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RESEARCH ARTICLE

VOLUME EQUALIZATION METHOD FOR LAND GRADING DESIGN: VARIABLE SLOPED GRADING IN ONE DIRECTION AT RECTANGULAR FIELDS

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ABSTRACT

This paper presents the principles of a new method for variable sloped grading in one direction that is adapted from Ayranci and Temizel (2011) which has been developed to perform land grading design for uniform sloped grading in one direction. 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 the 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 is accurate in rectangular fields.

INTRODUCTION

A significant amount of water (20 to 25%) is lost at the time of surface irrigation during its application to the crops because of uneven land level of the fields and inappropriate farming practices (Bansal *et al.,* 2014). Surface irrigation methods depend on gravity and slope that make the water flow in a field (Jat *et al.,* 2006). The preparation of the field surface for conveyance and distribution of irrigation water (Brye *et al.,* 2005; Brye *et al.,* 2006) is as important to efficient surface irrigation as any other single management practice the farmer employs. 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 (Cazanescu *et al.,* 2010). Land topography is of great factor for selection of surface irrigation methods. When this factor is not considered, some problems such as water loss, soil erosion and leaching of useful nutrients resulting yield reduce would occur. A successful application of surface irrigation methods and high irrigation performance depend mostly on land leveling project which is crucial for land preparation and appropriateness for irrigation (Demirtas and Demir, 2011). Land leveling is the first step for better land development (Chilur *et al.,* 2016). Precision land leveling can help the farmers to utilize the scarce land and water resource more effectively and efficiently towards increased crop production (Naresh *et al.,* 2014) also, it increases yields and cultivable lands and reduces delivery losses (Sharifi *et al.,* 2014). The purpose of the land leveling projects is to determine the most suitable leveling plane to the natural topography, taking into account the slope grades required by the irrigation method (Yildirim, 2008).

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The effective application of surface irrigation methods is directly related to specific land surface properties. For example; border irrigation method requires constant slope grading in one direction, furrow irrigation method requires variable slope leveling in both directions etc. Reviewing of the literature indicates that much data exist except (Shih and Kriz, 1971) who proposed a method (*Symmetrical Residuals Method*) to grade lands that allows for uniform or nonuniform slopes in both directions on application of variable sloped leveling in one direction. According to the Scallopi and Willardson (1986), the Symmetrical Residuals Method for land leveling is still considered too laborious for general use. Nowadays, laser leveling applications are getting widespread (Rickman, 2002; Zimmermann *et al.,* 2005; Cazanescu *et al.,* 2010; Bansal *et al.,* 2014; Chilur *et al.,* 2016). This research introduces the principles and an application at a hypothetical area of the variable sloped grading method in one direction.

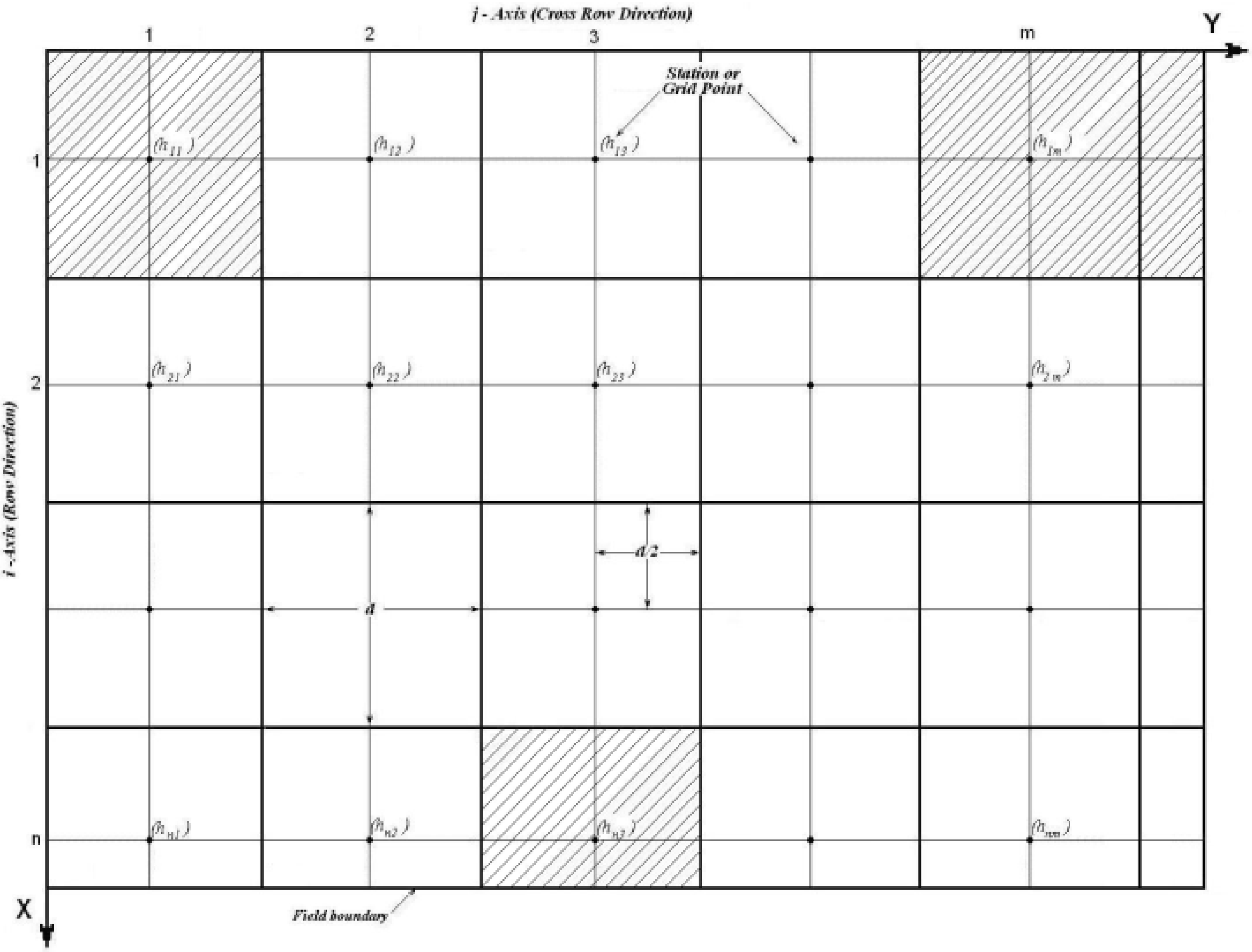

Fig. 1. Field layout and the adopted coordinates system (Ayranci and Temizel, 2011)

The new method is adapted from the method Volume Equalization Method (VEM) developed by Ayranci and Temizel (2011). For this reason, this new method uses some equations given by Ayranci and Temizel (2011) during the preparation phase of its.

MATERIALS AND METHODS

Land grading 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. In this study, the principles and an application of variable sloped grading in one direction at rectangular fields which adapted from the Volume Equalization Method developed by Ayranci and Temizel (2011) are issued. Regarding the method, the following remarks are worthy to be mentioned;

- Variable sloped grading is mainly applied to reduce deep seepage losses in the border irrigation method. For this reason, soil properties as texture play a decisive role in slope values to be applied to land. Accordingly; it can be said that the first slope should be higher in light soils and lower in heavy soils.
- Land lengths that will have different slopes should also be determined depending on soil properties. It may be appropriate to keep land lengths shorter in light soils and longer in heavy soils.

Variable Sloped Grading in One Direction

A field layout and the adopted coordinate system are shown in Fig. 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 form a matrix that has mxn dimensions. There was distance of half a square length between a grid point and land borders (Fig. 1). Thus, each station or 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. 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 (Ayranci and Temizel, 2011). Similarly; there is a somewhat different application for the application of variable sloped land grading in one direction. As a characteristic of the method, in the application of variable sloped grading in one direction, the surface has to be leveled having two different slopes (M_{x1}, M_{x2}) through the direction of water flow and on the opposite direction the land has a surface no slope (Figure 2). For this reason, the amount of unit area represented by each grid point needs to be determined according to the lengths of the land portions having different slope (L_{x1}, L_{x2}).

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.

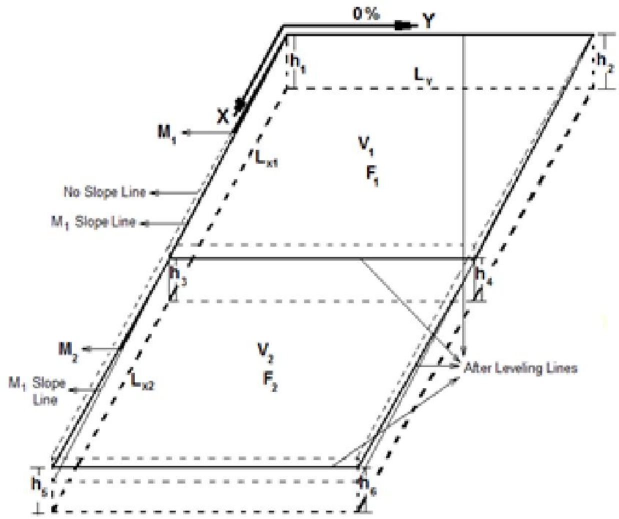

Fig 2. Schematic view of the land after grading

Before-Grading Volume

The principle of the method is based on to calculate the soil volume above a specific reference plane and the utilization of this soil volume during grading process. For the calculating the soil volume before grading, firstly the contour lines are passed over the land. Soil volumes between two consecutive contour lines are calculated separately, and at the end these volumes are summed up to determine the soil volume before grading. The equation below is used to calculate the volume of soil between two consecutive contour lines (Ayranci and Temizel, 2011).

$$V_z = \frac{c_z + c_{z+1}}{2} . F_z \qquad \text{……………………………… (1)}$$

where; V_z; the volume of the soil between two consecutive contour lines (m^3), c_z; the elevation of the smaller one of the two consecutive contour lines (m), c_{z+1}; the elevation of the bigger one of the two consecutive contour lines (m), F_z; the projection area between the two consecutive contour lines (m^2). In every land, there were land fractions higher than the biggest contour line and lower than the smallest contour line. The calculation of soil volume (V_r) in these fields, the elevation values of the contour lines and the border point of the land in that field can be used with the help of the Equation 1. The total soil volume before grading (V_{bl}) could be obtained by summing all of the volumes between the two grading points. Hence, the total soil volume before grading could be found with the help of Equation 2.

$$V_{bl} = \sum_1^z V_z + V_r \qquad \text{…………………………………... (2)}$$

where; V_{bl}; total soil volume before grading (m^3), n; the number of land fractions separated by contour lines in the field, V_r; soil volume belonging to the field outside of contour lines (m^3), z; the number of areas between contour lines ($z=1,2,3,\ldots..,z$)

Finding the heights of corner points after the grading of the land

One of the basic rules of land grading is “neither the soil is brought from another place to the land to be leveled nor the soil be taken away from the land to be leveled to another place. In accordance with this principle, the soil volume of before grading (V_{bl}) must be equal ($V_{bl} = V_{al}$) to the soil volume after grading (V_{al}). Variable sloped grading in one direction is a method used to reduce deep seepage losses, especially in surface irrigation methods. For this purpose, the field is leveled with a larger slope after the irrigation canal, and then with a lower slope. The application of variable sloped grading is a method used to facilitate the application of the border irrigation method. For this reason, the position of the channel where the irrigation water is received will determine the direction (X or Y) in which the land grading will be applied. Also; the slope values (M_1, M_2) to be used and the land lengths (L_{x1}, L_{x2}) having these slope values should be determined. In the case of grading of the land variable sloped in the X direction, some properties related to the area after grading will occur as in Fig 2. According to the Fig.2, the following equations can be written.

$$V_{al} = V_1 + V_2 \qquad \text{………………………………………….. (3)}$$

where; V_{al} is the soil volume after grading (m^3), V_1 is the soil volume of high sloped section (m^3), V_2 is the soil volume of low sloped section (m^3).

$$F = F_1 + F_2 \gg F_1 = L_{x1} . L_y \; ; F_2 = L_{x2} . L_y \qquad \text{……………. (4)}$$

where; F_1 is the projection area of the high sloped section (m^2), F_2 is the projection area of the low sloped section (m^2), L_{x1} is the length of through slope of the high sloped section (m), L_{x2} is the length of through slope of the low sloped section (m), L_y is the length of the edge no slope of the land (m).

The V_1 and V_2 equations can be expressed as;

$$V_1 = \frac{h_1 + h_2 + h_3 + h_4}{4} . F_1 \; ; V_2 = \frac{h_3 + h_4 + h_5 + h_6}{4} . F_2 \qquad \text{…………… (5)}$$

where; h_1, h_2, h_3, h_4, h_5, h_6 are the elevations of the corner points of the land after grading. Accordingly, the following equations can be written regarding the elevations of the corner points of the land after grading.

$$h_1 = h_2; \; h_3 = h_4; \; h_5 = h_6 \qquad \text{……………………….. (6)}$$

The equations V_1 and V_2 Y are become;

$V_1 = \frac{2h_1 + 2h_3}{4} . F_1$ If necessary simplifications are made;

$$V_1 = \frac{h_1 + h_3}{2} . F_1 \qquad \text{………………………………………….. (7)}$$

$V_2 = \frac{2h_3 + 2h_5}{4} . F_1$ If necessary simplifications are made;

$$V_2 = \frac{h_3 + h_5}{2} . F_2 \qquad \text{……………………………………….. (8)}$$

The elevations of the ($h_3 = h_4$) and ($h_5 = h_6$) corner points can be calculated by the following equations.

$$(h_3 = h_4) = h_1 - \frac{M_1.L_{x1}}{100}\ ;\ (h_3 = h_4) = h_1 - \frac{M_1.L_{x1}}{100} \quad \text{......... (9)}$$

$$(h_5 = h_6) = h_3 - \frac{M_2.L_{x2}}{100} \gg (h_5 = h_6) = h_1 - \frac{M_1.L_{x1}}{100} - \frac{M_2.L_{x2}}{100} \quad \text{.................... (10)}$$

where; M_1 is the slope of the high sloped section (%), M_2 is the slope of the low sloped section (%). If these equations are placed in Equations 7 and 8;

$$V_1 = \frac{h_1 + h_1 - \frac{M_1.L_{x1}}{100}}{2}.F_1 \quad \text{.................................... (11)}$$

$$V_2 = \frac{\left(h_1 - \frac{M_1.L_{x1}}{100}\right) + \left(h_1 - \frac{M_1.L_{x1}}{100} - \frac{M_2.L_{x2}}{100}\right)}{2}.F_2 \quad \text{................... (12)}$$

If these equations (11 and 12) are placed in Equation 3 and necessary simplifications are made;

$$V_{al} = \frac{h_1 + h_1 - \frac{M_1.L_{x1}}{100}}{2}.F_1 + \frac{\left(h_1 - \frac{M_1.L_{x1}}{100}\right) + \left(h_1 - \frac{M_1.L_{x1}}{100} - \frac{M_2.L_{x2}}{100}\right)}{2}.F_2 \gg$$

$$2V_{al} = \left[h_1 + h_1 - \frac{M_1.L_{x1}}{100}\right].F_1 + \left[\left(h_1 - \frac{M_1.L_{x1}}{100}\right) + \left(h_1 - \frac{M_1.L_{x1}}{100} - \frac{M_2.L_{x2}}{100}\right)\right].F_2 \gg$$

$$2V_{al} = \left[2h_1 - \frac{M_1.L_{x1}}{100}\right].F_1 + \left[2h_1 - 2\frac{M_1.L_{x1}}{100} - \frac{M_2.L_{x2}}{100}\right].F_2 \gg$$

$$2V_{al} = 2h_1.F_1 - \frac{M_1.L_{x1}}{100}.F_1 + 2h_1F_2 - 2\frac{M_1.L_{x1}}{100}.F_2 - \frac{M_2.L_{x2}}{100}.F_2 \gg$$

$$2h_1F_1 + 2h_1F_2 = 2V_{al} - \left(-\frac{M_1.L_{x1}}{100}.F_1 - 2\frac{M_1.L_{x1}}{100}.F_2 - \frac{M_2.L_{x2}}{100}.F_2\right) \gg$$

$$h_1 = \frac{2V_{al} - \left(-\frac{M_1.L_{x1}}{100}.F_1 - 2\frac{M_1.L_{x1}}{100}.F_2 - \frac{M_2.L_{x2}}{100}\right)}{2F} \gg$$

$$h_1 = \frac{2V_{al} + \frac{M_1.L_{x1}}{100}.F_1 + \frac{M_1.L_{x1}}{50}.F_2 + \frac{M_2.L_{x2}}{100}.F_2}{2F} \quad \text{.............................. (13)}$$

The height of the h_1 point after grading is determined by means of the Equation 13. If $h_1 = h_2$ according to equation 6, the value of h_2 point is also found. The V_{bl} value obtained from equation 2 can be used instead of V_{al} in the equation 13. After finding the height of point h_1 and h_2 by the equation 13, the height values of the point's h_3 - h_4 and h_5 - h_6 are determined with the help of the equations 9 and 10 respectively. Slope values in the equation 13 are used with just numeric values, without sign.

Finding the heights of the grid points after grading

After finding the heights of the corner points, starting from h_1 point, the elevation of the $h_{1,1}$ grid point can be found with the aid of equation 14.

$$h_{1,1} = h_1 - \frac{M_1.L_u}{200} \quad \text{.................................. (14)}$$

where; $h_{1,1}$ is the height of the $h_{1,1}$ grid, m, L_u is the edge length of unit grid, m

Since the land has no slope in *Y* direction, the heights of the grid points $h_{1,2}$, $h_{1,3}$ and $h_{1,4}$ will be equal to $h_{1,1}$. The heights of the following grid points in the X direction can also be found with the equation 15.

$$h_{2,1} = h_{1,1} - \frac{M_1.L_u}{100} \quad \text{..................................... (15)}$$

Since the land has no slope in *Y* direction, the heights of the grid points $h_{2,2}$, $h_{2,3}$ and $h_{2,4}$ will be equal to $h_{2,1}$. Similarly, the heights of the grid points $h_{3,1}$, $h_{4,1}$ etc can be found by means of equation 15. In this way, the heights of all the grid points on the ground are found. The cut and fill heights at the each grid point can be determined by comparing the grading grid heights with the natural grid heights. Depending on the cut or fill heights at each grid point, cut and fill volumes may be found at each grid unit. The volume of cut or fill at any station can be calculated by multiplying the cut or fill height of that station by the unit area value of the station.

$$V_{c,f} = h_{c,f}.F_u.C_w \quad \text{.. (17)}$$

where; $V_{c,f}$ is the volume of cut or fill in the grid unit, m^3, $h_{c,f}$ is the height of cut or fill in the grid point, m, F_u is the area of the grid unit, m^2, C_w is the area weighting factor.

Area weighting factor can be find by the equation below;

$$C_w = \frac{L_{gx}.L_{gy}}{F_u} \quad \text{.. (18)}$$

where; L_{gx} is the length of the edge which parallel to the X axis of the area that the grid represents, m, L_{gy} is the length of the edge which parallel to the Y axis of the area that the grid represents, m,

To reach the total cut and fill volume, the cut and fill volumes in each station can be summed up. The cut/fill ratio ($R_{c/f}$) is found by proportioning the total cut and total fill heights. At land grading, it is desired that the ratio of cut/fill according to the soil texture is between the values in Table 1. If the cut/fill ratio is within the desired limits, the grading process is performed according to the determined values.

Table 1. Cut/fill ratios according to the soil texture (*Yıldırım, 2008*)

Texture	Kazı/Dolgu Oranı ($R_{c/f}$)
Sandy	1.15-1.25
Loamy	1.25-1.40
Loamy-Clay	1.40-1.60
Clay	1.50-1.80

If the cut/fill ratio is not within the range of the desired values, the height of the grading plane must be changed. In this case, the amount of change to be made at the height of the grading plane can be found by the following equation.

$$h_d = \frac{\left(V_{cf} - \frac{2V_{cf}}{D_{c/f}+1}\right) - (V_c - V_f)}{F_{cf}} \quad \text{........................ (19)}$$

where; h_d is the amount of change to be made at the height of the grading plane, cm, V_{cf} is the total cut and fill volume, m^3, $D_{c/f}$ is the desired cut/fill ratio, V_c is the total cut volume, m^3, V_f is the total fill volume, m^3, F_{cf} is the total projected area of cut and fill, m^2.

Application of the method to a hypothetical area

In order to test the method, variable sloped grading calculations have been done on a hypothetical area. The sample area is a size of 22100 m^2 and a rectangular shape having 170m in the *X* direction and 130m in the *Y* direction. The distance between grid points is 30m. Accordingly, the unit grid area is 900 m^2. Grading calculations has been done assuming that the land has a sandy texture (the cut/fill ratio is between 1.15 and 1.25) and for the slopes of M_1(0.5%) and M_2 (0.4%) through the *X* direction. It is assumed that the land lengths (L_{x1} and L_{x2}) with different slope values are equal (85m).

The application of the method is carried out in the following stages. Firstly, as mentioned in the *Section 2.1.1.*, the contour lines are passed on the land. After that, the grid points' locations and the amount of area represented by each grid point are determined. Depending, the soil volume before grading is determined. At this point, according to the method's characteristic (*Section 2.1.2.*), the soil volume after grading is also determined. Subsequently, the height of corner point h_1 is determined by means of Equation 13. At this point, according to Equation 6, the height of point h_2 is also determined. By means of Equations 14 and 15, the heights of all the grid points in the field can be determined. After determining the heights of the grid points, compared with the ground elevations in each grid point, the cut and fill heights and accordingly the cut and fill volumes in each grid are found by Equation 17.

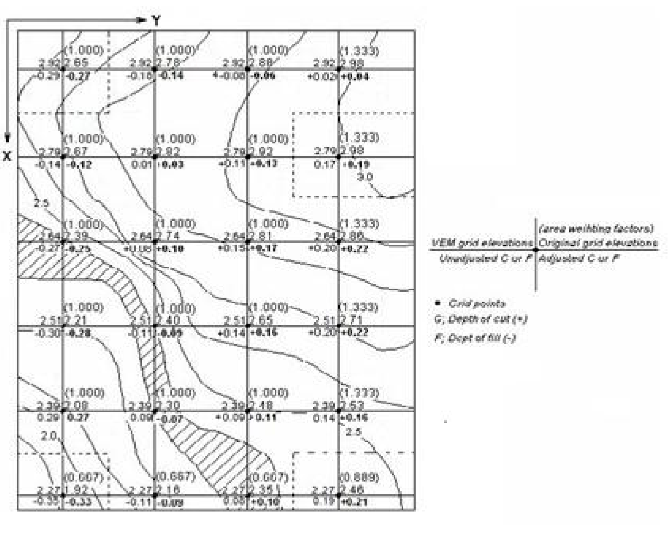

Figure 3. The grading results of the VEM for variable sloped grading in one direction

Table 2. The results of the variable sloped grading calculations of the VEM Method for slope values -0.5% (M_1) and -0.4% (M_2) in the X direction

	Attribute	Results of VEM Method
Unbalanced	∑Volume of cut, m^3	1705.3
	∑ Volume of fill, m^3	1819.6
	Cut to fill ratio, $R_{c/f}$	0,937
Balanced	∑Volume of cut, m^3	2015.8
	∑ Volume of fill, m^3	1579.6
	Cut to fill ratio, $R_{c/f}$	1.276
	Volume of cut per hectare, m^3ha^{-1}	911.7

Similarly, the cut and fill volumes at all grid points are found. The total cut volume is obtain by the cut volumes at each grid point are summed and the total fill volume is obtain by the fill volumes at each grid point are summed. $R_{c/f}$ is determined by proportioning the total cut volume to the total fill volume. If the $R_{c/f}$ ratio is between the values given in Table 1, the grid values found are accepted. If not, to bring it to the desired limits, the grading plane is replaced help of the Equation 18. Table 2 and Figure 3 are representing the results of the variable sloped grading in one direction of the Volume Equalization Method.

Conclusion

In this article; based on the Volume Equalization Method developed by Ayranci and Temizel 2011, variable sloped grading calculations in one direction are presented. The basis of the method is "the soil cannot be brought from the outside to the land grading area and the soil cannot be taken to the outside". Accordingly, the before and after grading soil volumes measured from a reference elevation are equal. In this study; it is given the mathematical principles of the method and it was applied to a hypothetical area with a size of 22100 m^2 for testing the method for variable sloped grading in one direction at rectangular fields. The presented method eliminates the need for use trial and error procedures that existing land grading design methods involve to determine the planet hat balances cut and fill volumes. Although it is based on least-squares theory, it doesn't have the time consuming calculations that appear in the conventional least-squares method. It is seen that both methods produced almost the same results in rectangular fields. As was done in the example 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. According to the unbalanced grading results (Table 2), the total cut volume was 1705.3 m^3, and the total fill volume was 1819.6 m^3. The cut/fill ratio ($R_{c/f}$) was 0.937. According to this conclusion, since the required cut/fill ratio according to soil properties should be in the range of 1.15-1.25, the grading plane had to be changed. After balancing process, it is necessary to increase the excavation height by 2 cm and the fill height by 2 cm. In this case, the total cut volume is 2015.8 m^3 and the total fill volume is 1579.6 m^3. And, The cut/fill ratio ($R_{c/f}$) is 1.276. This result can be accepted. The cut volume per hectare for the newly developed method is 911.7 m^3. Because of the topography of the hypothetical area is very rough, the values of the cut and fill volume are high.

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