## RESEARCH ARTICLE

# VOLUME EQUALIZATION METHOD FOR LAND GRADING DESIGN: UNIFORM SLOPED GRADING IN TWO DIRECTIONS AT RECTANGULAR FIELDS

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| ARTICLE INFO | ABSTRACT |
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| | This paper presents a new method (*Volume Equalization Method-VEM*) which has been developed to perform land grading design at designing the uniform sloped grading in two directions. The method is a second design alternative of the method developed by Ayranci and Temizel (2011) which about uniform sloped grading in one direction at rectangular fields. The main goal of this method is to minimize the volumes of earth work required for acceptable smooth surface. The method 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 for a known slope values in X and Y directions for a hypothetical area about 2.21 ha, the cut volumes per hectare for Least Square Method and Volume Equalization Method are 419.5 m$^3$ and 403.2 m$^3$ respectively. According to the results, it can be expressed that Volume Equalization Method has a significantly smaller cut volume than conventional least-squares method in rectangular fields. |

## INTRODUCTION

Land grading (or leveling, or smoothing) is the process of moving soil from high spots on the land surface to low spots to provide a more uniform plane for water flow. Land grading usually improves the uniformity of water application within basins, borders, and furrows (L.G. James, 1988). Land leveling always improves the efficiency of water, labor and energy resources utilization. The leveling operation, however, can be the most intensively disruptive cultural practice applied to the field and several factors should be considered before implementing a land leveling project (W.R. Walker, 1989). Land grading designs were first accomplished by elementary calculations using trial-and-error (S.N. Hamad and A.M. Ali, 1990). The first systematic procedure to perform land-grading designs for rectangular plots is used by Givan (1940). The method was based on least-squares theory. G.E. Chugg (1947) also used least-squares method (LSM) but, in irregularly shaped plots. The Average Profile Method (APM) developed by J.C. Marr (1957) is also based on the LSM theory and can be used in rectangular fields. W.S. Harris *et al,* (1966) introduced a new method to define a best-fit warped surface.

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Such a surface has variable slope in the irrigation direction, while the cross-irrigation slope follows the natural ground profile with minor modifications. N.A. Gebre-Selassie and L.S. Willardson (1991) introduced a user-friendly land-leveling program developed for the computation scheme presented by E.J. Scallopi and L.S. Willardson (1986). S.P. Shih and G.J. 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, and (e) variable slope along individual profiles allowing drainage in one direction and minimum and maximum allowable slopes in the other direction. S.N. Hamad and A.M. Ali (1990) used a new technique using non-linear programming to fit a curved or a plane-graded surface to the natural ground surface. L.R. Srinivasa (1996) developed a nonlinear optimization model based on genetic algorithms for land grading design of irregular fields. Another method proposed by (Easa 1998) 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. A land-leveling system provided by (K.R. Zimmermann *et al*, 2005) which use the Global Positioning System (GPS). Lately, Y. Ayranci and K.E. Temizel (2011) presented a new method (Volume Equalization Method-VEM) to perform land grading design in designing the uniform sloped grading in one direction in rectangular fields. This research presents a new method (VEM) which a second design alternative of the method developed by Y. Ayranci and K.E. Temizel (2011) to design a uniform sloped grading in two directions at rectangular (or square) fields. The method uses the principle which also used by V.S. Raju (1960) and by S.M. Easa (1998) that the volume under the original ground surface is equal to the volume under the computed land grading plane.

## MATERIAL AND METHODS

Land grading is performed on land 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 two directions of VEM on smooth patterned lands was issued.

### Uniform Sloped Grading in Two Directions

A field layout and the adopted coordinate system are shown in Figure 1. The grid elevations, $h_{ij}$ ($i=1,2,3...,n_j$ in row direction and $j=1,2,3...,m_i$ in cross row direction) were taken at equal intervals, $d$. The numbers of rows and cross rows may not be equal. In this case, the stations (grid points) are forming 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 (Y. Ayranci and K.E. Temizel 2011) below.

$$H_{i\ mean} = \frac{\sum_{j=1}^{m} h_{ij}*F_{ij}}{m} \qquad (1)$$

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

where $H_{i\ mean}$ 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 (m²), $m$ is the number of unit grids at the $j$ direction, and $n$ is the number of unit grids at the $i$ direction.
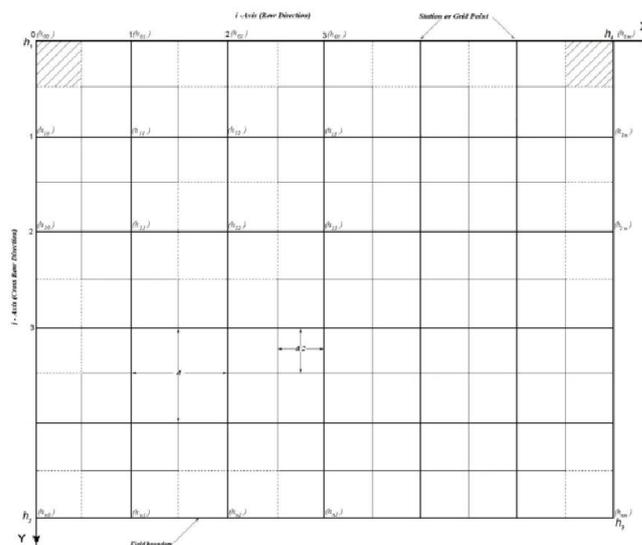


**Figure 1. Field layout and the adopted coordinates system**

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 (i.e., the area between the contours 2.3 m and 2.4 m in Figure 1) within the land borders were calculated one by one with the help of the program. The sum of the areas between contour lines and the areas out of the contour lines equal to the projection area (F) of the land will be graded.

### Volume Before Grading

The significance of the method lies in the calculation of the amount of the soil in the land which is to be graded based on a reference plane and utilization of this soil volume in grading process. The equation below (Ayranci and Temizel 2011) is used to calculate the volume of soil between two consecutive grading curves.

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

where $V_z$ is the volume of soil between two consecutive grading curves (m³), $c_z$ 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 to be calculated (m²). On every land, there were land fractions higher than the biggest grading curve and lower than the smallest grading curve. The calculation of soil volume ($V_{ad}$) in these fields, the elevation values of the grading curves and the border point of the land in that field can be used with the help of equation 3. For example, on the calculation of the soil volume of the grey colored area in figure 2(A); 3.0 m contour line can be taken as $c_z$ value and the average of the points 3.02, 3.03 and 3.05 m can be taken as $c_{z+1}$ value (3.033). The total soil volume before grading ($V_{bg}$) can be obtained by summing all of the volumes between the two grading points.

Hence, the total soil volume before grading can be found with the help of equation 4 (Y. Ayranci and K.E. Temizel 2011).

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

where $V_{bg}$ is the total soil volume before grading (m$^3$), $V_{ad}$ is soil volume belonging to the field outside of grading curves (m$^3$), $z$ is the number of areas between grading curves ($z=1,2,3,.....,z$), and $V_z$ is the soil volume between the two grading curves consecutive (m$^3$).

### Volume After Grading

According to the principle of *"soil should not be brought from another place to the land which is to be graded, nor should it be removed from the land which is to be graded to another place"* which is among the basic rules of land grading, the soil volume before grading ($V_{bg}$) should be equal ($V_{bg}=V_{ag}$) to the soil volume after grading ($V_{ag}$). This form of grading is especially preferred by the *Furrow Irrigation* method. Because of after application of uniform slope grading in two directions all the heights of land corners will be different the total soil volume after grading can be calculated by the following equation 5.

$$V_{ag} = \frac{h_1+h_2+h_3+h_4}{4} * F \qquad (5)$$

where $V_{ag}$ is the total soil volume after grading (m$^3$), $h_1$, $h_2$, $h_3$ and $h_4$ are after grading heights of the corners of the land (m), and $F$ is the projection area of the land to be graded (m$^2$). At this stage it should be decided in which direction the land should be graded and how much slope should be given; a decision between the directions X and Y and the amounts of slope. This decision is affected by the following two possibilities:

- The irrigation method (or the land owner's request, etc.) is an important factor for the decision of direction and slope of the land grading.
- Another possibility is to grade the land according to its natural slope.

### If Slope Values in X and Y Directions Are Predetermined

Uniform sloped grading in two directions with known slope (*requested or provided*) in X and Y directions can be explained as follows. After application of uniform sloped grading in two directions, the elevation values of all corners of the land will be different.

$$h_1 \neq h_2 \neq h_3 \neq h_4 \qquad (6)$$

Accordingly, after grading the elevation values of land corners 2, 3 and 4 can be calculated by means of the following equations 7, 8, and 9.

$$h_2 = h_1 \mp \frac{M_x*L_x}{100} \qquad (7)$$

$$h_3 = h_2 \mp \frac{M_y*L_y}{100} \qquad (8)$$

$$h_4 = h_1 \mp \frac{M_y*L_y}{100} \qquad (9)$$

where $M_x$ is the requested/provided slope value in X direction (%), $M_y$ is the requested/provided slope value in Y direction (%), $L_x$ is the length of the land in X direction (m). $L_y$ is the length of the land in Y direction, *m*. If equations 7 and 9 are put in equation 5, equation 5 will be as follows.

$$V_{ag} = \frac{2h_1+2h_2 \mp 2\frac{M_y*L_y}{100}}{4} * F \qquad (10)$$

If equation 8 is put in equation 10 and the necessary simplifications are made, equation 10 will be as follows.

$$V_{ag} = \frac{4h_1 \mp 2\frac{M_x*L_x}{100} \mp 2\frac{M_y*L_y}{100}}{4} * F \qquad (11)$$

Following equation 12 which can be used in finding the elevation of the corner point $h_1$, can be obtained from equation 11.

$$h_1 = \frac{\frac{2V_{ag}}{F} - \left( \mp \frac{M_x*L_x}{100} \mp \frac{M_y*L_y}{100} \right)}{2} \qquad (12)$$

After the determination of corner point ($h_1$), the elevations of the corner point's $h_2$, $h_3$ and $h_4$ determined by equations 7, 8 and 9 respectively. The height of the grid point $h_{1,1}$ can be found with the help of equation 14.

$$h_{1,1} = h_1 \mp \frac{M_x*L_s}{200} \mp \frac{M_y*L_s}{200} \qquad (13)$$

where $h_{1,1}$ is the height of the grid point 1,1 (m), $L_s$ is the side length of grid (m). After finding the height of grid point *1,1* after grading, the heights of following points in X and Y directions can also be found by helping equation 14 and 15.

$$h_{2,1} = h_{1,1} \mp \frac{M_x*L_s}{100} \qquad (14)$$

$$h_{1,2} = h_{1,1} \mp \frac{M_y*L_s}{100} \qquad (15)$$

The heights of the following grid points in X and Y directions are found in the same way. In this way, the heights of all grid points of the land are found. The heights in the grids, found by calculation are compared with the natural heights in the grids. The heights of cut and fill for every grid points are determined accordingly. According to the found cut and fill heights, the cut and fill volumes are determined for each grid. By calculating of the volume of cut and fill on any grid, the values of cut or fill in that grid in *m* is multiplied by the value of the area unit in m$^2$ of the grid (equations 16 and 17 [Y. Ayranci and K.E. Temizel 2011]). If the slope values of X and Y directions is positive (*sign +*), if negative (*sign −*) are used in equations 7, 8, 9, 10, 11, 12, 13, 14, and 15.

$$V_{pc} = h_{pc} * F_{pc} \qquad (16)$$

$$V_{rf} = h_{rf} * F_{rf} \qquad (17)$$

where $V_{pc}$ is the volume of cut at the $p^{th}$ grid (m$^3$), $h_{pc}$ is the height of cut at the $p^{th}$ grid (m), $F_{pc}$ is the unit area of $p^{th}$ grid (m$^2$), $V_{rf}$ is the volume of fill at $p^{th}$ grid (m$^3$), $h_{rf}$ is the height of fill at $r^{th}$ grid (m), and $F_{rf}$ is the unit area of $r^{th}$ grid (m$^2$).

The total volume of cut and fill equals the sum of cut and fill volumes (equations 18 and 19 [Y. Ayranci and K.E. Temizel 2011]) of each grid.

$$V_c = \sum_1^p V_{pc} \qquad (18)$$

$$V_f = \sum_1^r V_{rf} \qquad (19)$$

where $V_c$ is the total cut volume (m$^3$), $V_f$ is the total fill volume (m$^3$), $p$ is the number of cut grid (p=1,2,3,…..,p), and $r$ is the number of fill grid (r=1,2,3,….,r).

The cut/fill ratio (Rc/f) is found by dividing the total cut volume into the total fill volume. In land grading, according to the soil texture, cut/fill ratio is requested to be in the ranges of the values given in table 1. If the cut/fill ratio is within the desired limits, the grading operation is performed according to its specified values.

**Table 1. Cut/fill ratio limits according to the soil texture ($R_{c/f}$)**

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

If the cut/fill ratio found is not within the limits, the grading plane height should be changed. In this case, the amount of the change to be done on the height of the grading plane can be found with the help of the equation 20 (Y. Ayranci and K.E. Temizel 2011).

$$h_d = \frac{\left[V_{cf} - \frac{2V_{cf}}{D_{c/f}+1}\right] - (V_c - V_f)}{F_{cf}} \qquad (20)$$

where $h_d$ is the amount of change in height of the plane of grading to be done (cm), $V_{cf}$ is the total cut and fill volume (m$^3$), $D_{c/f}$ is the desired cut/fill ratio, and $F_{cf}$ is the total projected area of cut and fill (m$^2$). Cut/fill ratio can be determined with the help of the equation 21 (Y. Ayranci and K.E. Temizel 2011).

$$R_{c/f} = \frac{\sum V_c}{\sum V_f} \qquad (21)$$

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

***Land Grading According to Its Natural Slope***

If the land is to be graded according to its natural slope, primarily, the natural slopes in X (i) and Y (j) directions should be determined. Equations 22 and 23 (Y. Ayranci and K.E. Temizel 2011) can be used to determine the natural slope values of the land in X and Y directions.

$$S_x = \frac{\sum_{n=1}^n \frac{H_{i\ mean\ n-1} - H_{i\ mean\ n}}{L_s} * 100}{N_{x-1}} \qquad (22)$$

$$S_y = \frac{\sum_{m=1}^m \frac{H_{j\ mean\ m-1} - H_{j\ mean\ m}}{L_s} * 100}{N_{y-1}} \qquad (23)$$

where $S_x$ is the natural slope value of the land in X direction (%), $H_{i\ mean\ n-1}$ is the value of the closest one to the Y axis of the two $H_{i\ mean}$ values consecutive in X direction (m), $H_{i\ mean\ n}$ is the value of the farthest one to the Y axis of the two $H_{x\ mean}$ values consecutive in X direction (m), $N_x$ is the number of grids in *X* direction, $S_y$ is the natural slope value of the land in Y direction (%), $H_{j\ mean\ m}$ is the value of the closest one to the X axis of the two $H_{j\ mean}$ values consecutive in Y direction (m), $H_{j\ mean\ m-1}$ is the value of the farthest one to the X axis of the two $H_{j\ mean}$ values consecutive in Y direction (m), and $N_y$ is the number of grids in *Y* direction.

If the sign of the value obtained from equations 22 and 23 is positive (+), it means that the natural slope decreases in X and Y directions, similarly, a negative (–) sign signifies an increasing slope. After determination of the natural slope of the land, the elevation of the corner h$_1$ can be calculated with the help of equation 12. The heights of the corner point's h$_2$, h$_3$ and h$_4$ are calculated with the help of equations 7, 8 and 9, respectively. The height of each grid point of the land can be found with the help of equations 13, 14 and 15, respectively. The values of the grid points found are compared with the natural height for each grid point. According to this comparison, the heights of cut and fill in each grid points are determined. After that, the cut and fill volumes in every grid are found with the help of equations 18 and 19. The cut/fill ratio is found by dividing the total cut volumes into the total fill volumes, and it is checked whether the cut/fill ratios are within the limits given in table 1. If the cut/fill ratio is within the desired limits, the process can be completed. If it is not within the desired limits, the new height of the grading plane can be found with the help of equation 20, and consequently new cut and fill volumes can be found with help of equations 18 and 19. The cut/fill ratio is rechecked and if the ratio is within the desired limits, grading is performed according to the new heights obtained.

## RESULTS AND DISCUSSION

This section is about testing the validity of a newly developed land grading method (VEM) applied on a hypothetical area. For this purpose, VEM is applied for a known slope in X and Y directions (*application 1*) and for its natural slope in X and Y directions (*application 2*). In order to assess the results of the VEM method, LSM and SRM methods are also applied in the same area.

***Land Grading According to a Known Slope Value in X and Y Directions (Application 1)***

The sample land is a regular rectangular area which extends 170 m (185.9 yd) in X direction and 130 m in Y direction. Grid length is 30 m. Figure 2 shows the results of the application of the VEM method.

The assumptions of grading calculation were: (1) the cut/fill ratio is between 1.15 to 1.25, and (2) the slope values in X and Y directions are –0.5% and 0.4%, respectively. For the comparison of the results of the VEM method, *Least Square Method (LSM), Symmetric Residuals Method (SRM)* and *VEM method* results are presented in Table 2.
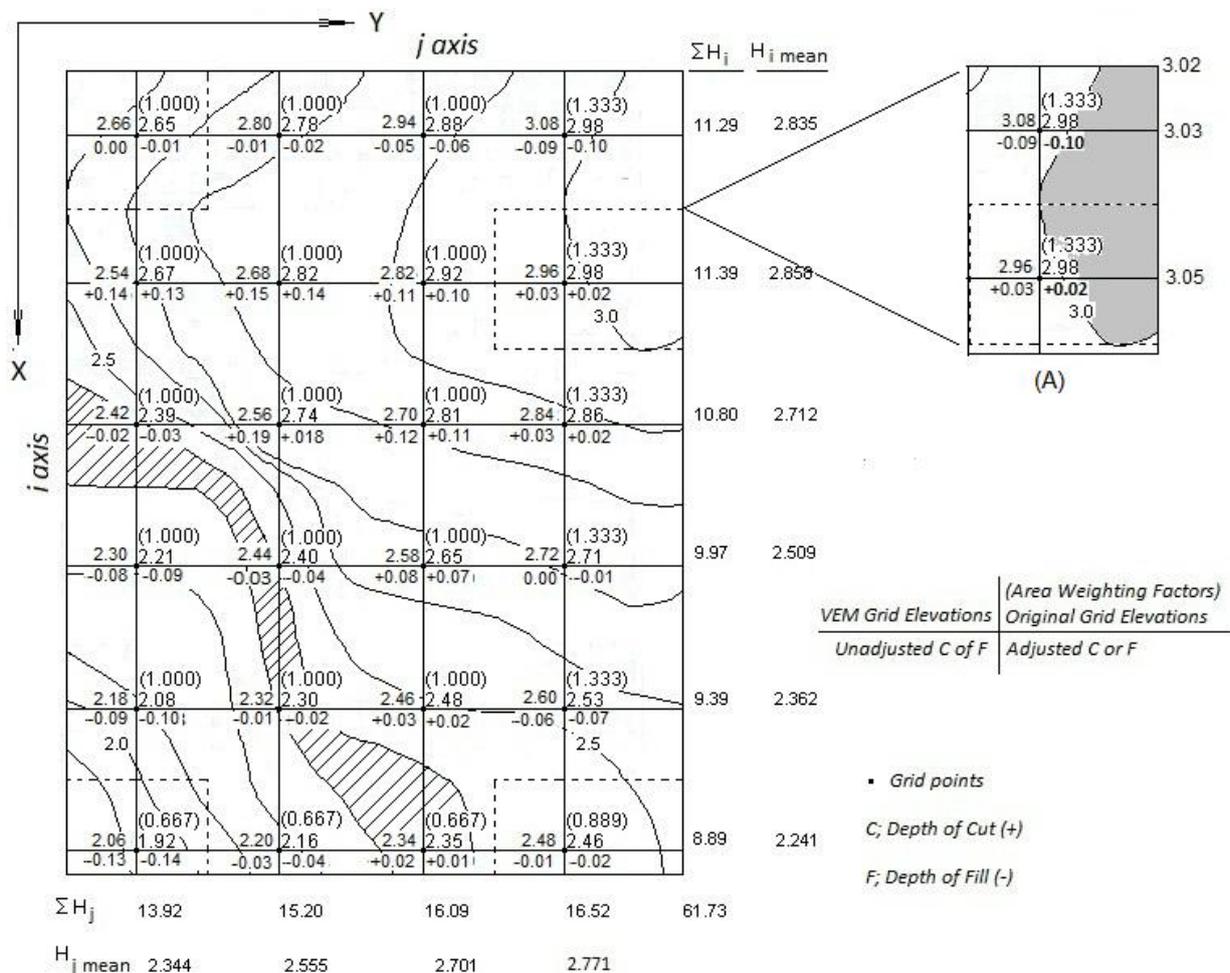
**Figure 2. The grading results of the VEM for known slope in two directions**

**Table 2. Grading calculations in *X* and *Y* directions for slope – 0.5% and 0.4% respectively**

| 8 | Features | Methods | | |
|---|---|---|---|---|
| | | Least Square Method (LSM) | Symmetric Residuals Method (SRM) | Volume Equalization Method (VEM) |
| UB[*] | Total cut volume, m$^3$ | 273.0 | 273.0 | 891.0 |
| | Total fill volume, m$^3$ | 1,479.0 | 1,479.0 | 771.0 |
| | Cut/ fill ratio | 0.185 | 0.185 | 1.156 |
| B[*] | Total cut volume, m$^3$ | 927.0 | 927.0 | 891.0 |
| | Total fill volume, m$^3$ | 771.0 | 771.0 | 771.0 |
| | Cut/fill ratio | 1.202 | 1.202 | 1.156 |
| | Cut volume per hectare, m$^3$ha$^{-1}$ | 419.5 | 419.5 | 403.2 |

UB; unbalanced results, B; balanced results

As shown in table 2, LSM and SRM methods have same results. This is because all equations of the two methods are similar except the slope calculation methods. In this study, because the slope value is known in advance, the results of both methods as expected give the same results. According to the unbalanced grading results, the total cut volumes of VEM, LSM and SRM methods were 891.0 m$^3$, 273.0 m$^3$ and 273.0 m$^3$, respectively. According to the total fill volumes, LSM and SRM methods gave the same result, 1,479.0 m$^3$, whereas VEM method has found 771.0 m$^3$. The cut/fill ratio was 0.185 in LSM and SRM, and 1.156 in VEM. Because the proposed method (VEM) had a desired cut/fill ratio (1.156) after unbalanced grading results, there was no need for the balancing process and unbalanced grading results remained the same. After the balancing process, the total cut volume is 927.0 m$^3$ and the total fill volume is 771.0 m$^3$ in LSM and RSM.

The obtained cut/fill ratio (1.202) is within the allowed limit. On the other hand, the total cut volume for VEM is 891.0 m$^3$ before the balancing process. The cut volumes per hectare for each of the three methods are 419.5 m$^3$ (LSM), 419.5 m$^3$ (SRM) and 403.2 m$^3$ (VEM), respectively. According to these results, it can be expressed that VEM method has a significantly smaller cut volume than LSM and SRM methods. Due to the smaller cut volume the cost of land grading is reduced; this can be seen as a positive side of VEM. However, the difference of balanced cut/fill ratios between VEM method and LSM and SRM methods (1.156, 1.202, respectively) has an effect on the appearance of this positive factor. Even if this difference is not taken into account, it can be expressed that VEM method results are as true as the results of LSM and SRM methods.

### Land Grading According to Its Natural Slope (Application 2)

In order to test the performance of the developed method (VEM), land grading calculations were performed in the same area according to its natural slope values. The calculations were performed for a cut/fill ratio between 1.15 and 1.25 assuming the land had light textured soil (Table 1) and for a natural slope value in X and Y directions based on the natural elevations of the land (Figure 3). For the comparison of VEM results, the land grading calculations were also performed for the current methods, LSM and SRM on the same area and the results obtained are summarized in Table 3. In each of the three methods applied in this study the natural slope is identified different ways. Because of that, natural slopes in X direction for LSM, SRM and VEM methods were −0.450%, −0.483%, and −0.396% respectively (Table 3).

Similarly, natural slopes in Y direction for LSM, SRM and VEM methods were 0.483%, 0.483%, and 0.474%, respectively. Even if different values were obtained for each of the three methods, natural slope was found negative in X direction and positive in Y direction. The proposed VEM method gives a slightly low natural slope than LSM and SRM methods. Considering the terms of surface irrigation, on the condition that the slope is within the limits of the irrigation method to be applied, the low slope value is desirable especially in terms of soil erosion. According to the unbalanced grading results; the total cut volumes for LSM, SRM, and VEM methods were found 339.0, 288.0, and 822.0 $m^3$, respectively. The total fill volumes obtained in LSM, SRM and VEM methods were 1,367.9, 1,459.9, and 545.0 $m^3$, respectively.

**Table 3. Grading calculations in X and Y directions with natural slope**

|  | Features | Methods | | |
|---|---|---|---|---|
|  |  | Least Square Method (LSM) | Symmetric Residuals Method (SRM) | Volume Equalization Method (VEM) |
|  | Natural slope in X direction, % | −0.450 | −0.483 | −0.396 |
|  | Natural slope in Y direction, % | 0.483 | 0.483 | 0.474 |
| UB[*] | Total cut volume, $m^3$ | 339.0 | 288.0 | 822.0 |
|  | Total fill volume, $m^3$ | 1367.9 | 1459.9 | 545.0 |
|  | Cut/ fill ratio | 0.248 | 0.197 | 1.508 |
| B[*] | Total cut volume, $m^3$ | 730.0 | 808.0 | 729.0 |
|  | Total fill volume, $m^3$ | 653.9 | 653.9 | 673.0 |
|  | Cut/ fill ratio | 1.120 | 1.223 | 1.080 |
|  | Cut volume per hectare, $m^3ha^{-1}$ | 330.3 | 365.6 | 329.9 |

UB; unbalanced results, B; balanced results
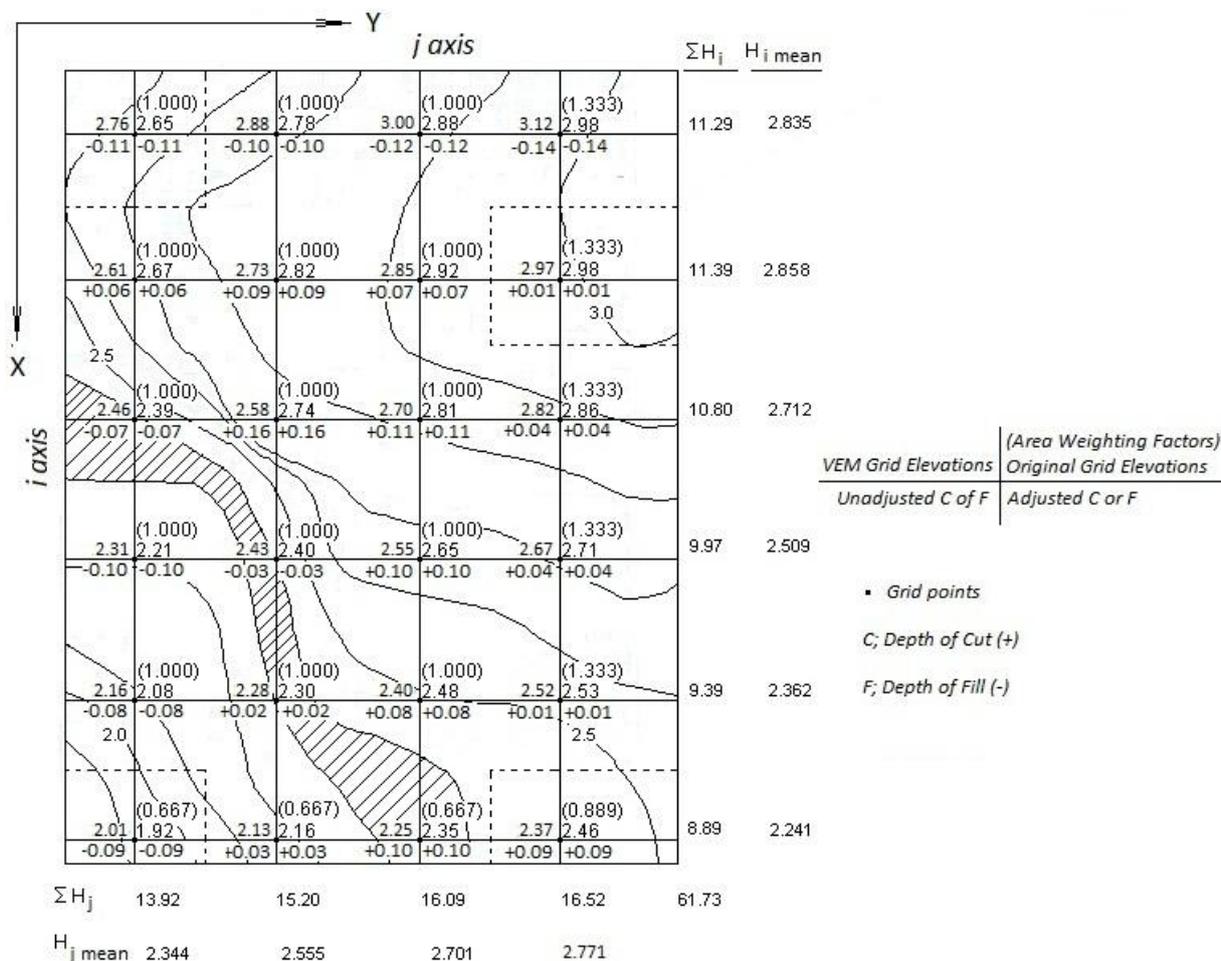


**Figure 3. The grading results of the VEM for natural slope in two directions**

Accordingly, the cut/fill ratios in LSM, RSM, and VEM methods were 0.248, 0.197, and 1.508, respectively. According to the balanced grading results, the total cut volumes obtained for LSM, SRM, and VEM methods were 730.0 m$^3$, 880.0 m$^3$ and 729.0 m$^3$, respectively. Similarly, the total fill volumes for the three methods (LSM, SRM and VEM) were 653.9 m$^3$, 653.9 m$^3$ and 673.0 m$^3$, respectively. The cut/fill ratio values in the same order were 1.120, 1,223, and 1.080. Here, the cut/fill ratio values of LSM and VEM methods remained slightly below the required limit (1.15 to 1.25). This is why the balancing process is carried out on the basis of *cm* for all methods. If the height of the grading plane is lowered by 1 cm during the balancing process, the cut/fill ratio value rises above the upper limit value (1.25). Therefore, the values obtained (1.12 and 1.08) are accepted as appropriate. On the other hand, the volumes of cut per hectare were found 330.3 m$^3$, 365.6 m$^3$ and 329.9 m$^3$ in LSM, SRM, and VEM methods, respectively. According to the land grading calculations for natural slope in two directions, the total cut volume values of the three different methods are almost equal, and it can be said that VEM method gives as accurate results as LSM and SRM methods which are in practice. There is a minor difference between the methods and the reason for that difference is the cut/fill ratios of the methods. If not taken into account the difference between cut/fill ratios of the methods, it is understood that the cut volume per hectare for all methods is very close to each other.

## Conclusions

This study presents "uniform sloped land grading in two directions of the Volume Equalization Method (VEM)" newly developed for land grading design, and it can be seen as continuation of "uniform sloped land grading in one direction developed by Y. Ayranci and K.E. Temizel (2011). The method is based on the principle "*the soil should not be brought from another place to the land grading area nor should it be removed from the land grading area*". Hence, the soil volumes before and after grading measured from a reference elevation are equal. In this study, the mathematical principles of the VEM for uniform sloped land grading in two directions are presented and land grading for its natural slope in two directions and the method has been tested in a hypothetical area covering 2.21 ha. In order to assess the VEM results, LSM and SRM methods were also applied to the same area. According to the results, the VEM is as accurate as the conventional methods, Least Squares Method (LSM) and Symmetric Residuals Method (SRM) in rectangular fields.

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