and electrical conductivity of saturated paste extract (Table 1).

Box

Table 1

Characterization of soil sampling sites with different degrees of salinity disturbance: 1) soil behind the greenhouse; 2) soil next to the lagoon; 3) soil under mesquite canopy; 4) soil under tabachin canopy. The variables measured were bulk density (DA), saturation point (PS), pH and electrical conductivity.

Sample	DA(g/mL)	PS(mL H_2O)	pH	CE(dS/m)
1	0.8258	82.5	10.4	9.45
2	0.9941	50.0	10.5	8.98
3	0.8083	80.0	10.7	7.15
4	0.814	37.0	10.0	7.75

Composting process

The composting process of the mixture of saline soil samples, cattle manure and garden grass *Cynodon dactylon* pruning stubble from CUI in a 3:1:1 ratio, lasted 120 days, according to the procedure described by Lal-Meena et al. (2021), the trial was developed in 1 L polyethylene cups, with four treatments and three replicates per treatment.

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To prevent that the temperature of the mixtures exceeded 50 °C, were turned daily for the first 10 days, the measurement of the temperature and humidity was during the turning. The measurement of the EC and pH of the saturated paste extract was monthly, using an Orion Model 230A potentiometer calibrated at pH 4.0 and 7.0, and at 1.4118 dS/m for EC.

At the end of the process, the composts were harvested, stored at room temperature in sacks for maturation, and later sieved (> 5 mm) for later use.

In vitro germination essay

To evaluate the effect of different concentrations of NaCl on the *in vitro* germination of redwood seeds. The experiment consisted of a randomized complete block design with two substrates (blocks): B1) 50% sand – 50% perlite, B2) 25% sand – 25% perlite – 50% compost, and five treatments: 0, 0.3, 0.4, 0.5 and 0.6 M, with eight replicates per treatment. The reference was the substrate B2. The experimental unit was one plant.

The seeds were provided by the biotechnology laboratory of the UAIM Mochicahui Unit.

As pre-germinative treatment, the seeds were scarified with No. 400 waterproof sandpaper to abrade the seed coat sufficiently to allow water to penetrate the embryo (Sánchez-Soto *et al*. 2016).

The sand was washed with running water to remove the soil particles present; two substrates were used: T1 sand - perlite (1:1 ratio); T2 sand - perlite - compost (1:1:2 ratio). One seed per cavity was sown in the substrate, i.e. 400 seeds in total. Polystyrene trays of 200 cavities of 182 mL each were used, with dimensions of 58.8 x 33.5 x 4.5 cm (length, width, upper diameter of the cavity, respectively).

The trays were watered three times a week to favor germination; once the seedlings had the first true leaves, they were transplanted into 233 mL polyethylene cups with the aforementioned substrates.

Subsequently, irrigation was started with the saline solutions at different concentrations. The variables measured were: plant survival, root and aerial dry weight (g).

Sowing was carried out in 200-cavity polyethylene trays; eight seeds per treatment were considered. The trial started on October 15, 2019; seed emergence lasted 6 days.

Polyethylene cups test

When the seedlings had the first true leaves, were transplanted into 233 mL polyethylene cups with the aforementioned substrates. Subsequently, irrigation started with the saline solutions at different concentrations.

The variable to be measured was the accumulation of aerial and root biomass.

Statistical analysis

The data were checked for normality of residual errors with the Shapiro-Wilk test ($p > 0.05$), homoscedasticity with Bartlett's test ($p > 0.05$); and non-autocorrelation of the data by the Durbin-Watson Contrast test.

Statistical analysis and tests were performed with the statistical package R Software, version 4.1.1 (R Core Team, 2021). The experimental design was completely randomized.

For the one-way ANOVA, the "aov" function was used and for the comparison of means, Tukey's multiple range test was used with the "agricolae" package (from Mendiburu 2021). The significance level for all tests was $\alpha = 0.05$.

Results and discussion

Composting significantly influenced the pH and EC of the mixtures (Table 2). The EC of the four samples decreased. In pH, a trend was observed (Table 2), in all four samples the pH changed from alkaline to neutral in T1 and T2, and to moderately acidic in T3 and T4.

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Table 2

Mean initial and final electrical conductivity and pH measurements of compost samples at the end of the composting process: 1) soil behind the greenhouse; 2) soil next to the lagoon; 3) soil under mesquite canopy; 4) soil under tabachín canopy.

Treatment	CE (dS/m)		pH	
	Initial	Final	Initial	Final
T1	9.45	2.4 ±0.27 ab*	10.4	7.1 a
	8.98	2.79 ±0.30 a	10.5	7.0 a
T2	7.15	1.75 ±0.26 ab	10.7	6.6 a
T3	7.75	1.13 ±0.05 b	10.0	6.5 a
T4	9.45	2.4 ±0.27 ab*	10.4	7.1 a

* Different letters in columns indicate significant differences, according to Tukey's multiple range test ($p< 0.05$).
** Standard error of the mean

Karanja et al. (2019) mentioned that, at the end of the composting process of rice bran with chicken manure and donkey manure the pH of the humus was close to neutral, is consistent with the findings of the present study, the pH ranged between 6.5 – 7.1.

As for the electrical conductivity, the authors mentioned that the final EC of the compost ranged between 0.016 – 0.021dS/m, the EC reported by the authors are lower than the EC from our composts, which ranged from 1.13 to 2.78dS/m.

It is worth mentioning that the Karanja et al. (2019) trial lasted 64 days, and our trial lasted 120 days.

Gondek et al. (2020) mention that salinity in soil and compost is related to the presence of Na^{+}, K^{+}, Ca^{+2}, Mg^{+2}, Cl^{-}, SO_4^{+2}, CO_3^{-2}, HCO_3^{-}, NO_3^{-} ions. The authors mention that a saline compost is one with an EC >5 dS/m, and it could be thought that using this compost would affect the soil and plant development, but, on the contrary, the authors comment that a saline compost favors soil bioremediation, when mixed with substrate or zeolite, to reduce the EC of the compost.

The humification process of SOM helps to increase the cation exchange capacity, and the humic substances present favor the chelation of ions so that they are not toxic to plants (Tan, 2014).

The results obtained are in agreement with that reported by Barbaro et al. (2019) who report that the EC of a compost used for substrate should range between 0.09 - 5.55 dS/m, and that EC is an important factor in the formulation of substrates, and that it is necessary to know the tolerance to salt concentrations of the species to be grown.

The composts in the present study had an EC < 5 dS/m. In the nursery trial, nor the salt concentration of the solutions applied or the substrate didn´t affect significantly the plant development (stem and root weight) (Table 3).

Savy et al. (2022) report that compost application helps mitigate salt stress in tomato plants relative to mineral fertilization.

The authors attribute this beneficial effect to the induction of a more efficient metabolic response that increases the accumulation of metabolites involved in the modulation of salt stress.

Box

Table 3

Average of the variables stem weight and root weight of redwod plants.

Treatment	Substrate	Stem weight (μ ± ES)*	Root weight (μ ± ES)*
0 M	Sand-Perlite	0.49 ±0.03 a**	0.10 ±0.01 a
0.3 M	Sand-Perlite	0.28 ±0.06 a	0.10 ±0.05 a
0.4 M	Sand-Perlite	0.16 ±0.02 a	0.03 ±0.004 a
0.5 M	Sand-Perlite	0.19 ±0.014 a	0.03 ±0.003 a
0.6 M	Sand-Perlite	0.09 ±0.02 a	0.02 ±0.003 a
0 M	Sand-Perlite-Compost	0.53 ±0.14 a	0.13 ±0.04 a
0.3 M	Sand-Perlite-Compost	0.28 ±0.03 a	0.05 ±0.02 a
0.4 M	Sand-Perlite-Compost	0.21 ±0.03 a	0.02 ±0.005 a
0.5 M	Sand-Perlite-Compost t	0.20 ±0.02 a	0.03 ±0.006 a
0.6 M	Sand-Perlite-Compost	0.19 ±0.02 a	0.03 ±0.004 a

* Different letters in columns indicate significant differences, according to Tukey's multiple range test ($p< 0.05$).
** Standard error of the mean

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Ait-El-Mokhtar et al. (2022) evaluated the effect of green waste compost to mitigate the effect of salt stress in date palms, reporting that compost helped to lower lipid peroxidation and hydrogen peroxide (H_2O_2) accumulation in stressed plants, which they attribute to the stimulation of antioxidant enzyme activity and increased soluble sugars and proline accumulation. The authors report that the use of compost favors the tolerance of date palms to salt stress.

According to Yusuf et al. (2024) there are plant hormones and signaling molecules that helps to mitigate abiotic stress in plants. They evaluate 24-Epibrassinolide (EBL) and Melatonin (ML) in enhancing plant tolerance to different abiotic stresses, like saline stress, they found that the joint application of both EBL and ML can improve plant tolerance to stress.

Ali et al. (2023) mentioned that the application of compost can improve the production of melatonin in stressed plants.

Humic substances produced during composting (Tan, 2014), help to reduce Na^+ ions so that they are not toxic to plants (Kumar Gautam et al., 2021). Jarukas et al. (2021) mention that humic substances present in compost form complexes with minerals through chelation, this improves the availability of nutrients, and form complexes with clay, improving soil structure and permeability, in the plant they favor plant resilience to withstand salinity stress.

In this sense, the biomass accumulation of the redwood plants produced in the substrate with saline compost was similar to the sand-perlite substrate, but the plants that grew in the saline compost, could present greater tolerance to saline stress, compared to the plants that grew in the sand-perlite-compost substrate, this would favor the survival to transplanting in a soil disturbed by salinity in projects for bioremediation of disturbed soils.

Conclusions

Composting favored a decrease in EC in soils with different degrees of disturbance; the pH of the composts tended to be neutral or slightly acid, which facilitates the availability of the nutrients present.

It is feasible to use the saline compost as a complement in a substrate to produce redwood plants, since the effect of the substrate with saline compost and the sand-perlite substrate was similar. These plants produced in a substrate with saline compost could be better adapted to a disturbed soil than a plant produced in sand-perlite substrate.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Roblero-Roblero, Elier Rutilo:Data collection.

Ruelas-Ayala, Rey David: Study conception and design.

Sañudo Torres, Rosario Raudel:Analysis and interpretation of results.

Félix-Herrán, Jaime Alberto: Manuscript preparation.

Availability of data and materials

The data of the article were obtained from the thesis work "Attenuation of the effect of salinity on red wood (*Caesalpinia platyloba*) by compost" of the forestry engineer Elier Rutilo Roblero-Roblero

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Abbreviations

Ca^{+2} Calcium ion
CE Electrical Conductivity
Cl^- Chlorine ion
cm centimeter
dS/m deciSiemmens per meter
ES Standard error
g grams
g/mL grams per milliliter
K^+ Potassium ion
Mg^{+2} Magnesium ion
μ Mean
M Molar

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mL milliliter
mm millimeters
Na^+ Sodium ion
NaCl Sodium chloride
pH Hydrogen ion potential
SO_4^{+2} Sulfate ion
CO_3^{-2} Carbonate ion
HCO_3^- Bicarbonate ion
NO_3^- Nitrate ion

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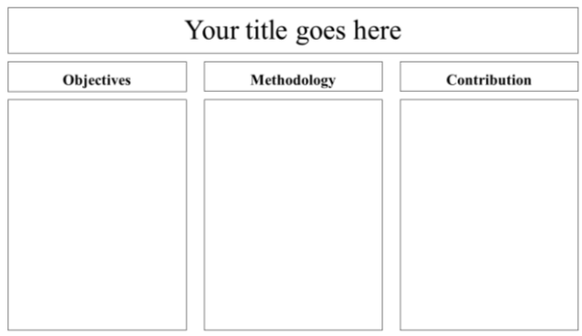
Must contain up to 150 words
Graphical abstract [In Spanish]



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Introduction

Text in TNRoman No.12, single space.

General explanation of the subject and explain why it is important.

What is your added value with respect to other techniques?

Clearly focus each of its features.

Clearly explain the problem to be solved and the central hypothesis.

Explanation of sections Article.

Development of headings and subheadings of the article with subsequent numbers

[Title No.12 in TNRoman, single spaced and bold]

Products in development No.12 TNRoman, single spaced.

Including figures and tables-Editable

In the article content any table and figure should be editable formats that can change size, type and number of letter, for the purposes of edition, these must be high quality, not pixelated and should be noticeable even reducing image scale.

[Indicating the title at the bottom with No.10 and Times New Roman Bold]

Box

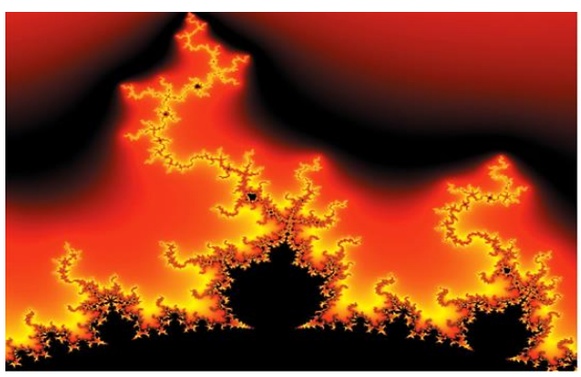

Figure 1

Title [Should not be images-everything must be editable]

Source [in italic]

Box

Table 1

Title [Should not be images-everything must be editable]

Source [in italic]

The maximum number of Boxes is 10 items

For the use of equations, noted as follows:

$$Y_{ij} = \alpha + \sum_{h=1}^{r} \beta_h X_{hij} + u_j + e_{ij} \quad [1]$$

Must be editable and number aligned on the right side.

Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Conclusions

Clearly explain the results and possibilities of improvement.

Annexes

Tables and adequate sources.

The international standard is 7 pages minimum and 14 pages maximum.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Specify the contribution of each researcher in each of the points developed in this research.

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Prot-
Benoit-Pauleter, Gerard: Contributed to the project idea, research method and technique.

Availability of data and materials

Indicate the availability of the data obtained in this research.

Funding

Indicate if the research received some financing.

Acknowledgements

Indicate if they were financed by any institution, University or company.

Abbreviations

List abbreviations in alphabetical order.

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ANN	Artificial Neural Network

References

Use APA system. Should not be numbered, nor with bullets, however if necessary numbering will be because reference or mention is made somewhere in the Article.

Use the Roman alphabet, all references you have used should be in Roman alphabet, even if you have cited an article, book in any of the official languages of the United Nations [English, French, German, Chinese, Russian, Portuguese, Italian, Spanish, Arabic], you should write the reference in Roman alphabet and not in any of the official languages.

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Mandelbrot, B. B. [2020]. Negative dimensions and Hölders, multifractals and their Hölder spectra, and the role of lateral preasymptotics in science.Journal of Fourier Analysis and Applications Special. 409-432.

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