

Terra: system for land leveling projects with regular or variable topography

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Abstract

Land leveling is essential to reduce the volume of water applied and increase the uniformity of gravity irrigation. The electronic computing system Terra is presented, for calculating agricultural land leveling projects, useful for examining innumerable design alternatives in a very short period of time. The field data with which it is fed, can be points obtained with a topographic survey of a rectangular grid or a survey of variable distribution (radiation). The calculation of cut and fill volumes is performed using ‘the four point method’ supported by the Kriging method in the case of variable distribution topography. The algorithm developed is capable of dividing the land into tables for independent leveling, with the aim of reducing cut and fill volumes, directly impacting the leveling cost. Plans of the terrain topography are generated before and after leveling; plus cut and fill plans and a block diagram as a guide for the operator in the leveling process.

Keywords: isolines, Kriging, MDE.

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Introduction

According to CONAGUA (2014) of the irrigation surface in Mexico, 90% has problems of low application efficiencies, which can be improved with land leveling if the topographic slopes are adequate, which implies greater uniformity of irrigation and a reduction of the volume of water applied (Saucedo *et al.*, 2006; Fuentes and Rendon, 2012).

Land leveling is justified in any irrigation project, since generally considerable sums are invested in catchment and distribution works, comparatively low investments are made in the plot, which is where the goodness of an entire complex irrigation system is reflected (Walker, 1987). Many computer programs have been developed on the issue of leveling agricultural land, always seeking to save time in design and perform optimal calculations with the lowest possible cost (Covarrubias, 1968).

Among the first programs in Mexico there is Nivterra v1.0 developed for personal computers in Fortran 77, with later improvements in Pascal for its version 2.0 (Chávez *et al.*, 1990), giving rise to systems that are used today in practice, such as the Sinivet in its different versions used for grid surveys and for leveling without divisions (Hernández and Sánchez, 2008). The few programs currently in existence for the design of land leveling projects use grid surveys as a data source.

As a result of several years of work in the area of software development applied to land leveling, the Terra 1.0 program was developed to process field data obtained with topographic surveys with the traditional survey method with points plotted on a grid rectangular or with a variable distribution (radiation).

Terra, seeks to adapt to new technologies that involve the collection of information from field data, for the use and application of land leveling. The objective was the development of an electronic computing system, which includes topographic survey methods with modern equipment, such as total stations or precision GPS, which helps in the precise and expeditious calculation for the preparation of executive projects for leveling agricultural land.

Managing a mass of points taken by radiation instead of a grid implies generating a digital elevation model (MDE) that describes the characterized property with high reliability. This is accomplished on Terra using the Kriging method for terrain modeling.

Materials and methods

The methodology includes the application of spatial interpolation using the Kriging method (Villatoro *et al.*, 2008) for the determination of the weights or weighting factors in the calculation, estimation and quantification of cut and fill volumes and plotting curves of ground level before and after grading, covering areas that the surveyor does not do on a homogeneously spaced grid in the traditional procedure.

The solution of the Kriging method allows the user to define a variogram of elevations based on the best fit made to his experimental semivariogram (Clark, 1979). The models used to fit the variograms are: linear, quadratic, spherical, exponential, and Gaussian, with or without the nugget

effect (Delhome, 1978). Like Walker (1987); Cano (1997), Terra 1.0 includes the division of the land into independent tables proposed by Marr (1957) in case the slopes of the land are heterogeneous. In Figure 1, the algorithm used for the development of the Terra 1.0 system is described in simplified form.

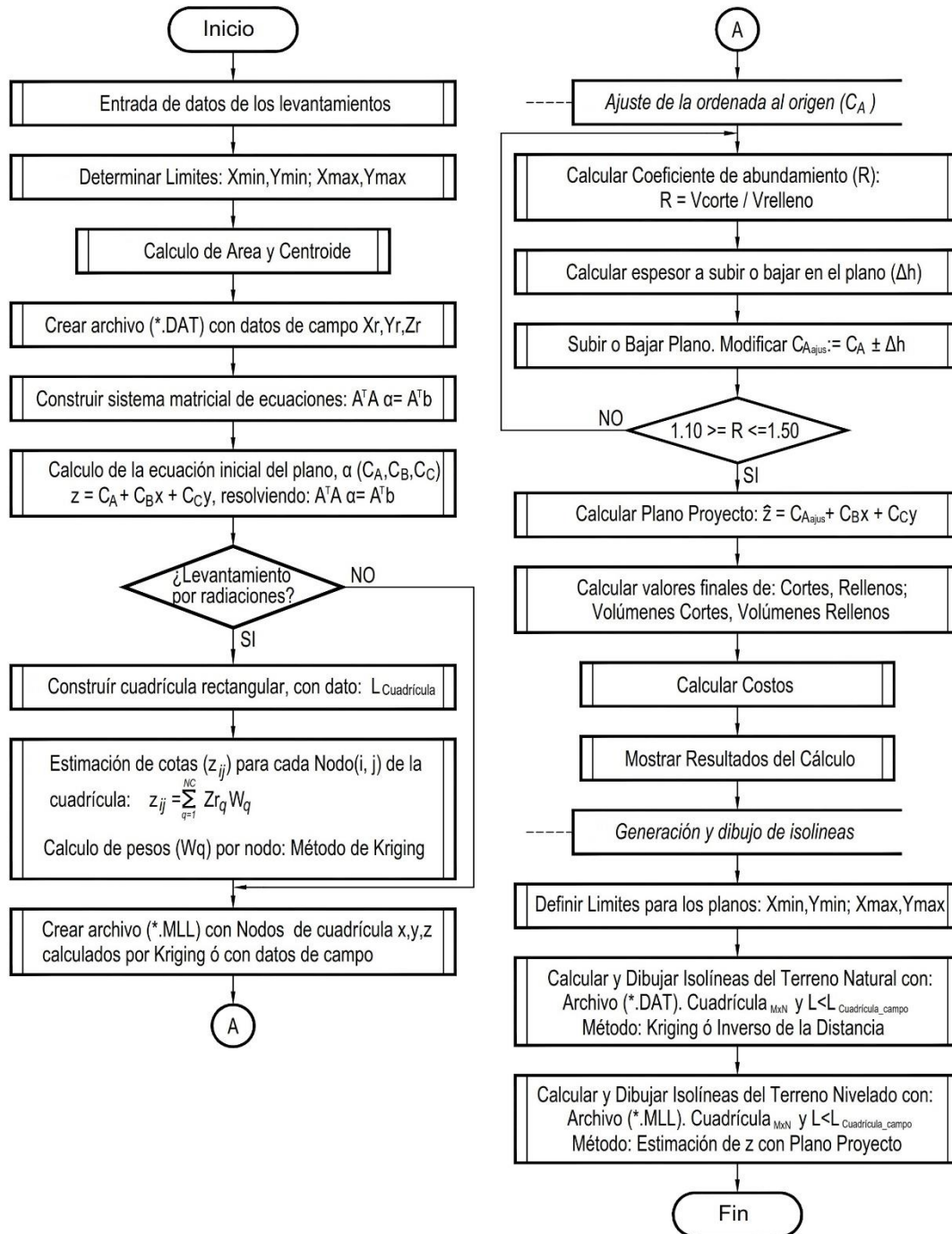


Figure 1. Leveling algorithm, implemented in Terra to calculate the project plan, without divisions or in a single table.

Definition of survey data

Depending on the type of topographic survey carried out, field coordinates were obtained for each measured point, either in a rectangular grid using the proposal of Marr (1957), in which case they are already coordinates (x_i, y_j, z_{ij}) , where $i=1, 2, \dots, n$; $j=1, 2, \dots, m$; n = number of rows and m = number of columns of the grid or radiations, in which case they are coordinates (X_{rk}, Y_{rk}, Z_{rk}) . Where: $k= 1, 2, \dots, P$ and P = number of points raised by radiation; which will enter the program dialog box, activating the corresponding capture option according to the survey carried out. In the same way, the coordinates of each of the vertices of the terrain polygonal with their respective coordinates (X_v, Y_v) are entered. Where: $v= 1, 2, \dots, NV$ and NV = number of vertices of the traverse of the terrain.

Work limits, area and centroid

With the information of the captured field points, the extreme limits of a rectangular area are determined for the leveling project work, defined by (X_{min}, Y_{min}) in the lower left corner and (X_{max}, Y_{max}) in the upper right corner. In the case of a radiation survey, the nodes of a grid of dimensions $m \times n$ are created in the defined rectangular area, with a distance between nodes ($L_{cuadrícula}$), thus for each node there is information (x_i, y_j) , missing estimating z_{ij} . With the coordinates of the vertices of the traverse, the area and centroid of the terrain (x_c, y_c, z_c) is calculated.

Calculation of the project plan

This is carried out by ordinary least squares using a matrix solution such as that proposed by Montgomery and Runger (2008), in which the way in which the topographic survey was carried out is indistinct, the equation of the initial project plane is: $\hat{z}_{ij}=C_A+C_B x_i+C_C y_j - 1$. Where: \hat{z}_{ij} = estimated elevation of the project plane at a coordinate point (x_i, y_j) , in m; C_A = constant that geometrically represents the elevation of the project plane, at the origin of the coordinate system, in m; C_B = average slope of the terrain in the direction of the X axis, in dec; C_C = average slope of the terrain in the Y direction, in dec; x_i = X coordinate of row i, in m; y_j = Y coordinate of column j, in m; $i= 1, 2, 3, \dots, n$; $j= 1, 2, 3, \dots, m$; n = number of rows; m = number of columns. Guajarati and Porter (2010), propose to calculate the coefficients of a plane with: $(A^T A) \hat{\beta} =$

$$A^T b \quad 2); \quad (A^T A) = \begin{bmatrix} 1 & 1 & 1 & \dots & 1 \\ X_1 & X_2 & X_3 & \dots & X_n \\ Y_1 & Y_2 & Y_3 & \dots & Y_n \end{bmatrix} \begin{bmatrix} 1 & X_1 & Y_1 \\ 1 & X_2 & Y_1 \\ 1 & X_3 & Y_1 \\ \vdots & \vdots & \vdots \\ 1 & X_n & Y_n \end{bmatrix} \quad 3);$$

$$(A^T b) = \begin{bmatrix} 1 & 1 & 1 & \dots & 1 \\ X_1 & X_2 & X_3 & \dots & X_n \\ Y_1 & Y_2 & Y_3 & \dots & Y_n \end{bmatrix} \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ \vdots \\ Z_n \end{bmatrix} \quad 4)$$

Where: A = matrix of XY coordinates; A^T = transpose of the XY coordinate matrix; b= Z coordinate vector; $\hat{\beta}$ = vector of unknowns or coefficients (C_A, C_B, C_C). From equation (2) the vector of

unknowns or vector of coefficients ($\hat{\beta}$) is cleared, to obtain the values of the slopes of the plane (C_B and C_C) and the ordinate to the origin (C_A): $\hat{\beta} = (A^T A)^{-1} (A^T b)$ 5); $\hat{\beta} = \begin{bmatrix} \hat{\beta}_1 \\ \hat{\beta}_2 \\ \hat{\beta}_3 \end{bmatrix} = \begin{bmatrix} C_A \\ C_B \\ C_C \end{bmatrix}$ 6).

Homogeneous grid calculation

If the survey was by means of a grid, it was already drawn in the field when doing the topographic survey, but if it was by radiation, the grid is created from the limits previously calculated and with a regular equidistance from the grid assigned for the size calculation. $L_{\text{cuadrícula}}$ (m), which can be the same as the regular grid or another as the case may be. This defines the number of nodes in X and Y (Figure 2).

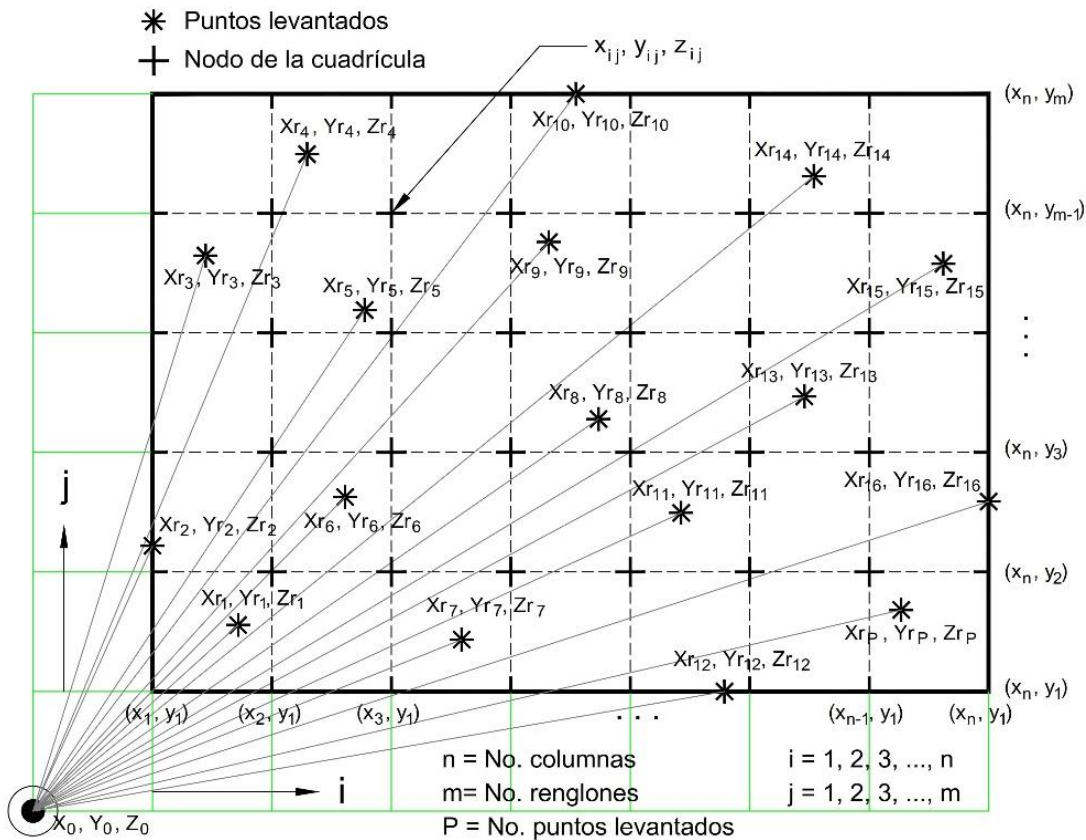


Figure 2. Elements to determine the homogeneous grid, from a topographic survey by radiation and an MDE.

The problems that were detected at this point are due to having very short fields where only one line can be defined, and therefore, no frame can be generated, the most practical solution is to redefine a smaller value of the $L_{\text{cuadrícula}}$. With the above information, it is possible to determine the location (x_i, y_j) of each node within the grid.

Determination of the coordinates z_{ij}

In each node (i, j) of the grid, the values of z_{ij} are determined through a geostatistical process of spatial interpolation, starting from the information collected in the field $(X_{r_k}, Y_{r_k}, Z_{r_k})$ of the field data defined as neighboring points to the node (i, j) . The definition of neighboring points is performed by calculating the distance from each node (i, j) to all the coordinates obtained in the topographic survey $(X_{r_k}, Y_{r_k}, Z_{r_k})$, the NC points with the smallest distances will make up the set of neighboring points or close for the estimation of z_{ij} , using equation (7). $z_{ij} = \sum_{q=1}^{NC} W_q Z_q$ (7).

Where: z_{ij} = estimated data at node (i, j) of the generated grid of $m \times n$ dimensions; $i = 1, 2, 3, n$; $j = 1, 2, 3, \dots, m$; n = number of rows; m = number of columns. $Z_q = Z_{r_k}$ coordinate of the field point located at position q of the set of neighboring or nearby points. W_q = weight or weighting factor calculated for the site q of the set of neighboring or close points for the estimation of z_{ij} at node (i, j) . NC= total number of points near or near the node (i, j) , which will be used to estimate the data z_{ij} . The sum of the values of the weights or weighting factors (W_q) of the set of points near or close to the node (i, j) must meet the restriction defined in equation (8): $\sum_{q=1}^{NC} W_q = 1$ (8).

Calculation of the weights or weighting factor (W_q)

The calculation of the weights is carried out by applying the Kriging method. Clayton and Andre (1998) indicate that the essence of Kriging is the estimation of the semivariogram (Figure 3), in this case of elevations, which is constructed by defining 20 classes of distances with all field data (P) and calculating $\gamma(h)$ for each class located at a distance (d_{t+h}) the value of the semivariogram $\gamma(h)$ through equation 9. $\gamma(h) = \frac{\sum_{t=1}^P [Z_r(d_t) - Z_r(d_{t+h})]^2}{2P}$ (9).

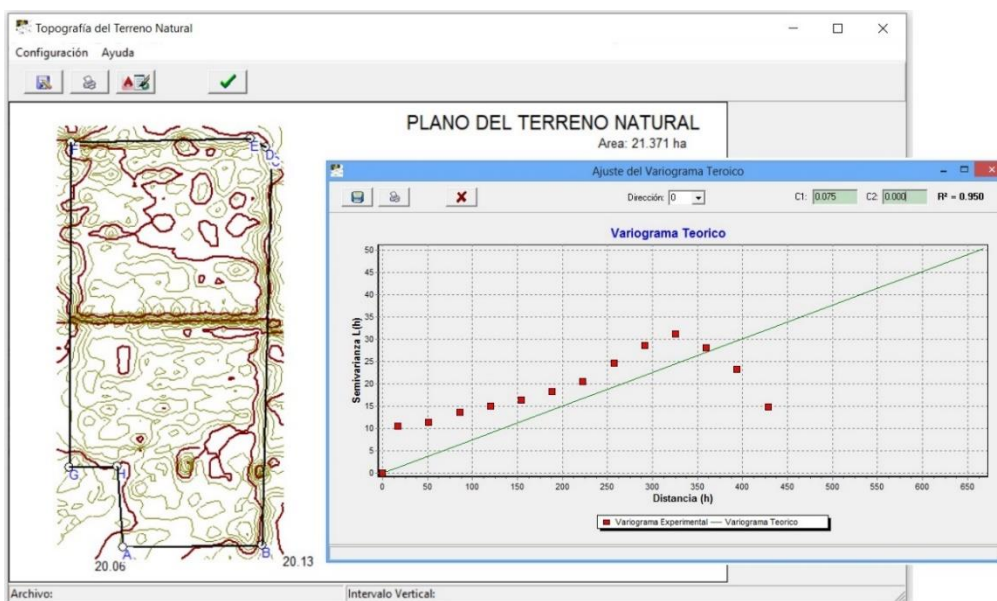


Figure 3. Topography of the natural terrain, applying the Kriging method, in a topographic survey with variable radiation distribution.

Where: $Z_r(d_t)$ = value of the topography elevation (Z) at point t; $Z_r(d_{t+h})$ = value of the topographic elevation (Z) at the site located at distance h from point t; P= total number of points in the radiation survey.

Once the semivariogram is calculated for each of the distances defined in the classes, a theoretical model is adjusted (Cisneros-Ilturbe *et al.*, 1999), which can be: linear, quadratic, spherical, exponential or Gaussian (Table 1) equations 10, 11, 12, 13 and 14.

Table 1. Mathematical models (Delhome, 1978; Clark, 1979), available in Terra for fitting the theoretical variogram, from the experimental semivariogram.

Model	Function for $(0 < h \leq C_2)$ and linearization
Linear	$\gamma(h) = C_1 h$ (10)
Quadratic	$\gamma(h) = C_1 \left[2 \left(\frac{h}{C_2} \right) - \left(\frac{h}{C_2} \right)^2 \right]$ (11)
	$\gamma(h) = \beta_1 h + \beta_2 h^2$ (11a)
Spherical	$\gamma(h) = C_1 \left[\frac{3}{2} \left(\frac{h}{C_2} \right) - \frac{1}{2} \left(\frac{h}{C_2} \right)^3 \right]$ (12)
	$\gamma(h) = \beta_1 h + \beta_2 h^3$ (12a)
Exponential (*)	$\gamma(h) = C_1 \left[1 - \exp \left(- \frac{h}{C_2} \right) \right]$ (13)
	$\gamma(h) \cong C_1 \left[1 - \frac{5}{2e} \right] + \frac{2}{e} \left(\frac{C_1}{C_2} \right) h - \frac{1}{2e} \left(\frac{C_1}{C_2^2} \right) h^2$ (*) (13a)
	$\gamma(h) \cong \beta_0 + \beta_1 h + \beta_2 h^2$ (13b)
Gaussian (*)	$\gamma(h) = C_1 \left[1 - \exp \left(- \frac{h}{C_2} \right)^2 \right]$ (14)
	$\gamma(h) \cong C_1 - \left(\frac{4 C_1}{e} \right) + \left(\frac{4 C_1}{e C_2} \right) h - \left(\frac{C_1}{e C_2^2} \right) h^2$ (*) (14a)
	$\gamma(h) \cong \beta_0 + \beta_1 h + \beta_2 h^2$ (14b)

When $h > C_2$: $\gamma(h) = C_1$ (for Quadratic and Spherical models) (*) function approximated to polynomial, using Taylor series and for $h = C_2$.

Michael and Clayton (2014), mention that the behaviors at the origin of the models may or may not consider the nugget affect; that is, the intersection with the Y axis or, consider that they leave the origin, as is the case with topography. Initially, it was tested with varigram models that include the nugget effect; however, most solutions implied negative values for the coefficient C_0 , which is why it was decided to use the model that comes from the origin (Legra-Lobaina *et al.*, 2010).

The calculation of the coefficients of the models (C_0 , C_1 and C_2) was done with the Newton-Raphson method for the solution of systems of non-linear equations (Chapra and Canale, 2015), with unfavorable results, therefore, the models were linearized (Table 1) equations 11a, 12a, 13b and 14b, improving the solutions.

Before linearization, the exponential and Gaussian models were approximated to a polynomial function (equations 13a and 14a), using Taylor series (Purcell and Varberg, 2009). Once the models were linearized, equation (5) was applied to determine the β_i coefficients and for the calculation of the C_1 and C_2 coefficients of the variogram, the solutions are listed in (Table 2) equations 15 to 20b.

Table 2. C_1 and C_2 coefficients, obtained to determine the theoretical variogram.

Model	Coefficients for variograms starting from the origin ($C_0=0$)			
	C_2 (rank)		C_1 (Sill)	
Quadratic	$C_2=-0.5 \left(\beta_1 / \beta_2 \right)$	(15)	$C_1=-0.25 \left(\beta_1^2 / \beta_2 \right)$	(15a)
Spherical	$C_2=0.58143 \sqrt{-\beta_1 / \beta_2}$	(16)	$C_1=0.66667 \beta_1 C_2$	(16a)
Exponential	$C_2=-0.25 \left(\beta_1 / \beta_2 \right)$	(17)	$C_1=-0.33979 \left(\beta_1^2 / \beta_2 \right)$	(17a)
	$C_2=1.51348 \sqrt{-\beta_0 / \beta_2}$	(18)	$C_1=12.45308 \beta_0$	(18a)
Gaussian	$C_2=-0.25 \left(\beta_1 / \beta_2 \right)$	(19)	$C_1=-0.16989 \left(\beta_1^2 / \beta_2 \right)$	(19a)
	$C_2=-3.12081 \left(\beta_0 / \beta_1 \right)$	(20)	$C_1=2.12081 \beta_0$	(20a)

Once the coefficients of the theoretical variogram have been calculated, the estimation of the weights or weighting factors (W_q) for each of the nodes is done through a matrix process (equations 21, 22 and 23).

$$Sw=b \quad 21) \quad S = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \dots & \gamma_{1n} & 1 \\ \gamma_{21} & \gamma_{22} & \dots & \gamma_{2n} & 1 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \gamma_{n1} & \gamma_{n2} & \dots & \gamma_{nn} & 1 \\ 1 & 1 & \dots & 1 & 0 \end{bmatrix}; \quad w = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \\ \lambda \end{bmatrix}; \quad b = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_n \\ 1 \end{bmatrix} \quad 22)$$

Where: $S=$ is a square matrix of order $n \times n$; each element of the matrix is calculated by evaluating the theoretical variogram with the distance between points; for example: the element γ_{12} is calculated by evaluating the variogram function with the existing distance between point 1 and 2 of the NC close or neighboring points that were involved for the interpolation process. W and $b=$ are the vectors of order $n \times 1$.

The vector b is obtained by evaluating the function of the variogram with the distance between the node (i, j) where z_{ij} will be estimated and the neighboring data q . w contains the n unknowns involved in the calculation; that is, the weights of each of the NC data, plus a Lagrange multiplier

(λ) that stores the residual error calculated in the process, thus clearing the vector w will obtain the weights or weights sought (W_q). $w = S^{-1}b$ (23). As a product of this step, a file (*.MLL) is obtained with the z_{ij} information for each of the nodes of the homogeneous grid.

Adjusting the ordinate to origin (C_A)

The adjustment of the ordinate to the origin (C_A) of the project plan calculated in the second step is carried out according to the relationship between the cuts and fills defined by the abundance coefficient ($R = \text{cut}/\text{fill}$), most authors agree that the abundance coefficient (R) must be in the range: $1.1 \leq R \leq 1.5$ (Walker 1988).

In practice, where there were fillings, there will be compaction and holes will remain, these will appear over time due to rain and soil compaction, so it is necessary to increase the cuts, therefore the fillings will decrease, this is done until have a coefficient of abundance (R) within the desired range, the adjustment is made by lowering or raising the project plane in $\pm\Delta h$, h is the value of increase or decrease in the elevation of the plane in m, depending on the ground and its greater or lower content of organic matter.

That is, if a soil is sandy the coefficient R will be close to 1.1, clay the value of the coefficient will be close to 1.5. If an intermediate soil (clay loam) is considered, the coefficient values will vary between 1.20 and 1.30 (Walker, 1988). The calculation of the cut and fill volumes is done using the 4-point method; it is necessary to have a grid with field data or generated by the Kriging method.

The incorporation of the Kriging method for estimating the elevation (z_{ij}) at each node (i, j) of the grid is a new procedure in land leveling and has shown technically adequate results in the calculation of volumes of land. cut and fill. As a result of the step, an adjusted C_A coefficient ($C_{A\text{ajus}}$) is obtained for the equation of the project plan. With the above, final values of cut or fill thicknesses are calculated for each node (i, j) of the grid and therefore cut and fill volumes, as well as leveling costs per hectare and total.

Generation and drawing of isolines

Contour drawings are drawn for the natural terrain (pre-grading setup) and for the graded terrain project (post-grading setup). This process is carried out in two ways: a) contour lines are created for the entire terrain, regardless of how the topographic survey was carried out, a new, finer grid (x'_i, y'_j, z'_{ij}) generated with Smallest inter-node lengths, about a quarter the length of the grid for leveling.

This new grid is calculated from the field data collected in a rectangular grid (x_i, y_j, z_{ij}) or by radiation (X_{rk}, Y_{rk}, Z_{rk}) applying the spatial interpolation process with the Kriging method explained in the previous points or the inverse distance method. The limits of the new grid are extended to perfectly cover the traverse of the terrain and avoid areas without curves. The calculation and drawing of isolines or level curves of the leveled terrain is carried out with the nodes (i, j) of the new grid, whose elevation z_{ij} is obtained with the final equation, equation (1)

defined for the project plan; and b) in the event that due to abrupt changes in slopes or lot size it is necessary to divide the land, to make its independent leveling by tables, an algorithm was designed that allows the property to be divided into two parts interactively with the user.

The example shows the topography of the natural terrain so that a dividing line can be drawn on it that allows separating the points raised in the new polygons and natural project planes, which result with the dividing line. In case you need to divide the property into more than two parts, you have a capture form to define the polygons.

The latter in order for the designer to manually identify the limits of the polygons and with this all the points surveyed in the field remain inside. Once the tables have been defined, the six points described above will be applied to calculate the natural project and final plan, as well as the calculation of cut and fill volumes independently of each of the tables.

Results and discussion

Terra 1.0 was developed with the Delphi (Pascal) programming language, designed to function as a tool in any land leveling project where the topography is raised in a grid with rectangular lines or radiations. The system allows the general leveling of the entire raised property or the division by tables.

The calculation of cut and fill volumes is performed with the rectangular grid applying the Kriging method for the calculation. The estimation of the values of the grid generates values congruent with the topography and therefore the calculation of volumes is obtained according to the pre-established technical procedures.

Information capture

Terra has three dialog boxes to capture the input information: 'project data and design parameters' for general data, 'terrain traverse data and centroid calculation' to capture the coordinates (X_v, Y_v) of the vertices of the terrain traverse and 'topographic data for leveling', for field data with coordinates (x_i, y_j, z_{ij}) or (X_{rk}, Y_{rk}, Z_{rk}) according to the topographic survey carried out and the length of equidistance from the grid.

Natural terrain topography

The program allows the generation and visualization of the terrain topography with contour lines (Figure 6). In order to draw them, a digital elevation model has been calculated using the Kriging method. According to Delhome (1979), he recommends the use of the Kriging method in applications to hydroscience, indicating that it adequately describes the behavior of the natural terrain topography. The initial proposal for the calculation of the coefficients C0 and C1 of the theoretical variogram model is automatically adjusted to the linear model; however, you can choose another one in a personalized way (Figure 3).

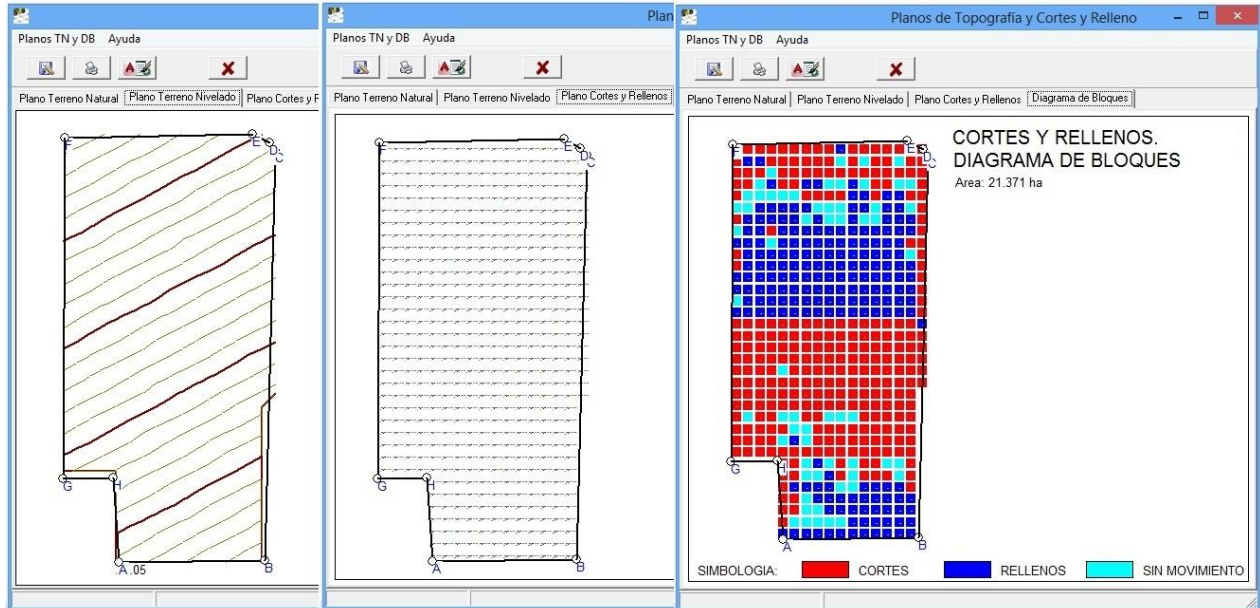


Figure 6. Level curve planes of leveled terrain cut and fill values at grid nodes and earthwork block diagram.

Topographic survey in rectangular grid

The software developed allows processing the information obtained with a survey with a rectangular grid, so the traditional methodology can be applied to calculate land leveling. In this case, the field grid already exists so there is no need to create a new one. As is the case of radiation survey where the grid is generated.

Division of the terrain in tables

The software developed allows the terrain to be divided into two tables, drawing a dividing line and generating the two independent polygons automatically (Figure 4). When a radiation survey is carried out, some points are taken close to the limits and with a high probability they can fall out of the ground, the system assigns all the points in one of the two polygons; however, when the division involves a greater number of parts, it will be very difficult to group the points, which is why there is an information entry sheet where the user must enter the coordinates of each polygon and for each table only it will extract the information that is within the defined polygon.

Once the division of the land has been carried out, each defined table is analyzed separately. In the example, leveling was carried out by tables, making a dividing line in the middle part of the terrain where it can be clearly seen that there is a sudden change in slope, seeking to reduce the cutting and filling volumes and therefore the total cost of leveling (Figures 4 and 5).

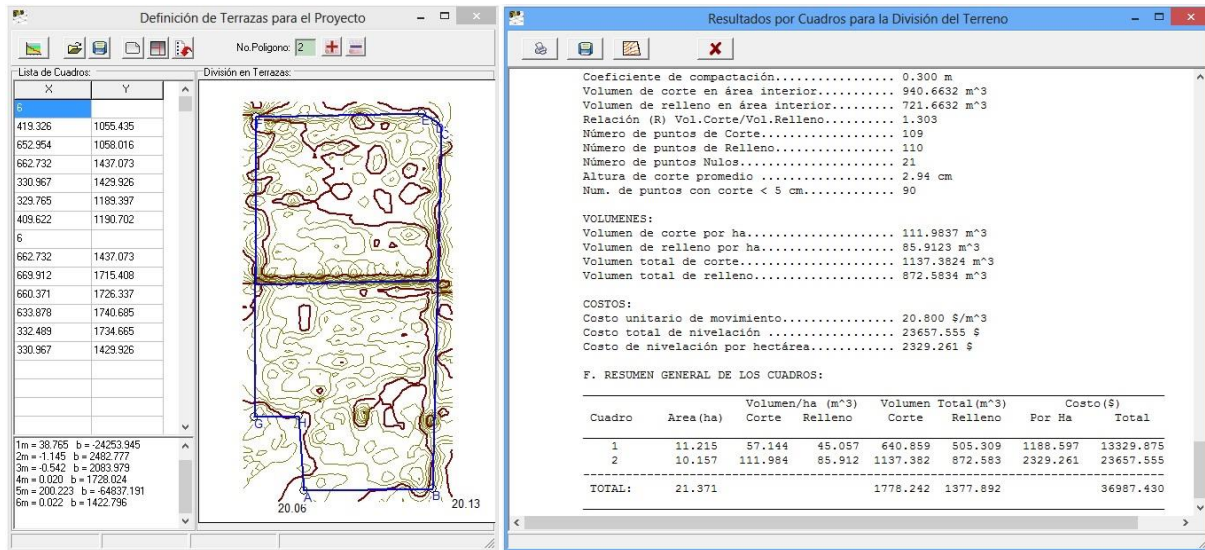


Figure 4. Division of the land in independent tables.

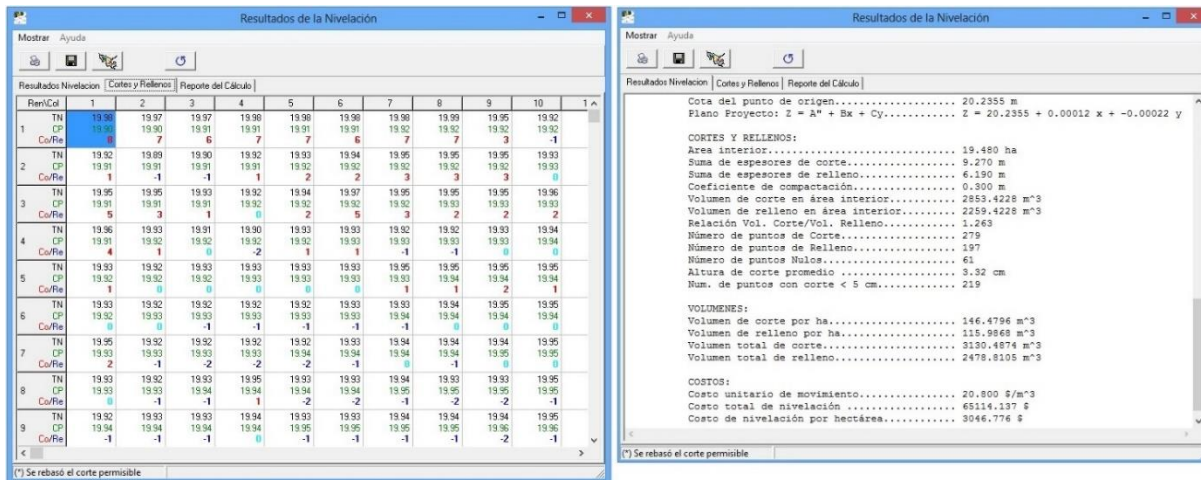


Figure 5. Leveling results for the farm in the example, without divisions.

Results of the calculation of the leveling project

After performing the respective calculations with the input data, Terra provides detailed information about the entire project, grouped into three tabs: results leveling, cuts and fills and report or calculation memory. The sections that are described in the results are: general project data, design parameters, traverse coordinates and leveling results (general, fit to plane, cuts and fills, volumes and costs).

In the section of cuts and fills, a table is presented that in each node (i, j) contains, the coordinates of the natural terrain, elevation of the project plane and the cut or fill in centimeters of each point of the grid. Finally, the report section of the memory is presented with the broken down calculation

of the results: the matrix solution of the system of equations to calculate the project plan, the calculation of the area, centroid and centroidal height, the initial project with the topographic information and of the project plan, the calculation of the equation of the plan and the iterations for the adjustment of the plan (Figure 5).

Calculation and generation of isolines

With Terra you can calculate and draw representative contour lines of the analyzed grid. To do this, the isolines are created in two different ways: the first with the field data obtained in the topographic survey by grid, the second through the geostatistical procedure of spatial interpolation detailed in the previous sections, with which a grid is created with one of two methods: the Kriging method or the inverse of distance method. Also presented is a cut and fill plan and a cut and fill block diagram that serves as a guide to the operator for leveling work in the field (Figure 6).

Cost estimation

The total leveling cost for the example of figures 4 and 5, whose summary is shown in Table 3, had a reduction of 43%, from \$65 114.14 to \$36 987.43 considering the cost m^{-3} of earthworks in \$20.80, by dividing the terrain into two tables based on the topography of the natural terrain, which improved the initial design without divisions, considering only average natural slopes.

Table 3. Comparison of volumes and costs for the example, applying the leveling to the entire land vs the property divided into two tables according to topography of the natural land.

No. Tables	Area(ha)	Volume ha (m ³)		Volume total (m ³)		Cost (\$)	
		Cut	Filling	Cut	Filling	Per hectare	Total
1	21.371	146.48	115.987	3 130.4874	2478.8105	3 046.776	65 114.137
2	21.371			1 778.242	1 377.892		36 987.43
	11.215	57.144	45.057	640.859	505.309	1 188.597	13 329.875
	10.157	111.984	85.912	1 137.382	872.583	2 329.261	23,657.555

The value of 1 in no. tables, indicates that the land was not divided.

One of the most important technical aspects of this work is the generation of the digital elevation model through the Kriging method, for the determination of cut or fill heights and quantification of cut and fill volumes, where the method of the four points suggested by the United States Department of Agriculture (1970) and which applies for its estimation a grid whose area of influence is a square. To ensure that the Terra model is technically adequate, the DEM was compared with a professional program such as Surfer (Golden software, 2011), the generated models are shown in Figure 7.

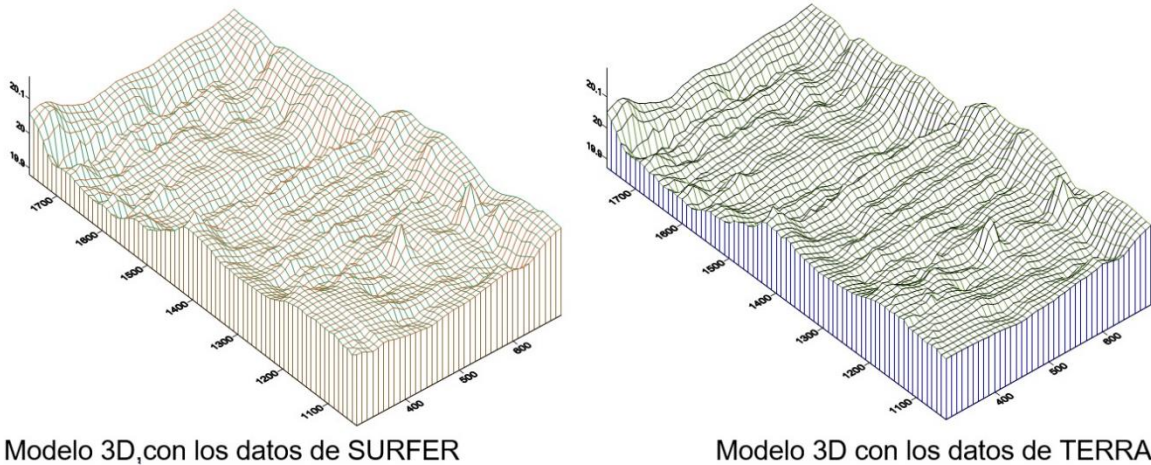


Figure 7. Digital elevation models generated by Surfer and Terra, for the example.

The models consist of 39 columns and 73 rows, with a total of 2847 Z elevation data, with means: Z_m . Terra= 20.00739094, Z_m -SURFER= 20.0099793 and variances: S^2 . Terra= 0.00373831, S^2 -SURFER: 0.0038837, when performing a statistical test for means different and different variances, it was concluded that the previous models with 97% reliability have equal mean values and with a 99% reliability value they have similar variances, which makes us conclude that they are practically equal.

This allows us to assert that the model generated by Terra, predicts the behavior in an adequate way and therefore, when generating the grid to estimate the values of cuts and fills, it generates congruent volumes that allow to adjust the project plane of the leveling in an appropriate way. With the application of modern technologies for land leveling, such as leveling with laser beam, the development of a leveling project seems unnecessary.

However, this is not the case; any leveling project, regardless of the way the field data is taken, needs an executive project with data and results that include a calculation memory with the estimation of cut and fill volumes and of course the cost of leveling, the plan with the original topography and level terrain. This will be the sustenance of the project and the support for the user to carry out the necessary procedures in case of requiring financial support in institutions that provide it to the field or in the payment of the earthworks to the tractor operator who carries out the work, without any doubt.

Conclusions

Terra 1.0, which is presented, is an electronic computing system developed as a fundamental tool to assist technicians in the formulation and optimization of executive projects for land leveling. It includes algorithms for calculating the project from a topographic survey carried out in a grid or with a variable distribution.

The use of the Kriging method was successfully integrated for the calculation of the isolines of the plane of the natural terrain, of the leveled terrain, and the use of a raised or generated grid that allows the calculation of the volume of cuts and fills. The methodology used involved

solving in detail the ordinary least squares fit using a matrix method for the calculation of the initial plane and implementing an efficient algorithm for the adjustment of the C_A coefficient of the plane equation.

In the case of the generated grid, algorithms are included for the determination of semivariograms and algebraic equations were proposed for the calculation of the coefficients C_1 and C_2 of the theoretical variogram, for the calculation of the weights in the spatial interpolation of the data of the grid. In the case of the division into tables or terraces, algorithms were implemented to separate the field points according to the divided polygons; the necessary routines are included so that the designer can generate a technically adequate design of the leveling, thereby reducing the total volumes of cuts and fillings and therefore reducing leveling costs. The Terra system can be used with the point clouds that are generated in topographic surveys that are carried out with VANTs, known as drones.

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