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Full Length Research Paper

Volume equalization method for land grading design: Uniform sloped grading in one direction in rectangular fields

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Land grading is an important procedure at accomplishing the efficient surface irrigation. This paper presents a new method (volume equalization method-VEM) which has been developed to perform land grading design in designing the uniform sloped grading in one direction. The main goal of this method was to minimize the volumes of earth work required for acceptable smooth surface. The method is based on the assumption that, before and after grading, the soil volumes measured from a reference elevation are equal. The method eliminates the need for trial and error procedures. According to the results of the application of the complete design procedure to a hypothetical area about 2.21 ha, the method was as accurate as the conventional least-squares method in rectangular fields.

Key words: Land grading, land leveling, volume equalization method.

INTRODUCTION

Land leveling (precision leveling or precision grading) is the practice of creating a slight, but uniform slope across a field to facilitate more uniform distribution of irrigation water (Brye et al., 2003, 2004, 2005; Abdullaev et al., 2007) and is routinely performed in fields (Brye et al., 2006). Effective land leveling reduces the work in crop establishment and crop management and increases the yield and quality (Rickman, 2002). Even, it is a process for ensuring that the depths and discharge variations over the field are relatively uniform and, as a result, that water distributions in the root zone are also uniform. There are perhaps two land leveling philosophies: (1) To provide a slope which fits a water supply and (2) to level the field to its best condition with minimal earth movement and then vary the water supply for the field condition. The second philosophy is generally the most feasible. Because land leveling is expensive and large earth movements may leave significant areas of the field without fertile topsoil, this second philosophy is also generally the most economic approach (Walker, 1989).

Land grading has been in practice for a long time, but land-grading designs were first accomplished by elementary calculations using trial-and-error (Hamad and Ali, 1990). The first accurate method to accomplish land grading designs was developed by Givan (1940). His method was based on least-squares theory and he showed its application in rectangular fields. Then, Chugg (1947) used least-squares method (LSM) in irregularly shaped plots. Another one, the average profile method (APM) developed by Marr (1957) is also based on the LSM theory and can be used in rectangular fields. The applications based on the LSM was continued by Scallopi and Willardson (1986) who developed a practical

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Abbreviations: LSM, Least squares method; **SRM,** symmetrical residuals method; **VEM,** volume equalization method; **APM,** average profile method; **FVCM,** fixed volume center method.

procedure to calculate the slopes of a graded plane by using least squares and then, Gebre-Selassie and Willardson (1991) introduced a user-friendly land-leveling program developed for the computation scheme presented by Scallopi and Willardson (1986). Jalal (2004) presented a new method for land grading design. The method was also based on the theory of the least squares and the statistical properties of the best statistic with an unbiased estimate and minimum variance.

Another method, the fixed-volume-center method (FVCM) was developed by Raju (1960) to calculate the slopes of the graded plane. The method ensures the least earth cutting and filling. Shih and Kriz (1971) introduced the symmetrical residuals method (SRM) to grade lands that allows for uniform or non-uniform slopes in both directions. The method can be used for five design alternatives; (a) uniform slopes allowing drainage in both directions; (b) variable slopes allowing drainage in both directions; (c) uniform slope along the individual profiles in one direction and variable slope in the other and allowing drainage in both directions; (d) uniform slope along individual profiles allowing drainage in one direction and minimum and maximum allowable slopes in the other direction; (e) variable slope along individual profiles allowing drainage in one direction and minimum and maximum allowable slopes in the other direction.

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. A field leveled with conventional equipment can attain a standard deviation of 20 to 30 mm, but while using laser leveling the technical limit extends up to 10 mm (Jat et al., 2006).

Paul (1973) developed two methods called the double-centroid method and the computer minimized cost method to calculate the slopes of the best-fit plane. Hamad's (1981) method used the theory of profitability provided for quick estimation of the volumes of earth work. In other research, a new technique was developed using non-linear programming by Hamad and Ali (1990) to fit a curved or a plane-graded surface to the natural ground surface. The new procedure proved efficient and very flexible in selecting a suitable graded surface for a given land.

Srinisava (1996) developed a nonlinear optimization model based on genetic algorithms for land grading design of irregular fields. The method proposed by Easa (1989) explicitly considers the required design specifications which may include the two edge slopes of the plane, one edge slope and a control point or two control points. The present method eliminated the need for use of trial and error. A land-leveling system that uses the global positioning system (GPS) was provided by Zimmermann et al. (2005); the system provided for an earth-moving machine mounted with antenna that receives GPS signals from the satellites of the GPS.

A new assessment technique was proposed by Osari (2003) for evaluating the leveling quality in paddy field. The new method used a state index, derived from two elements (field inclination and surface roughness), to effectively assess the state of a field. In addition, on the basis of the proposed new assessment method, the method also proposed a management plan for land leveling that would reduce the workload required for land leveling and make it more equitable.

In this research, a new method (volume-equalization method-VEM) has been introduced to design a uniform sloped-graded surface in one direction. The method covers regularly shaped (rectangular or square) fields. The method uses the principle also used by Raju (1960) and Easa (1989) that, the volume under the original ground surface is equal to the volume under the computed land grading plane.

MATERIALS AND METHODS

Land grading is performed in lands where surface irrigation techniques are employed in order to increase the efficiency of irrigation. Therefore, land was rendered compatible with the slope values required by the irrigation method via land grading. Depending on the irrigation method to be employed, land can be graded according to one of grading types such as uniformed sloped grading in one direction, uniform sloped grading in two directions, variable sloped grading in one direction and variable sloped grading in two directions or in accordance with the natural slope of the land. In this study, the application of uniform sloped grading in one direction of volume equalization method (VEM) on smooth patterned lands was issued.

Uniform sloped grading in one direction

A field layout and the adopted coordinate system are shown in Figure 1. The grid elevations, h_{ij} ($i=1,2,3\ldots,n_j$ in row direction and $j=1,2,3\ldots,m_i$ in cross row direction) were taken at equal intervals, d. The numbers of rows and cross rows may not be equal. In this case, stations (grid points) form an mxn sized matrix. There was distance of half a square length between a grid point and land borders. Thus, each station-grid point represented square shaped land with a side length of d. However, the area represented by each grid point was not always square shaped. Sometimes this area may be bigger or smaller than one unit of square. The area represented by any station (F_{ij}), was the area formed by connecting the side midpoints of the station and adjacent stations (Figure 1). For instance, grid points such as h_{11}, h_{21}, h_{23}, h_{32} represented the areas of 1.0 unit, h_{1m}, h_{2m}, h_{3m} grid points represented areas bigger than 1.0 unit and grid point like h_{n1}, h_{n2}, h_{nm} represented areas smaller than 1.0 unit.

The grid elevation of each grid point determined was measured and transferred to a CAD program. The grid elevations in every row and cross row were summed up to obtain $\sum H_i$ and $\sum H_j$ values and their means were calculated to acquire $H_{i\ mean}$ and $H_{j\ mean}$ values (Figure 1). $H_{i\ mean}$ ve $H_{j\ mean}$ values could be found with the help of the equations below:

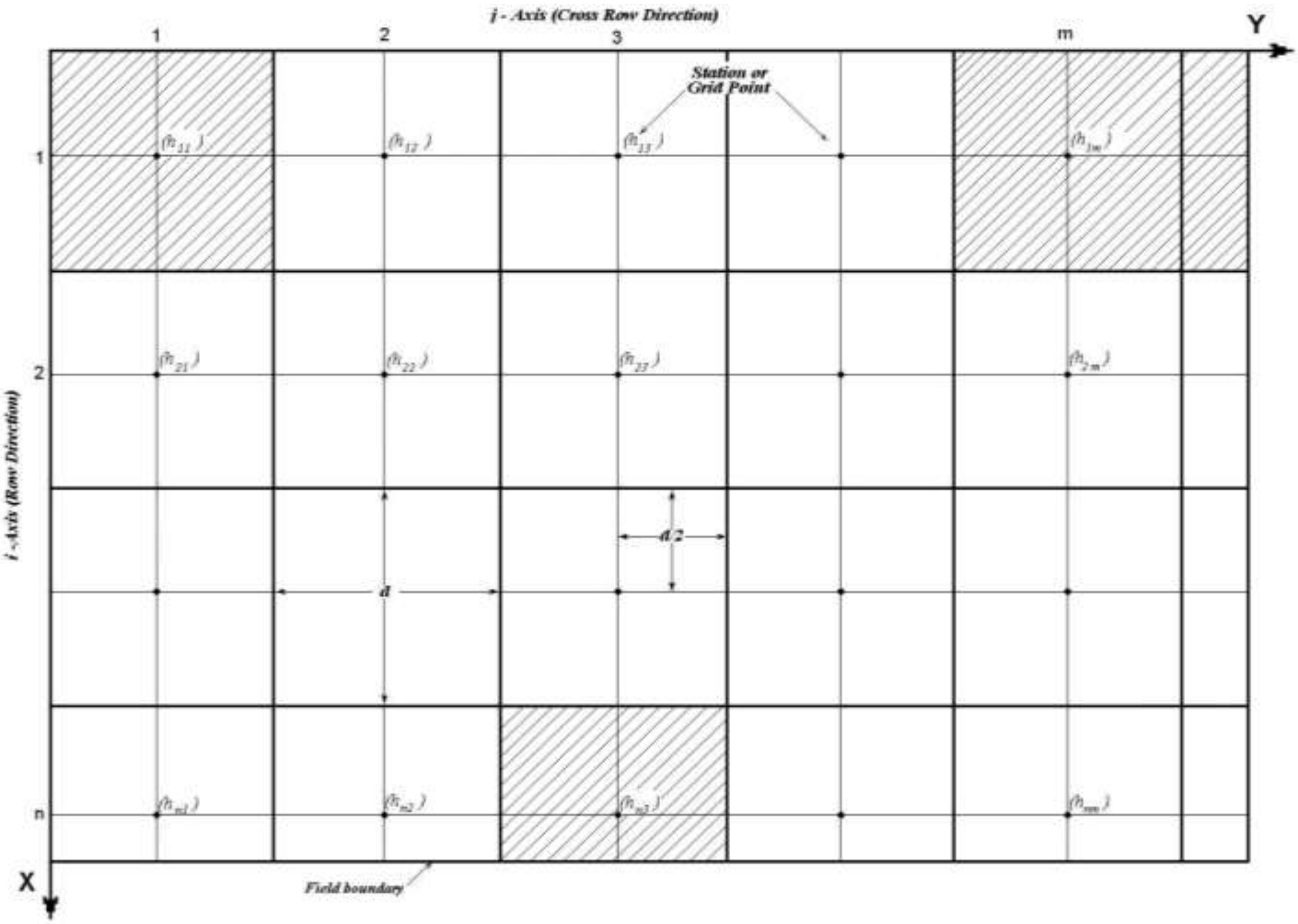

Figure 1. Field layout and the adopted coordinates system.

$$H_{i\,mean} = \frac{\sum_{j=1}^{m} h_{ij} x F_{ij}}{m} \quad (1)$$

$$H_{j\,mean} = \frac{\sum_{i=1}^{n} h_{ij} x F_{ij}}{n} \quad (2)$$

Where $H_{i\,mea,}$ is the value of the mean of i^{th} row (m); $H_{j\,mean}$, is the value of the mean of j^{th} cross row (m); h_{ij}, is the grid elevation of i^{th} row at j^{th} cross row (m); F_{ij}, is the unit area of grid of a i^{th} row at j^{th} cross row (m^2).

In the CAD program, contours were drawn with required intervals as coordinates and elevation values were entered for each grid and land borders were taken into consideration. Then, areas between every contour within the land borders were calculated one by one with the help of the program

Before-grading volume

The significance of the method laid in the calculation of the amount of soil in the land which was to be graded based on a reference plane and utilization of this soil volume in the grading process. Equation 3 was used to calculate the volume of soil between two consecutive grading curves:

$$V_z = \frac{c_z + c_{z+1}}{2} . F_z \quad (3)$$

Where V_z, is the volume of the soil between two consecutive grading curves (m^3); c_z, is the elevation of the smaller one of the grading curves of which the volume of soil was calculated (m); c_{z+1}, is the elevation of the bigger one of the grading curves of which the volume of soil was calculated (m); and F_z, is the projection area between the two grading curve of which the volume of soil was to be calculated (m^2).

In every land, there were land fractions higher than the biggest grading curve and lower than the smallest grading curve. The calculation of the soil volume (V_{ad}) in these fields, the elevation values of the grading curves and the border point of the land in that field were used with the help of the Equation 3.

The total soil volume before grading (V_{bg}) was obtained by summing all of the volumes between the two grading points. Hence, the total soil volume before grading was found with the help of Equation 4.

$$V_{bg}=\sum_1^z V_z + V_{ad} \quad (4)$$

Where, V_{bg}, is the total soil volume before grading (m^3); n, is the number of land fractions separated by grading curves in the field; V_{ad}, is the soil volume belonging to the field outside of the grading curves (m^3); and z, is the number of areas between grading curves ($z=1,2,3,\ldots,z$).

After-grading volume

According to the principle of *"soil should not be brought from another place to the land which is to be graded, nor it should be removed from the land which is to be graded to another place"* which is among the basic rules of land grading, the value of the soil volume before grading (V_{bg}) should be equal ($V_{bg} = V_{ag}$) to the value of the soil volume after grading (V_{ag}). In case of grading the land in one direction with a uniform slope which is a usually preferred style of grading for surface irrigation methods, total soil volume after grading in the field was calculated using the Equation 5:

$$V_{ag}=\frac{h_l+h_l+h_u+h_u}{4}.F = \frac{2h_l+2h_u}{4}.F \;\text{»}$$
$$V_{al}=\frac{h_l+h_u}{2}.F \quad (5)$$

Where, V_{ag}, is the total soil volume before grading (m^3); h_l, is the elevation of land corners which will be low elevation after grading (m); h_u, is the elevation of land corners which will be high elevation after grading (m); F, is the projection area of the land to be graded (m^2).

In this phase, a decision must be made on the direction and degree of slope for grading. There are three possibilities as the land is preferred to be graded sloped in X or Y direction and at a certain value; land may be preferred to be sloped in a certain direction at a certain value due to the irrigation method or other considerations such as the wish of the land owner. In such cases, the land was processed according to the desired direction and value; land may be preferred to be graded in accordance with its natural elevation and in such cases, the value and direction of land's natural slope should be determined; and land may be preferred to be graded 0% sloped (flat land) in any direction.

If the direction and value of grading is determined

The application of *"uniform sloped grading in one direction"* with a certain direction and value may be explained as follows. After such a grading process, the elevation of both low and high corner grid points of the land should be equal. After grading, if low elevation corner grid points were represented with h_l and high elevation corner grid points with h_u, then the following equation on high and low elevation corner grid points may be written as:

$$h_u=h_l+\frac{M.L_m}{100} \quad (6)$$

Where, h_u, is the elevation of land corners which will be high elevation after grading (m); h_l, the elevation of land corners which will be low elevation after grading (m); L_m, the length of the land in the slope direction (m); M, the amount of slope ($\%$).

As Equation 6 was placed in Equation 5 and the required reductions were made, the equation which was used in order to find the elevation of lower elevation land corner after grading was as follows:

$$V_{ag}= \left(\frac{h_l+h_u}{2}\right).F \;\text{»}\; 2V_{ag}=(h_l+h_u).F = (h_l+h_l+\frac{M.L_m}{100}).F = \left(2h_l+\frac{M.L_m}{100}\right).F$$
$$\text{»}\; h_l = \frac{2V_{al}-\frac{M.L_m.F}{100}}{2F} = \frac{V_{al}-\frac{M.L_m.F}{200}}{F} \;\text{»}$$
$$h_l = \frac{V_{ag}}{F} - \frac{M.L_m}{200} \quad (7)$$

After finding the elevation of low elevation grid point after grading with the help of Equation 7, the elevation of each corner grid point in the slope direction was found using Equation 8:

$$h_{l+1} = h_l + \frac{M.L_s}{100} \quad (8)$$

Where, h_{l+1}, is the elevation of the corner grid point consecutive to the low elevation corner grid point in the ascending direction (m) and L_s, the side length of the square (m).

The elevations of all of the grids in the land were found in this way. Cut and fill elevations at any grid point can be determined by comparing the grid elevations found and the natural grid elevations. Cut and fill volumes at every station were found according to the determined cut-fill elevations. For the calculation of cut or fill volume at any station, cut or fill depth at that station in terms of m is multiplied by the unit area value of the station.

$$V_{pc} = h_{pc} * F_{pc} \quad (9)$$

$$V_{rf} = h_{rf} * F_{rf} \quad (10)$$

Where, V_{pc}, is the cut volume at the p^{th} station p (m^3); h_{pc}, is the cut elevation at the p^{th} station (m); F_{pc}, is the unit area value of the p^{th} station (m^2); V_{rf}, the fill volume at the r^{th} station (m^3); h_{rf}, the fill elevation at the r^{th} station (m); and F_{rf}, is the unit area value of the r^{th} station (m^2).

$$V_c = \sum_1^p V_{pc} \quad (11)$$

$$V_f = \sum_1^r V_{rf} \quad (12)$$

Where, V_c, is the total cut volume (m^3); V_f, the total fill volume (m^3); p, the number of cut corners ($p=1,2,3,\ldots,p$); and r, the number of fill corners ($r=1,2,3,\ldots,r$).

Cut/fill ratio (Rc/f) was found by comparing total cut and fill elevations. In land grading, c/f ratio according to soil texture should be between the values presented in Table 1 (Yildirim, 2008). If the ratio was found within the limits, grading process would be performed according to the values determined.

If cut/fill ratio was not within the limits, the elevation of the grading plane should be changed. In this case, the amount of

Table 1. Cut/fill ratios ($R_{c/f}$) according to soil texture (Yildirim, 2008).

Texture	Cut/fill ratio ($R_{c/f}$)
Sandy	1.15-1.25
Loamy	1.25-1.40
Loamy-clay	1.40-1.60
Clay	1.50-1.80

required change in the elevation of grading plane could be found using Equation 13:

$$h_d = \frac{\left[V_{cf} - \frac{2V_{cf}}{D_{c/f}+1}\right] - [V_c - V_f]}{F_{cf}} \quad (13)$$

Where h_d, is the amount of required change in the elevation of grading plane (*cm*); V_{cf}, the sum of cut and fill volumes (m^3); $D_{c/f}$, the desired cut/fill ratio; V_c, the total cut volume (m^3); V_f, the total fill volume (m^3); F_{cf}, the total projection area where cut and fill were performed (m^2).

Cut/fill ratio was determined using the following equation:

$$R_{c/f} = \frac{\sum V_c}{\sum V_f} \quad (14)$$

Where, $R_{c/f}$, is the cut/fill ratio.

Grading the land to its natural slope

In case the land was desired to be graded to its natural slope; initially it should be decided whether the land is to be graded according to the slope in *X (i)* direction or *Y (j)* direction then, the natural slope in *X* or *Y* direction was determined.

When the land was to be graded according to the natural slope in X direction $H_{i\ mean}$ values (Figure 2) were taken into account. Similarly, when it was to be graded according to the natural slope in Y direction, $H_{j\ mean}$ values were used.

$$S_x = \frac{\left(\sum_{n=1}^{n} \frac{H_{i\ mean\ n-1} - H_{i\ mean\ n}}{L_s}\right) x100}{N_x - 1} \quad (15)$$

Where, S_x, is the natural slope of the land in *X* direction (*%*); $H_{i\ mean\ n-1}$, the value of the $H_{x\ mean}$ values consecutive in *X* direction which is closest to the *Y* axis (*m*); $H_{i\ mean\ n}$, the value of the $H_{x\ mean}$ values consecutive in *X* direction which is farthest to the *Y* axis (*m*); L_s, the side length of the square (*m*); N_x, the number of grids in *X* direction.

Similarly, if the land was to be graded according to the natural slope in Y direction equation16 was used:

$$S_y = \frac{\left(\sum_{n=1}^{n} \frac{H_{j\ mean\ n-1} - H_{j\ mean\ n}}{L_s}\right) x100}{N_y - 1} \quad (16)$$

Where, S_y, is the natural slope of the land in *Y* direction (*%*); $H_{y\ mean\ m}$, the value of the $H_{y\ mean}$ values consecutive in *Y* direction which is closest to the *X* axis (*m*); $H_{y\ mean\ m+1}$, the value of the $H_{y\ mean}$ values consecutive in *Y* direction which is farthest to the *X* axis (*m*); L_s, the side length of the square (*m*); N_y, the number of grids in *Y* direction.

While the positive (+) sign of the value obtained from the Equation means that the natural slope decreases in *Y* direction, a negative (-) sign signifies an increasing slope.

After the natural slope of the land was determined, the elevation of the corner grid points after grading was calculated with the help of Equations 7 and 8. Cut and fill elevations was found by comparing the values found with natural land elevation at every grid point; cut and fill volumes was obtained by using these elevations and employing Equations 11 and 13. Cut and fill volumes were compared and then the cut/fill ratio was checked whether it was within the limits given in Table 1. If the cut/fill ratio was within the limits, then the process was finalized. If it was not within the limits, a new grading plane elevation and accordingly new cut and fill volumes were found using Equation 13. Cut/fill volume was re-checked; if it was within the limits, grading process was realized according to the elevations found.

Developing a grading project for a flat land in both directions

For grading the flat land in both directions, which is a preferred grading type for rice cultivation, the corner elevations of the land after grading was found using Equation 17. In this case, all would be equal:

$$V_{ag} = \frac{4h}{4}.F \text{ » } h = \frac{V_{al}}{F} \quad (17)$$

Where, *h*, is the corner elevations of the land after grading (*m*).

The procedure after the determination of corner grid points of the land after grading was the same as the part explained following the determination of cut and fill elevations at every corner grid point in section on grading when the direction and value was determined.

RESULTS AND DISCUSSION

Application 1 (A land grading where the direction and value of the slope was determined)

The sample land was a regular rectangular land with an area (which extends 170 m in *X* direction and 130 m in *Y* direction) of 22.1 *da*. The sample application land and the results of VEM are shown in Figure 2. The distance between grid lines was 30 m; grading calculations were performed for a cut/fill ratio between 1.15 and 1.25 assuming the land had light texture and for slope values of -0.5 % in *X* direction and 0 % in *Y* direction. For the comparison of VEM results with the results of the current method, the grading calculations of the sample land were also performed employing “Least Square Method” and “Symmetric Residuals Method” and the results obtained are shown in Table 2.

As seen in Table 2, LSM and SRM gave the same results. This is due to the fact that, both methods utilized

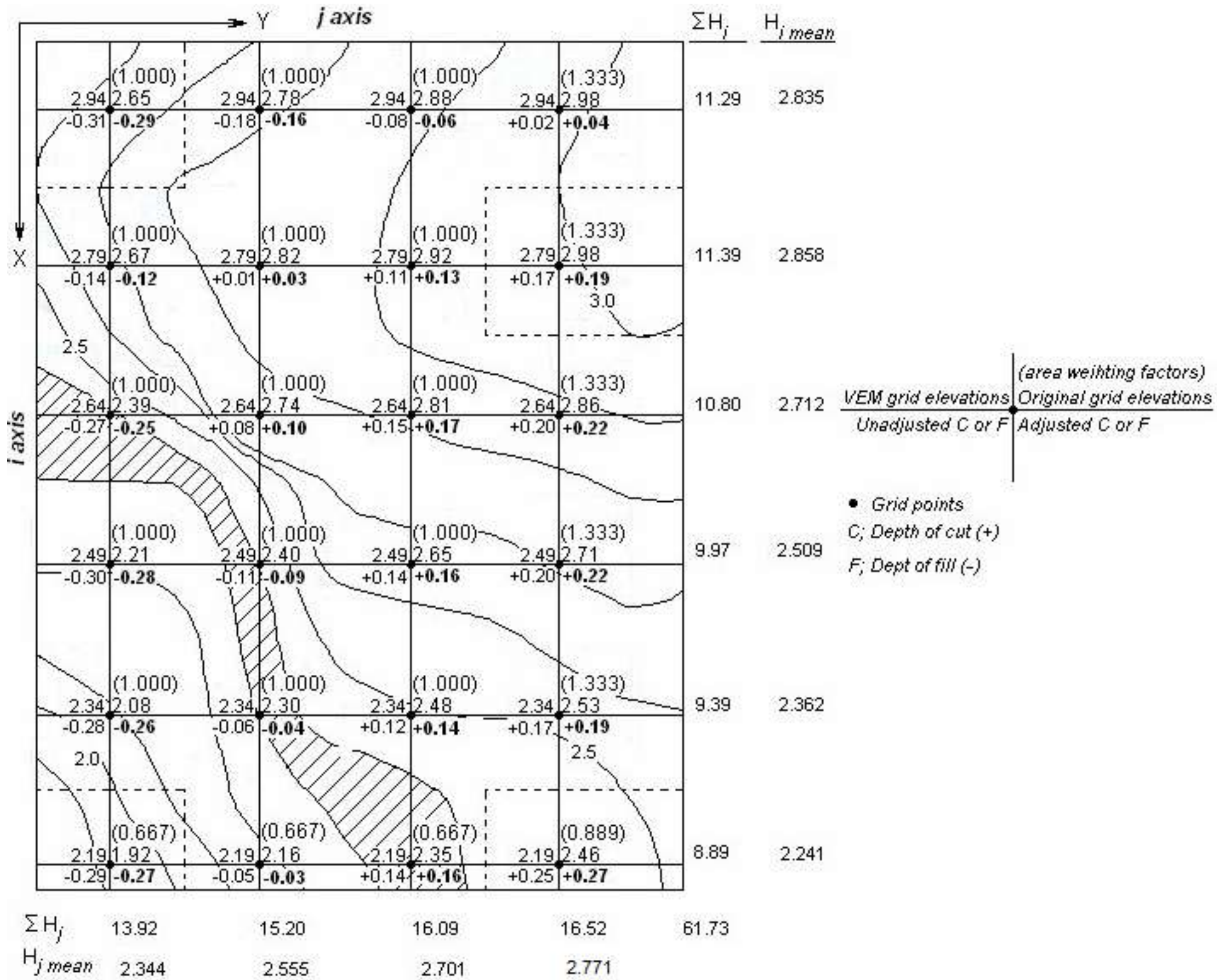

Figure 2. The results of the volume equalization method.

exactly the same equations except for slope calculation also in this study, since slope value was determined beforehand; both methods normally yielded the same results. As far as the unbalanced results are concerned, it was shown that the cut volume was 1792.8 m^3 for VEM, while it was 1708.8 m^3 for LSM and SRM. In regard to total fill volume, all the three methods yielded the result of 1761.1 m^3; thus, cut/fill ratio was 0.97 for LSM and RSM, while it was 1.02 according to VEM.

After balancing, the proposed method's (VEM) value was accepted, since it was very close (1.139) to the lower limit of the required cut/fill ratio (1.15 and 1.25). For LSM and SRM, the result (1.247) was close to the upper limit. With regard to the total volume of cut, the values for LSM, SRM and VEM were determined as 1964.8, 1964.8 and 1920.8 m^3, respectively. Hence, cut volumes per hectare for the three methods were 889, 889 and 869 m^3, respectively. According to these results, it can be argued that, VEM produced a smaller volume of cut compared with LSM and SRM. A smaller volume of cut may be regarded as an advantageous feature since it reduces the costs of land grading. However, the effect of the difference in cut/fill ratios between VEM and LSM – SRM in the generation of this advantage should be considered. Even if the difference is ignored, it may be concluded that VEM produces as correct results as LSM and SRM do.

Application 2 (Grading the land to its natural slope)

In order to test the performance of the developed method (VEM), grading calculations were performed in the same

Table 2. Grading calculations in X direction with -0.5% slope.

	Feature	Methods		
		Least-Squares	Symmetric Residuals	VEM
Unbalanced	∑Volume of cut, m^3	1708.8	1708.8	1792.8
	∑ Volume of fill, m^3	1761.1	1761.1	1761.1
	Cut to fill ratio	0.97	0.97	1.02
Balanced	∑Volume of cut, m^3	1964.8	1964.8	1920.8
	∑ Volume of fill, m^3	1575.1	1575.1	1686.1
	Cut to fill ratio	1.247	1.247	1.139
	Volume of cut per hectare, m^3ha^{-1}	889	889	869

Table 3. Grading calculations according to the natural slope of the land in X direction.

Parameter	Feature	Method		
		Least-square	Symmetric residual	VEM
	Natural slope at X direction, %	-0.450	-0.483	-0.396
Unbalanced	∑Volume of cut, m^3	1642.8	1693.8	2806.7
	∑ Volume of fill, m^3	1815.1	1788.1	1068.1
	Cut to fill ratio	0.905	0.947	2.627
Balanced	∑Volume of cut, m^3	2026.5	1980.0	1984.8
	∑ Volume of fill, m^3	1536.1	1566.0	1572.1
	Cut to fill ratio	1.32	1.26	1.263
	Volume of cut per hectare, m^3ha^{-1}	917	896	898

land according to the natural slope values. The calculations were performed for a cut/fill ratio between 1.15 and 1.25 assuming the land had light texture and for a natural slope value in X direction based on the natural elevations of the land. For the comparison of VEM results with the results of the current method, the grading calculations of the sample land were also performed employing "Least Square Method" and "Symmetric Residuals Method". The results obtained are summarized in Table 3.

All the three methods produced different values as results for the natural slope. The natural slope in *X* direction came out as -0.45% for least squares method, -0.483% for symmetric residuals method and -0.396% for volume equalization method. Despite producing different values, all of the three methods agreed on the fact that, the slope in *X* direction was negative. As far as surface irrigation aspect was concerned, low slope value was desirable especially for soil moving, provided that it was within the slope value required by the irrigation method employed.

According to the balanced results, total volume of cut for LSM, SRM and VEM was calculated as 2026.5, 1980.0 and 1984.8 m^3, respectively. Total fill values found for the three methods were 1536.1, 1566.0 and 1572.1 m^3, respectively. Thus, cut/fill ratio values were determined as 1.320, 1.260 and 1.263 in the same sequence. Cut volume value per hectare was 917 m^3 for LSM, 896 m^3 for SRM and 898 m^3 for VEM.

In grading calculations made for the value of natural slope in one direction, it may be argued that the values were almost equal and that VEM produced as correct results as LSM and SRM do. The difference between the methods was not high and arose from the cut/fill ratio. As the differences of cut/fill ratios were eliminated, it was observed that cut volume values per hectare were very close.

Conclusions

This study presented volume equalization method (VEM) recently developed to be used for land grading calculations. The method is based on the principle that soil should not be brought from another place to the land grading site nor should it be removed from there. Hence, the soil volumes measured from a reference elevation were equal before and after grading. In this study, the mathematical principles of the method regarding uniform sloped grading in one direction in smooth lands were presented and tested on a hypothetical field of 2.21 ha. The following remarks are worth mentioning; the presented method eliminated the need for use trial and error procedures that existing land grading design methods involved to determine the planet hat balances cut and fill volumes; although, it is based on least-squares theory, it does not have the time consuming calculations that appear in the conventional least-squares method. It was shown that both methods produced almost the same results in the rectangular fields; As shown in the sample application, the proposed method (VEM) can be performed manually using hand calculators. Its suitability to hand calculation is a big advantage. Furthermore, the design procedure can be easily translated to a computer or a calculator program.

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