A Simple Method for Land Grading Computations and its Comparison with Genetic Algorithm (GA) Method

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Abstract: *This paper reports the development of a new method for land grading computation having time saving and simplicity advantages. The conventional method uses the trial and error process to determine the desired cut-fill ratio, which is cumbersome and time-consuming. In developed method, the trial and error process is not necessary. Instead, the Excel Solver was applied to determine the plane equation of land grading, and minimize the earthwork volume based on a desirable cut-fill ratio. Then, results of the new method for three data sets were compared with the conventional and genetic algorithm (GA) methods. In all of the data sets, results of the new method were better than two other methods. The cut-to-fill ratio and cut volume were less in new method than others.*

Keywords: *Land leveling; Excel Solver; Plane equation; Cut-fill ratio; Minimum cut and fill volume.*

1. INTRODUCTION

Land leveling or land forming is a form of soil disturbance that alters soil physical properties to facilitate more uniform distribution of irrigation water and is essential in improving the efficiency of surface irrigation as well as in removing excess water from the field surface [1]. Land leveling is very important in surface irrigation systems, because field surface is main transfer for water movement. Thus field surface forming should be so that water distribution has maximum uniformity [2]. Land leveling will become also more important in the future. The use of the leveling program by farmers and engineers to improve surface irrigation systems will increase productivity and water-use efficiency [3]. So Land leveling can be effective on yield. Johnson et al. (1978) showed that the average yield of the precision leveled fields is significantly more than the yield for traditional leveled. In addition, the mean time to irrigate a hectare field is significantly less for precision leveled than the traditional leveled [4]. The land leveling causes differences in soil depth and in soil layer characteristics along and across the plot. This helps to generate different soil moisture conditions at the same depth at different positions of the plot, so that the areas located at the top of the plot can shows soil moisture conditions in the surface layer that are up to 5% lower than down slope. Also Leveled plots show a yield reduction in comparison with those undergoing less transformation [5]. The alteration of the soil profiles caused by land leveling significantly changed soil moisture at different depths and runoff rates at different slope positions., so that in low disturbed soils, low differences in soil moisture were observed, while in high disturbed soils, soil moisture and water infiltration of the surface were always lower than in the low disturbed ones, while soil sealing was higher in high disturbed than in the low disturbed soils. The most disturbed plot also showed a higher sediment concentration in runoff, which together with higher runoff volumes gave higher erosion rates and soil losses than the low disturbed one [6]. Irrigation application, distribution, and water-use efficiency are appreciably reduced with increase in leveling index (1.2 to 3.7 cm) or deterioration in

leveling quality. Yield is also similarly reduced and it is significantly less for leveling index values higher than 2.5 cm. [7]. Irrespective of tillage and crop establishment methods, precision land leveling improves rice-wheat system productivity as compared to traditional land leveling. Total irrigation water savings under precision land leveling versus traditional land leveling can be 12–14% in rice and 10–13% in wheat. Precision land leveling improves rice-wheat system profitability by US$113 ha^{-1} to $175 ha^{-1} [8]. A precision land leveling is laser leveling. The introduction of laser leveling in the 1970's produced a silent revolution that has raised potential of surface irrigation efficiency to the levels of sprinkler and drip irrigation [9]. The studies indicate significant increase in irrigation efficiencies of wheat and rice through precision leveling using laser land leveler [10]. Laser leveling is a process of smoothing the land surface (± 2 cm) from its average elevation using laser equipped drag buckets to achieve precision in land leveling. Precision land leveling involves altering the fields in such a way as to create a constant slope of 0 to 0.2%. This practice makes use of large horsepower tractors and soil movers that are equipped with global positioning systems (GPS) and/or laser-guided instrumentation so that the soil can be moved either by cutting or filling to create the desired slope/level [11]. Land leveling cans also increase penetration resistance and results in a 0.1m shallower hard pan, which effectively can be reduces the soil volume for subsequent crop root growth. Deep-tillage may be required following shallow-cut land leveling to help alleviate the poor soil physical condition [12]. Some factors that are necessary to consider in land leveling are consists of: land division to minimize soil displacement, field operations, other soil needs and conservation [13]. Plane method based on least squares is a usual way to land leveling computations that can be incorporated into computer programs to be used easily for all possible land leveling problems in fields with irregular boundaries [14]. The first accurate method for computing of land leveling cuts and fills based on least-squares theory was developed by Givan (1940). The least squares procedure leads to a system of three linear equations with three unknowns for determination of the best-fit plane. The equations can be solved by determinants (Cramer's rule) using a procedure capable of solution by many programmable calculators [15]. To determine best plane equation for minimizing cut and suitable cut-fill ratio, has been also written a program in FORTRAN and BASIC computer languages [16]. Simple formulas have been presented for direct land grading design that eliminates the need for trial and error procedures in land grading process. The formulas are based on the assumption that the before and after-grading volumes measured from a reference elevation are equal; the computed plane provides equal cut and fill volumes [17]. To reduce the cost of data collection can be used the three-point method that allows the use of unequal intervals in land-grading grids [18]. A nonlinear optimization model based on genetic algorithms (GA) is developed for land grading design of irregular fields too. The model can be used to obtain of plane as well as curved surfaces [19]. Raju (1960) developed a method to calculate the slopes of the graded plane, which he called the fixed-volume center method. His method is based on minimizing of the cut and fill volumes and earth movement [20]. Land grading design by using nonlinear programming has been also developed and compared with those obtained from previously developed methods that results showed, this method is more efficient and very flexible in selecting a suitable graded surface for a given land. In this method has been used from a curve function for elevation of the graded surface at the points [21]. Linear programming was used for land grading design too [22]. Weighted average method has been used as well as for land grading design, that it is based on least-squares theory and does not have the cumbersome and time consuming calculations of the terms of the simultaneous equations that appear in the conventional least squares method. This method is amenable to both hand calculation and computer programming. Its suitability to hand calculation is an advantage. It can be used for both square grids and rectangular grids [23]. Biswal and Singh (1980) developed a general computer program for land grading using linear programming as a mathematical optimization technique for the depth of cut and fill, based on the simplex method [24].

Land grading computations are cumbersome and time-consuming by hand. The computations must be done by trial and error to achieve an optimal soil cut-fill ratio in order to determine the proper design plane. In this paper has been developed a quick method to achieve best cut-fill ratio and design plane for land grading. New method was also compared with conventional and GA methods.

2. METHODOLOGY

2.1. Conventional Method

In this paper was used from plane equation for land leveling. If field be with coordinates of *X–Y*, its plane equation is written as following:

$$EL(X,Y) = AX + BY + C \tag{1}$$

Where $EL(X, Y)$ = the elevation of a point with coordinates of X and Y; A and B = the regression coefficients (slope is both in X and Y directions); and C = the elevation of the base coordinate. A, B and C values can be determined using following four steps in conventional method:

Step 1: Each point is related to an area, for example related area to point "a" is standard area (A_s) and $\theta_{51}.A_S$ is for point "b" in Fig.
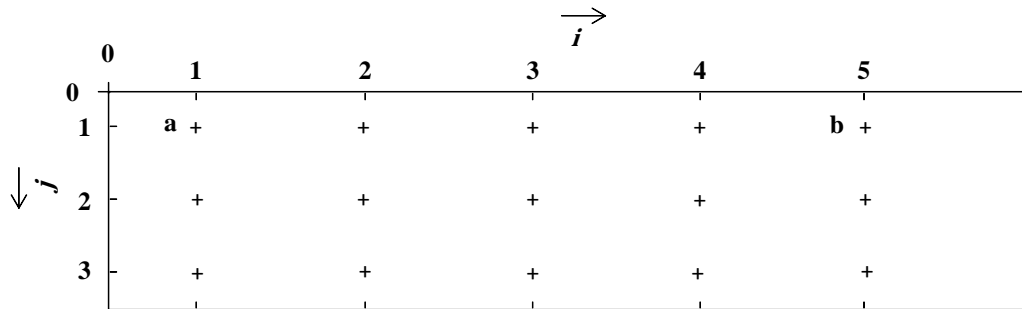

Fig 1. *Field gridding and points in i and j rows*

Therefore, for each point a weight factor is defined as following:

$$\theta_{ij} = \frac{A_{ij}}{A_s} \tag{2}$$

Where θ_{ij} = weight factor of a_{ij} point; A_{ij} = related area to a_{ij}. This is necessary to give different weights to related area to each point in the proximity of the field boundaries. Therefore, the actual cut and fill depths can be computed [25]. Interior regular grid points have a weighting factor of 1.00.

Using of Eq. 2, average elevation in i row, EL_i, is as Eq. 3:

$$EL_i = \frac{\sum_{j=1}^{N'} \theta_{ij} EL_{ij}}{\sum_{j=1}^{N'} \theta_{ij}} \tag{3}$$

Where N' = number of point in Y direction; EL_{ij} = elevation of point a_{ij}.

Similar equation can be written for calculating of average elevation of j, EL_j as following:

$$EL_j = \frac{\sum_{i=1}^{N''} \theta_{ij} EL_{ij}}{\sum_{i=1}^{N''} \theta_{ij}} \tag{4}$$

Where N'' = number of rows in X direction.

Step 2: Finding centroid location according to gridding system. Distance from point "O" to centroid in X direction is calculated from Eq. 5:

$$X = \frac{\sum_{j=1}^{N'} \theta_j X_j}{\sum_{j=1}^{N'} \theta_j} \tag{5}$$

Where X = distance from origin point to centroid; $X_j = X$ distance from origin point to j row, and:

$$\theta_j = \sum_{i=1}^{N''} \theta_{ij} \qquad (6)$$

Similarly,

$$Y = \frac{\sum_{i=1}^{N''} \theta_i Y_i}{\sum_{i=1}^{N''} \theta_i} \qquad (7)$$

Where Y = distance from origin point to centroid; $Y_j = Y$ distance from origin point to i row, and:

$$\theta_i = \sum_{j=1}^{N'} \theta_{ij} \qquad (8)$$

Step 3: Calculation of least squares line [26] through the average elevations in both X and Y directions. Slope of best line in X direction is A that is determined by Eq. 9:

$$A = \frac{\sum_{j=1}^{N'} X_j EL_j - \left(\sum_{j=1}^{N'} X_j\right)\left(\sum_{j=1}^{N'} EL_j\right) \Big/ N'}{\sum_{j=1}^{N'} X_j^2 - \left(\sum_{j=1}^{N'} X_j\right)^2 \Big/ N'} \qquad (9)$$

The best slope in Y direction is equal to Eq. 10:

$$B = \frac{\sum_{i=1}^{N''} Y_i EL_i - \left(\sum_{i=1}^{N''} Y_i\right)\left(\sum_{i=1}^{N''} EL_i\right) \Big/ N''}{\sum_{i=1}^{N''} Y_i^2 - \left(\sum_{i=1}^{N''} Y_i\right)^2 \Big/ N''} \qquad (10)$$

Step 4: Calculation of C value in Eq. 1. Average elevation in the field is EL_j or EL_i summation dividing to the rows number of gridding. This average elevation is elevation of field centroid (EL_F). X and Y coordinates also are specified for center of gravity. So C value is obtained from Eq. 11:

$$C = EL_F - AX - BY \qquad (11)$$

After determining of A, B and C, plane equation will be specified. New elevation in each point was calculated using this equation. It is important to note that difference between primitive and new elevation is cut (negative values) or fill (positive values) height. A and B values should be in the acceptable range. For example, $A=0$ in border irrigation system. Four steps that were explained are based on minimizing soil displacement operations.

Cut and fill volume are calculated by Eq. 12 and 13 respectively:

$$V_c = \sum_{m=1}^{N_c} A_m C_m \qquad (12)$$

$$V_f = \sum_{n=1}^{N_f} A_n F_n \qquad (13)$$

Where V_c = cut volume, m^3; V_f = fill volume, m^3; A_m, A_n = related area to point "m" and "n" respectively, m^2; C_m = cut depth in point "m", m^2; F_n = fill depth in point "n", m^2.

Ratio of Cut to fill volumes, R, is as following:

$$R = \frac{V_c}{V_f} \tag{14}$$

R value should be in range of 1.1 to 1.5 [27]. R depends on type of soil and the operating conditions during land grading [28].

2.2. New Method

New method for leveling is the purpose of presented paper that is to be minimize of $f(V_c, V_f)$ in Eq. 15 and $R = 1.1–1.5$.

$$f(V_c, V_f) = V_c + V_f \tag{15}$$

Thus $R = 1.1$ (or any arbitrary value according to soil type and leveling operation) and minimizing of $f(V_c, V_f)$ and V_c are objective functions. One of software for optimization and reaching to purpose functions is Solver Excel. For achieving to the paper purposes, leveling plane equation was calculated with using Solver software in Excel. An example using of Solver software for attaining to these objectives is showed in Fig.
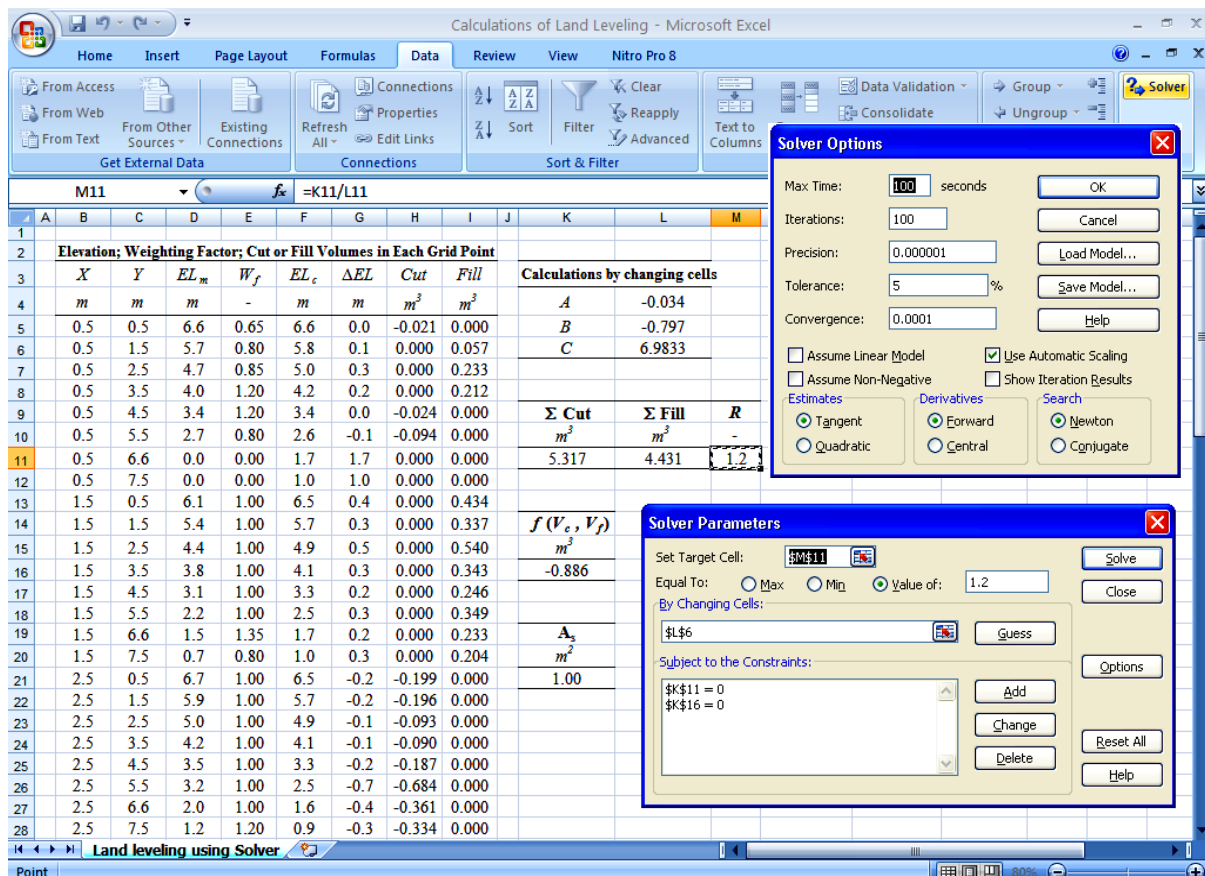

Fig 2. *Example of leveling plane equation calculated by Solver software in Excel*

For minimizing of V_c and $f(V_c, V_f)$ in "subject to the constraints" box were applied $V_c = 0$ and $f(V_c, V_f) = 0$.

In Fig, desired R is 1.2, W_f = Weighting Factor and ΔEL is cut or fill height that $\Delta EL = EL_c - EL_m$. Where EL_c = new elevation of points on leveling plane equation and EL_m = primitive elevation that was measured by surveying. It is important to say that negative slopes are downhill. In "Solver options" tab was used from "Use Automatic Scaling" according to Fig. Initial

values of *A*, *B* and *C* were determined according to slope and field shape constraints for gravity irrigation. Program was run by clicking of Solve key and optimal *A*, *B* and *C* values were obtained according to constraints. To determine of cut and fill volumes was used from IF function in Excel, so that functions of IF ($\Delta EL > 0$; ΔEL; 0) and IF($\Delta EL < 0$; ΔEL; 0) were applied for calculation of fill and cut volumes respectively. A_m, A_n were also used for determination of cut and fill volumes. A_m, A_n were obtained by standard area and weight factor in the gridding. ABS function was only used in calculation of cut volume not in $f(V_c, V_f)$, V_c and V_f calculations.

2.3. Genetic Algorithm Method

GA is based on Darwin's theory of survival of the fittest for optimal search techniques [29-33]. GA is different than more traditional nonlinear and linear optimization procedures. GA will be working with a group of most-fit decision vectors. In contrast, the more traditional nonlinear and linear optimization procedures work with only one decision vector at any given time [34-49]. GA uses a wide variety of parameters as decision variables. These differences make the genetic algorithms more robust for nonlinear and linear optimization problems such as land grading, over their more traditional counterparts. As GA works with an unconstrained objective function, the constrained optimization problem is converted into an unconstrained one, using exterior penalty functions [50-63].

In this paper GA method was used as following:

If E_{ij} is the elevation of the natural surface, vertical distance D_{ij} between the natural and the graded surface may be computed using D_{ij}:

$$D_{ij} = E_{ij} - Z_{ij} \tag{16}$$

$$Z_{ij} = C_1 + C_2 x_{ij}^m + C_3 y_{ij}^n \tag{17}$$

Where C_1 = elevation of graded surface at origin of coordinate axis; C_2 and C_3 are coefficients; and *m* and *n* are exponents. Exponents of *m* and *n* are 1.00 in linear optimization procedures.

The aim of any optimal land grading design should be to minimize the total volume of earth in cut while satisfying certain design constraints. In the proposed study, the optimal land grading design problem is formulated mathematically as a nonlinear programming problem subject to both linear and nonlinear constraints. The objective of the present optimization model is to minimize the volume of earth in cut. Mathematically, this may be written as:

$$minimize\ V_c(C_1, C_1, C_1, m, n) \tag{18}$$

Where V_c = volume of earth in cut, which is a nonlinear function described in Eq. 17. For all of field the objective function may now be written as:

$$minimize\ V_c = \sum_{i=1}^{NX} \sum_{j=1}^{NY} D_{ij} A_{ij} K_{ij};\ K_{ij} = 1\ for\ D_{ij} > 0, K_{ij} = 0\ for\ D_{ij} < 0 \tag{19}$$

Where A_{ij} = area represented by grid point (*i*, *j*); K_{ij} = multiplication factor; and *NX* and *NY* = number of grid points in the *X*- and *Y*-directions, respectively.

Optimization to minimize the objective function needs to be carried out subject to the following design constraints:

$$L_{C_1} \leq C_1 \leq U_{C_1} \tag{20}$$

$$D_{ij} \leq U_D \tag{21}$$

$$SX_{ij} = \frac{\partial Z_{ij}}{\partial x_{ij}} = C_2 m x_{ij}^{m-1};\ j = 1, 2, \ldots NY \qquad L_{SX_{ij}} \leq SX_{ij} \leq U_{SX_{ij}} \tag{22}$$

$$SY_{ij} = \frac{\partial Z_{ij}}{\partial y_{ij}} = C_3 n y_{ij}^{n-1};\ j = 1, 2, \ldots NX \qquad L_{SY_{ij}} \leq SY_{ij} \leq U_{SY_{ij}} \tag{23}$$

$$L_R \leq R \leq U_R \tag{24}$$

Where SX_{ij} and SY_{ij} are slope in the X and Y direction respectively, R = cut-to-fill ratio that is in specified range. In Eq. 20-24 L represents the lower bound and U represents the upper bound. Lower and upper bounds were determined based on gravity flow of water for irrigation, avoiding excessive loss of top productive soil for irrigation, facilitating the gravity flow of water for irrigation or to prevent soil erosion in the case of land drainage, soil type and land grading operation [64-66].

In the present model, a search technique based on GA is used to solve the optimal design problem, as it is most suited for problems of this kind.

In this study was applied MATLAB software for doing GA process.

3. APPLICATION

In this research a field with the width of 13m and the length of 110m was selected for land leveling. Soil compaction was resolved with plowing and disking and then initial leveling was done by traditional leveler. Field boundaries were marked and a bench mark point was considered to convert readings in surveying to elevation and then field was surveyed and gridded for leveling operation (Fig, 4 and 5).

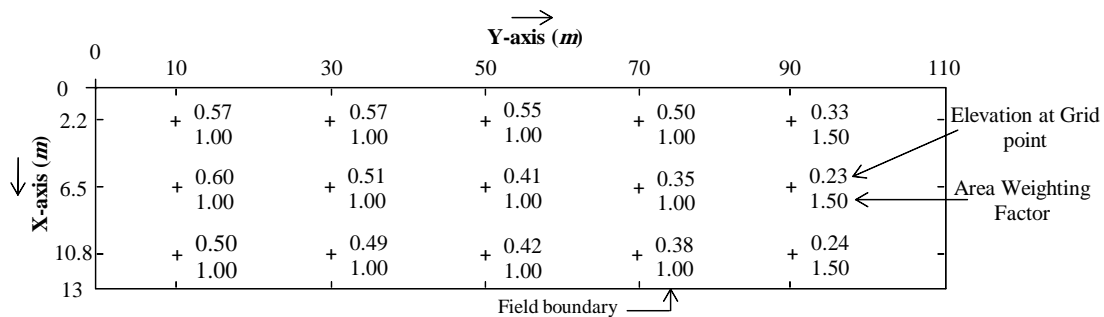**Fig 3.** *Field boundaries; Field surveying and gridding after initial leveling*

Fig 4. *Elevation (meter) and area weighting factor at each grid point (first data set)*
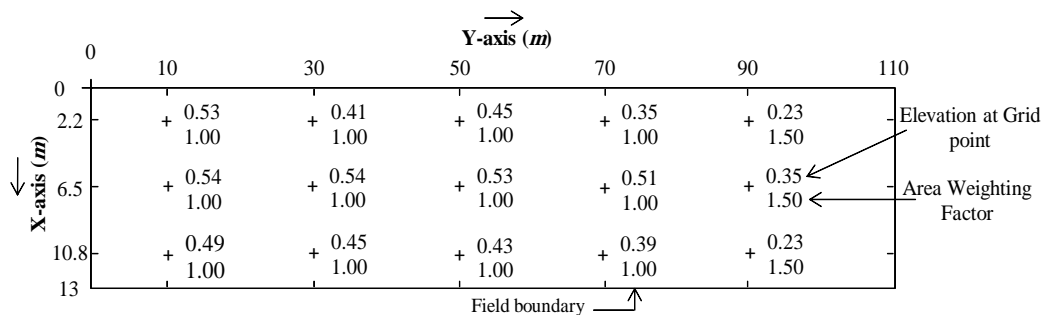

Fig 5. *Elevation (meter) and area weighting factor at each grid point (second data set)*

Topography and elevation of each point was determined and common, GA and new methods were used for leveling calculations and then were compared together. Leveling plane equations determined with usual, GA and new methods are presented as Eqs. 25, 26 and 27 for first data set respectively:

$$EL(X,Y) = -0.0112X - 0.0035Y + 0.684 \tag{25}$$

$$EL(X,Y) = -0.0140X - 0.0040Y + 0.764 \tag{26}$$

$$EL(X,Y) = -0.0104X - 0.0039Y + 0.701 \tag{27}$$

Similarly, for second data set equations were written as following:

$$EL(X,Y) = +0.0004X - 0.0028Y + 0.556 \tag{28}$$

$$EL(X,Y) = +0.0040X - 0.0020Y + 0.486 \tag{29}$$

$$EL(X,Y) = +0.0018X - 0.0029Y + 0.555 \tag{30}$$

In first and second data sets desired R is 1.1 and $A_s = 20 \times 4.3\ m^2$.

Third data set was used from Reddy (1996). This data are shown in Fig:

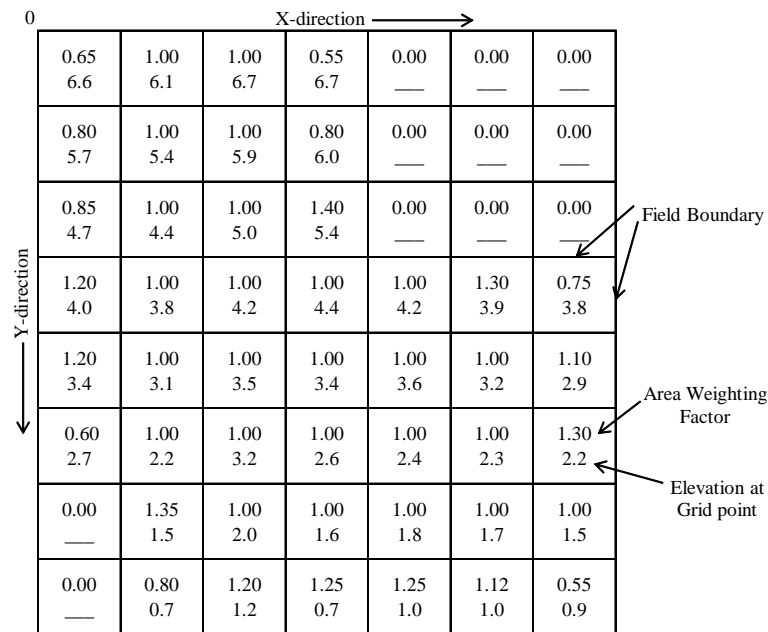|						
0.65 6.6	1.00 6.1	1.00 6.7	0.55 6.7	0.00 —	0.00 —	0.00 —
0.80 5.7	1.00 5.4	1.00 5.9	0.80 6.0	0.00 —	0.00 —	0.00 —
0.85 4.7	1.00 4.4	1.00 5.0	1.40 5.4	0.00 —	0.00 —	0.00 —
1.20 4.0	1.00 3.8	1.00 4.2	1.00 4.4	1.00 4.2	1.30 3.9	0.75 3.8
1.20 3.4	1.00 3.1	1.00 3.5	1.00 3.4	1.00 3.6	1.00 3.2	1.10 2.9
0.60 2.7	1.00 2.2	1.00 3.2	1.00 2.6	1.00 2.4	1.00 2.3	1.30 2.2
0.00 —	1.35 1.5	1.00 2.0	1.00 1.6	1.00 1.8	1.00 1.7	1.00 1.5
0.00 —	0.80 0.7	1.20 1.2	1.25 0.7	1.25 1.0	1.12 1.0	0.55 0.9

(X-direction; Y-direction; Field Boundary; Area Weighting Factor; Elevation at Grid point)

Fig 6. *Land gridding; area weighting factor; and elevation (third data set) at grid point (Reported by Reddy, 1996)*

Area of each square is 1.00 m^2 in Fig, thus, $A_s = 1.00\ m^2$ and desired $R = 1.2$. Obtained equations for leveling plane using usual, GA and the new methods are as following equations respectively:

$$EL(X,Y) = -0.0105X - 0.7976Y + 7.3094 \tag{31}$$

$$EL(X,Y) = -0.0270X - 0.8140Y + 7.4472 \tag{32}$$

$$EL(X,Y) = -0.0335X - 0.7970Y + 6.9833 \tag{33}$$

For better comparison of three methods and R, V_c, V_f values in three data sets, Table 1 has been presented:

Table 1. *Comparison of three methods for land grading with three data sets*

Parameters	Unit	First data set			Second data set			Third data set		
		Conv method	GA method	New method	Conv method	GA method	New method	Conv method	GA method	New method
V_c	m^3	26.904	30.267	23.936	38.396	40.780	37.477	5.359	5.346	5.317
V_f	m^3	23.746	27.516	21.760	34.082	37.072	34.070	4.466	4.455	4.431
R	m^3/m^3	1.133	1.100	1.100	1.127	1.100	1.100	1.200	1.200	1.200
S_x	m/m	-0.0112	-0.0140	-0.0104	0.0004	0.0040	0.0018	-0.0105	-0.0270	-0.0335
S_y	m/m	-0.0035	-0.0040	-0.0039	-0.0028	-0.0020	-0.0029	-0.7976	-0.8140	-0.7970

Note: Conv = Conventional; desired R in first and second data sets is 1.1 and in third data set is 1.2; S_x = slope in X-direction; S_y = slope in Y-direction.

It is important to note that to achieve to the desired R in conventional method was used from trial and error method, because R value was undesired in initial steps. For this work if R value to be too high, the leveling plane should be raised and if R value to be too small, the plane should be lowered by parallel shifting of initial plane and cut and fill volumes should be recalculated. So application of the conventional method is very complicated and time-consuming. With comparing of the three methods was found that new method has minimum cut and fill and is quicker than the other methods to determine optimal R. Table 1 shows that in the new method, cut volume is less than other methods and this is desirable, because of cut operations is expensive. This subject is one of the advantages of the new method. In the new method is not necessary to be done the previous four steps that were explained in conventional method. Best plane equation was calculated using the new method in the first stage even in fields with irregular boundaries and is not necessary to trial-and-error process. The centroid location and its elevation are not required also in the computational process in the new method in contrast of conventional method. According to Table 1 new method in first and second data sets implies better irrigation efficiency in the Y-direction (advance direction) due to more B value and less erosion in the X-direction due to less A value that are very important objects in irrigation system design. In third data set better irrigation efficiency and less erosion there are in X- and Y directions respectively in the new method. Also due to less top productive soil movement in the field, the new method could be important in sustainable development and agricultural operation that this subject shows itself more in the larger field. It should be noted that R greater than 1.00 is necessary, because of the soil compaction in fill parts by leveling machine and visual errors that can increase fill volume [67-73].

With comparison of new and GA methods (as optimal land grading method) was found that new method gives a better plane equation than GA in terms of cut volume and field slope.

Finally, the grade elevation at the farm turnout was checked to make sure that it allows gravity irrigation from the water source according to C value.

4. CONCLUSION

Because leveling is expensive and high soil displacement makes no surface fertile soil in some parts of the field, method with minimum soil displacement is common method of leveling operations in agricultural land. In this paper, to achieve these objectives were used three data sets and leveling plane equation was determined through minimizing cut and fill operations by Excel Solver as new method. Results showed that this method as compared to the conventional method, which is consists of four steps to determine of leveling plane equation, and GA method, as optimal land grading method, provides a high better plane equation in terms of cut volume and field slope and it is also a quicker method.

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