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Soil Layer Deformation Model During Wide Raised Bed's Construction

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Abstract: The raised beds in the wide ridge furrow system during vegetables planting was identified by turning the soil layer using two opposing moldboards. Due to the interaction between the two opposing moldboards on soil, a furrow slice shifting on the surface of the moldboards undergoes a certain bending and twisting defection, which causes loosening of soil particles in the upper parts and compressing of soil in the lower parts causing an additional crushing. The height and width of wide ridge can be adjusted for setting angles of moldboard share (20, 30 and 40°), operational depths (10, 15, and 20 cm) and forward speeds (3.9, 4.5, 5.0, and 6.9 km.h^{-1}) in sandy soil. Measurements were compared and found that increasing setting angle from 20 to 40° the raised beds height increased by 16.6 %, while the upper width decreased from 42 to 20 cm and the wall bed sloping angle decreased by 59.3 % also the cross section area and fertilizing depth increased by 37.4 % and 22.2 % respectively.

Key words: Bed former, opposing moldboards, sloping angle, digger device, wide ridge.

INTRODUCTION

The objectives of forming soils in raised bed's profile are to create and maintain a stable soil structure; a porous and permeable soil; and a deeper than normal seedbed. The desired outcomes from these management objectives are to ensure the wide bed profile function properly. That is, they: 1- drain and aerate freely, and thus prevent water logging, 2- increase root growth and proliferation, and thereby reinforce the loose structure, minimizes subsidence and increase soil organic matter; 3- increase plant water use, and in that way increase production and reduce deep drainage and water table recharge. Hassan (1988) indicated that, the vegetables planting on the raised beds in the ridge furrow system achieves better growth conditions as, it realizes low levels of ground water and height infiltration. The optimum dimensions of bed profile width that achieve the maximum productivity for Tomatoes, Cucumbers, Zucchinis and Marrow are 118, 100, 90 and 71 cm respectively (Economic affairs sector, 2007).

Connor *et al*. (2002) and Gupta *et al*. (2002) indicated that in bed planting systems, vegetable's crops are planted on the raised beds in the ridge furrow system. This system is often considered more appropriate for growing high-value crops that are more sensitive to temporary water-logging stress. Change over from growing crops in flat out the ridge-furrow system of planting crops on raised bed alters the crop geometry and land configuration, offers more effective control over irrigation and drainage as well as their impacts on transport and transformations of nutrients.

Deepak and Chaudhuri (2001) investigated of performance evaluation for the various types of wide bed openers. The studies showed in general that an increase in the rake angles increases both bed depth and bed area. For light sandy soils, a rake angle of 130° found to be the most appropriate for the depth stability of the bed maker. The comparative study for performance evaluation of different types of wide furrow openers carried out by Tajuddin and Balasubramanian (1995). Gupta *et al*. (2000) concluded that the furrow cross section area is a function of tillage depth, width of tillage point and furrow angle for a given soil type and condition which affects the width of each side crescent. Generally, it can be concluded that the furrow cross-section is approximately independent of speed. Furthermore, Koohestani and Gregory (1985) found, during tillage, that the cross section area tilled could be related to a trapezoidal cross section. Ismail and Hemeda (1991) determined a new mathematical model determined to compute the expected height of ridge profile after cultivation. This model showed a good predication of the average height of corn ridge profile. The results also showed that they performed profile shape after cultivation tended to have a normal distribution shape. The theoretical height of the profile was more compared to the actual height. The comparison result showed an agreement with each other.

Generally, the problem noticed at using the shovel opener is that the soil layer previously turned a side usually begins to slide down into the open ridge profile when the retarding action of the wings stopped and the conformed shape area of raised bed is loose. The efforts were identified to select and evaluate a suitable bed former to conform to the wide profile. Therefore, this investigation aimed to determine the theoretical basics of a raised bed's profiles, and develop a broad ridge former unit to be conventional with varying heights, profile sizes and controlling the fertilizer depth that could achieve the agronomic requirements for different vegetable crops.

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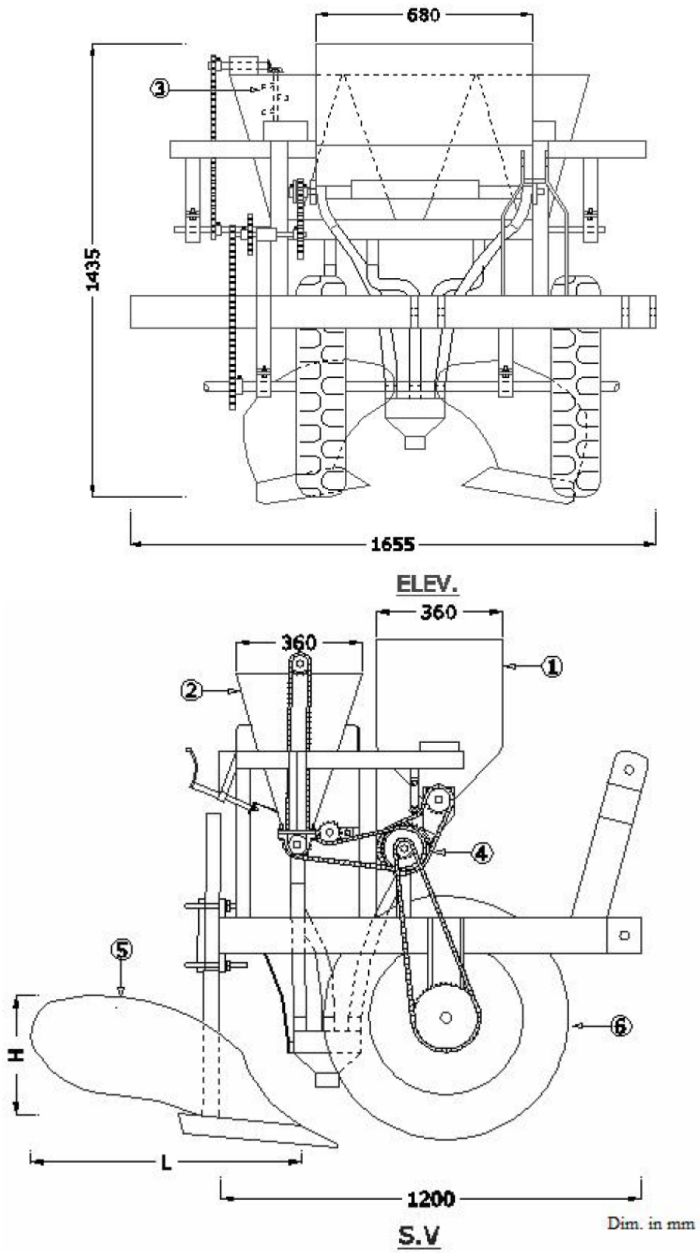
Soil Layer Deformation Model:

The broad ridge former prototype is one machine with two functions of placing fertilizers and forming a wide bed's profile (Fig. 1). It consists of two opposing moldboards plows mounted on a tool bar in which the distance between them is controlled. Due to the inter-action between the two opposing of moldboards plows and soil, a furrow slice shifting on the surface of the moldboards under goes to a certain bending and twisting defection, which causes loosening of soil particles in the upper parts and compressing of soil in the lower parts that is, an additional crushing. The movement of soil particles on the moldboard surface is found at varies speeds. This making theoretical analysis difficult, those for simplification it is easy to assume that, the furrow slice movement on the moldboard is in continuous flow without changes in cross section. Generally, the shapes or the dimensions of the wide ridge profile mainly depend on many factors. The most important are the forward speed, setting angle and depth of the ridge former unit. In general, observation during experiments carried out, increasing the setting angle, translate to more soil compressing in the lower parts and then increasing the height of a raised bed's profiles.



1-2 Fertilizer hopper 3- Agitator 4- Transmission system 5- Forming unit 6- Land wheel

Fig. 1: A schematic of designed machine

The Modeling Of The Ridge Former Depth As A Relation To Ridge Profile Bottom Width:

To determine the effect of the wide ridge former on the profile width dimension, the slow motion of primary field experiments was photographed and drawn. Fig. (2) indicates the typical location of a soil slices from left and right of the moldboard units (the wide ridge former). By considering that the width of slide is "b", "d_o" is the depth of the wide ridge former unit and "Δy" is the radius of the slide projection, then; the wide dimensions according to the action of the right moldboard of bed former (S_r) may be equal to;

$$S_r = \frac{b}{2} + d_o + \Delta y \qquad (1)$$

But;

$$\Delta y = \frac{P}{2} \cdot \cos(\gamma + \beta) \qquad (2)$$

and from the first principles

$$\cos(\gamma + \beta) = \cos\gamma \cdot \cos\beta - \sin\gamma \cdot \sin\beta \qquad (3)$$

and from geometric principles into Fig. (3), then:

$$\sin\gamma \cong \frac{d_o}{b} \quad \text{and} \quad \sin\beta = \frac{d_o}{P} \qquad (4)$$

and

$$\cos\gamma = \sqrt{1 - \left(\frac{d_o}{b}\right)^2} = \frac{1}{b}\sqrt{b^2 - d_o^2} \qquad (5)$$

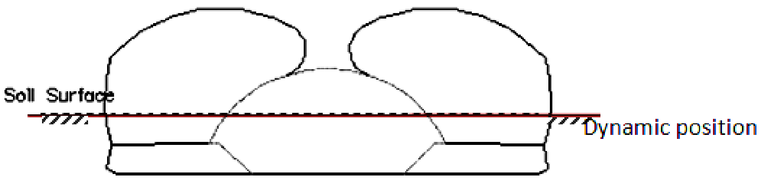
$$\therefore \sqrt{b^2 - d_o^2} = b\cos\gamma$$

$$= \frac{d_o}{\sin\gamma} \cdot \cos\gamma$$

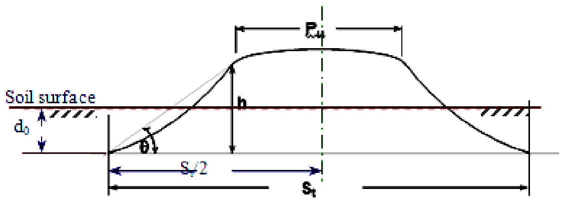
$$\sqrt{b^2 - d_o^2} = d_o \cot\gamma \qquad (6)$$

Substituting the parameters from equations 3, 4, 5 and 6 in equation 2. Then,

$$\Delta y = \frac{P}{2}\left[\frac{b}{P} \cdot \frac{1}{b}\sqrt{b^2 - d_o^2} - \frac{d_o}{b} \cdot \frac{d_o}{P}\right]$$



Soil deformation due to wide ridge former



Soil deformation after the wide ridge former was leveling the soil.

Fig. 2: The geometrical shape of wide ridge profile as the interaction between soil and forming unit

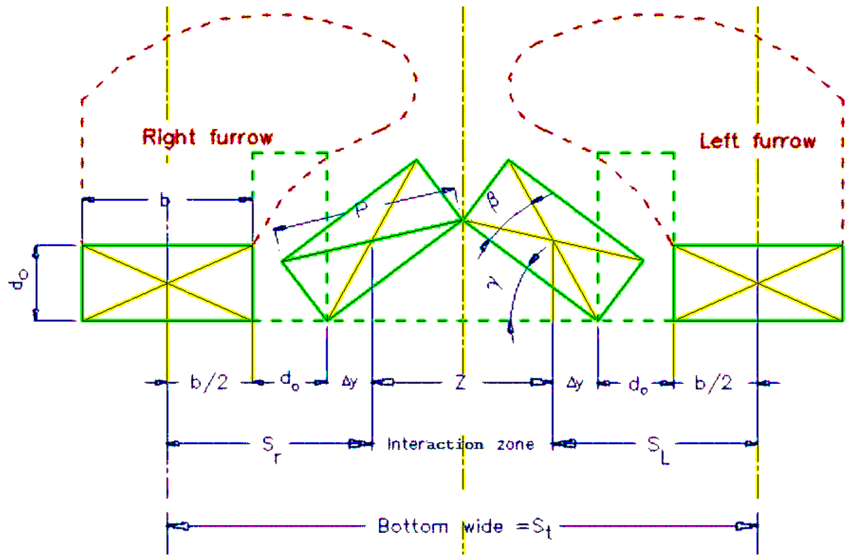


Fig. 3: The typical location of forming unit during forming the wide ridge profile

$$\therefore \Delta y = \frac{1}{2}\left[\sqrt{b^2 - d_o^{\,2}} - \frac{d_o^{\,2}}{b}\right] \tag{7}$$

and hence

$$S_r = \frac{b}{2} + d_o + \frac{1}{2}\sqrt{b^2 - d_o^{\,2}} - \frac{1}{2}\left(\frac{d_o^{\,2}}{b}\right) \tag{8}$$

Where
S_r : the profile slice displacement
b : profile slice width ≅ the share width, cm
d_o : profile slice depth, cm
: assuming that the profile slices depth ≅ depth of wide ridge former
P : the slice diagonal, cm
γ : the inclined angle of profile maker slice, degrees
β : the internal angle (Fig. 3), degrees

Similarly, the left moldboard of forming unit gave the same effect on moving the profile slice and may be equal to;

$$S_L = \frac{b}{2} + d_o + \frac{1}{2}\sqrt{b^2 - d_o^{\,2}} - \frac{1}{2}\frac{d_o^{\,2}}{b} \tag{9}$$

Then the total profile slice displacement is nearly equal the width of wide ridge profile bottom "S_t" may be equal to the "$S_r + S_L$" plus the interaction zone "Z" as shown in Fig. (3)

Then,

$$S_t = S_r + S_L + Z \tag{10}$$

From Fig. 3, the interaction zone may calculated as,

$$Z \cong 2\ d_o \cos \gamma \tag{11}$$

Substituting the equation (8) in equation (10), then

$$S_t = 2\left[\frac{b}{2} + d_o + \frac{1}{2}\sqrt{b^2 - d_o^{\ 2}} - \frac{1}{2}\frac{d_o^{\ 2}}{b}\right] + 2\ d_o\ \cos\ \gamma \tag{12}$$

$$S_t = d_o\ .\ \tau \tag{13}$$

Where; τ is considered a constant factor depending on the inclined angle of bed former slice that depends on the physical properties of soil in turn (Eq. 12).

Equation (13) represents the general formula which relates the span of the wide-ridge bottom to the operation depth. The constant "τ" is considered as quality of soil performance which equal referring Eq. (4 to 6);

$$\tau = \left[\frac{1}{\sin\gamma} + 2 + 2\cot\gamma - \sin\gamma + 2\cos\gamma\right]$$

Practically, to identify the good shape of the wide-ridge profile, the following points must be achieved:

- the distance (S_t) may be less than the theoretical value.
- the side force acting between the share and the soil may compact and deform and shift the soil over the moldboard as well as throwing of furrow slices away.

3. The Modeling Of The Ridge Former Depth As A Relation To Raised Bed's Height (h):

Increasing the operating depth of the ridge former increases, the amount of turned soil and the soil slice will find its way to the top of the furrow (Fig. 4). For simplification, assume that the shape of the turned soil on both sides of the ridge former takes a triangular shape with the "h" height of a profile (Fig. 4). From geometric shape of a profile;

$$h = \left[\frac{S_t}{2}\right]\tan\theta \tag{14}$$

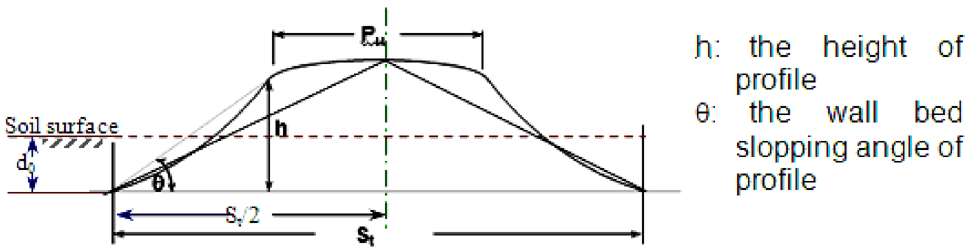


Fig. 4: The geometric shape of wide ridge profile

Substituting the values of "S_t" in equation (13), then;

$$h = \frac{d_o \cdot \tau}{2}\tan\theta = d_o\sigma \tag{15}$$

Where;

$$\sigma = \frac{\tau\ .\ \tan\theta}{2}$$

Increasing the angle "θ" (Fig. 4) increases the values of tan θ and increases the height of a profile, and so the height of a profile is increased with increasing the soil performance "σ".

MATERIALS AND METHODS

A sketch of a designed machine (Fig-1) consists of two units, one for fertilizer application and second for forming a wide ridge profile (Ismail and Ismail, 2007). The wide ridge former consists of two moldboards that mounted in opposing direction. The height and width can be adjusted using a special shank of 950 mm length with two different cross sectional areas. The upper end of the shank has a circular shape of 40 mm diameter fixed at the frame while the bottom end has a rectangular shape of 45 × 45 mm fixed at moldboard. This design is convenient for easy change setting moldboard angle's (Fig. 5-a). The moldboards have a share with 560, 150 and 125 mm for shear length, front and rear height respectively. The surface of moldboard takes a helical form. These dimensions are to obtain better turning for a furrow slice with square shape crown of the furrow given. Both shares and moldboards are attached together as shown in Fig. (5-b). A leveling roll of 800 mm width, diameter of 115 mm and 15 kg mass is located behind the two ends of the two opposing moldboard to make the top bed surface flat with lightly pressed soil.

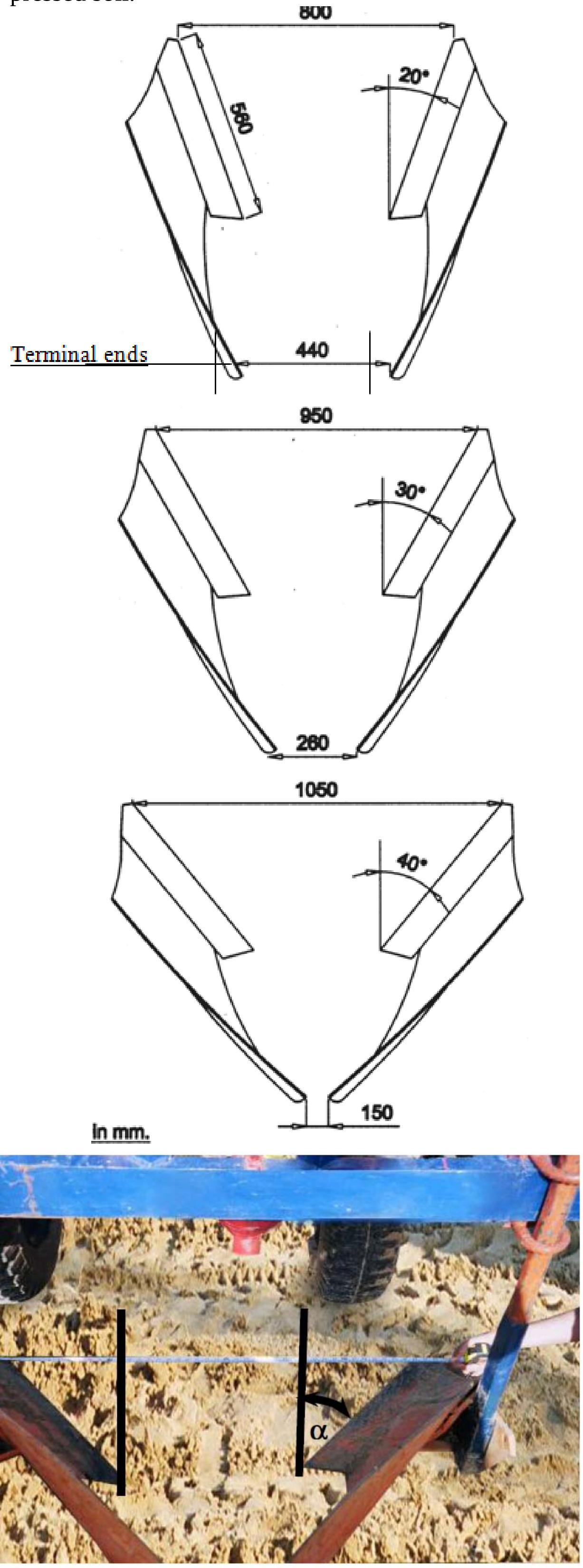


Fig. 5: The setting angle (α) of wide raised beds former.

The two previous units and their parts are fixed on the frame. The frame is fixed above two special iron connected at the axes of land wheels by two ball bearings. Three different setting angles for former unit (Fig. 5-a) relative to the traveling direction were identified. There were 20, 30 and 40°.

The experimental studies were executed at summer (2010) to determine the effects of forward speeds of 3.9, 4.5, 5.0 and 6.9 km.h^{-1} for the wide ridge former at different operational depth of 10, 15 and 20 cm and three dissimilar setting angles of 20, 30 and 40°, on wide ridge profile dimensions, cross sectional area and fertilizing depth in sand soil. A rectangular field of about 2 hectares is used as the field experiments. It is located at Agricultural Faculty Experimental Station (Kalabashu farm), Mansoura University, Egypt. It is divided into 108 plots each of them has 2 m wide and 75 m long. There were replicated three times.

Soil mechanical analysis of experimental field at average soil depth of 0 – 20 cm indicated that the soil has clay of 3.48 %, silt of 3.14 %, and 13.97 % fines sand and coarse sand of 79.41%. Then the texture class of experimental soil is sandy soil. The soil moisture content was about 20 % d.b. at ranges from zero to 20 cm depth.

The soil bulk density was 1.4 g.cm^{-3}, it measured before ridging. The samples were taken at depths of 10, 15 and 20 cm. A two-wheel drive, Romanian's tractor model (Universal 650-M) was used as the power source with (48.50 kW).

According to (Abou Elmagd, 2001 and Ismail and Abo-Habaga, 2002) the wide bed profile was determined using a local manufactured profile meter. The profile cross section areas (A) are determined directly after every test by the following equation:

$$A = \frac{S_t}{2}\left(a + 2\, t_n\right) \tag{16}$$

Where:

A : operated cross section area, cm^2

a : sum of first and last ordinates, cm

t_n : sum of all ordinates excluding the first and last ones, cm.

Red material color used is mixed with fertilizers to detect fertilizer's depth easily. The fertilizing depths measured after digging lateral sector in the wide bed profile, and when the color fertilizers appeared, the distance between the top surfaces and fertilizers bottom measured by vertical scale. About ten readings taken from each plot at the different location and each plot was replicated three times to determine the average depth of fertilizer that just considers the height of soil. All data collected for all parameters of dissimilar treatments statistically analyzed. The strip plot design Gomez and Gomez (1984), is used to carry out the field experiments and Statistical Analysis System (SAS, 2003) were used to analyze data obtained.

RESULTS AND DISCUSSION

The Ridge Profile Dimensions:

The most important indicators used to evaluate the interaction between the operating parameters are the wide ridge profile dimensions. Figure (6) shows the effect of forward speed "V_m" on the height and upper width of the ridge profile respectively at different levels of operational depth and setting angle. As shown, it is obvious that increasing the forward speed decreases the height, while increases the ridge profile upper width. The results also indicated that the highest value of ridge profile height (Fig. 6-C) was 26.5 cm at the operational depth, setting angle and forward speed were 20 cm, α_3 = 40° and 3.9 km/h respectively. However, the lowest value of ridge profile height (Fig. 6-B) was found to be 14 cm at the operational depth, setting angle and forward speed were 10 cm, α_1 = 20° and 6.9 km.h^{-1} respectively. This trend may be attributed to the effect of increment of forward speed on preventing the forming unit share to penetrate in soil, and not encouraging more soil layers to accumulate and construct highest ridge profile. On the other hand, increasing in both setting angle and operating depth encourage soil layer to form a good accumulation.

Fig. (6) shows that increasing the setting angle "α_1" within the range of α_1 = 20° to α_3 = 40°, increases the ridge profile height, while decreases the ridge profile upper width at all levels of operational depth and forward speeds. This result is agreement with the theoretical equation (15). The results also show that the lowest value of ridge profile upper width was found to be 16.5 cm at the operational depth and setting angle were d_3 = 20 cm, α_3 = 40° and forward speed of 3.9 km.h^{-1} respectively. However, the highest value of ridge profile upper width of 51 cm was achieved at operational depth of 10 cm, setting angle of α_1 = 20° and forward speed of 6.9 km.h^{-1}. This can be explained by the fact that increasing forward speed, increases the collapsed soil and consequently, more soil would fall down on the profile sides. In addition, decreasing the distance between the moldboard terminals ends increases the setting angles, thus the upper width was reduced.

2. The wall bed sloping angle

The effects of operation parameters on the wall bed sloping angle of the ridge profile at different operational depth are illustrated in Fig. (7). As shown, increasing forward speed decreases the wall bed sloping angle of the bed profile at all levels of operational depth. It is also obvious that increasing the setting angle decreases the wall bed sloping angle of the ridge profile. This may be due to the high motion of soil layers since the increment of forward speed lead to bad accumulation of soil layer.

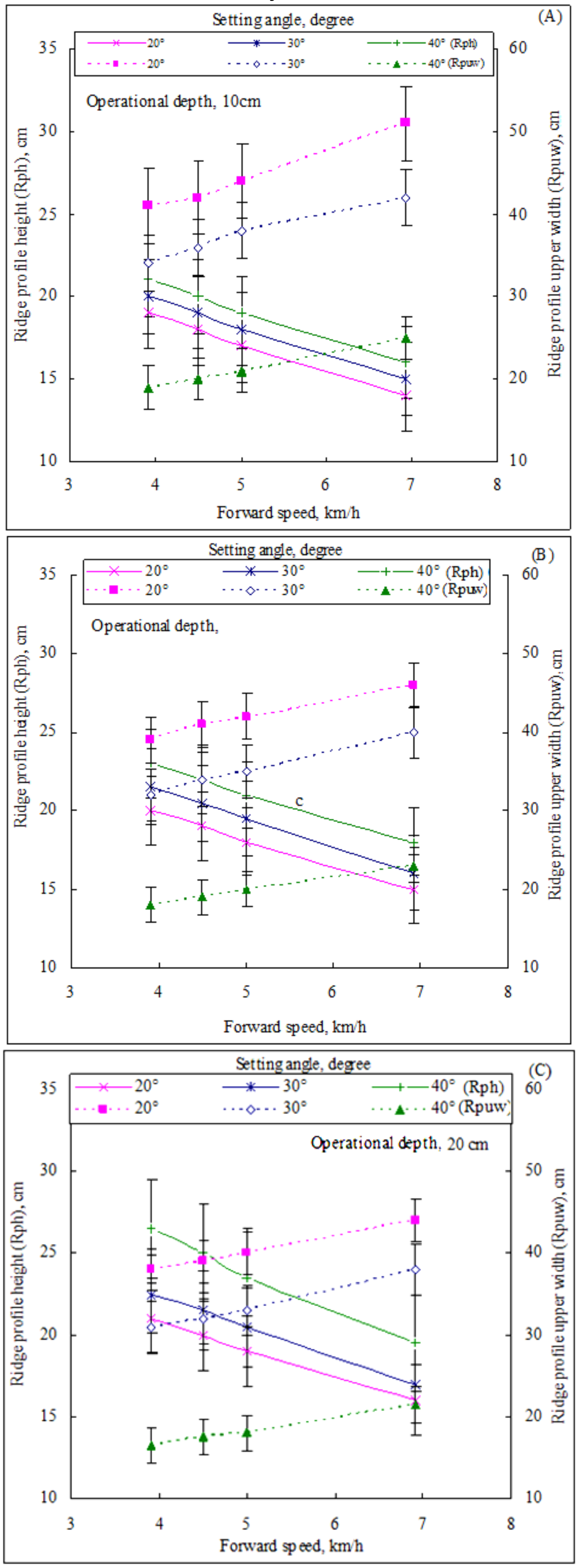


Fig. 6: Effect of forward speed on each of ridge profile height and upper width

Nevertheless, by increasing the setting angle "α" from 20° to 40° the slope angle of ridge profile decreased by 59.3 % because the upper width of ridge profile becomes large when the setting angle was adjusted on α_1 = 20° than α_3 = 40° as shown in Fig. (7). The upper widths have a positive effect on the ridge profile slope angle. While it increases about 5 % by increasing the operational depth from 10 to 20 cm. This may be attributed to the effect of the ridge profile height which has a positive effect on ridge profile slope angle and is increased by increasing operational depth

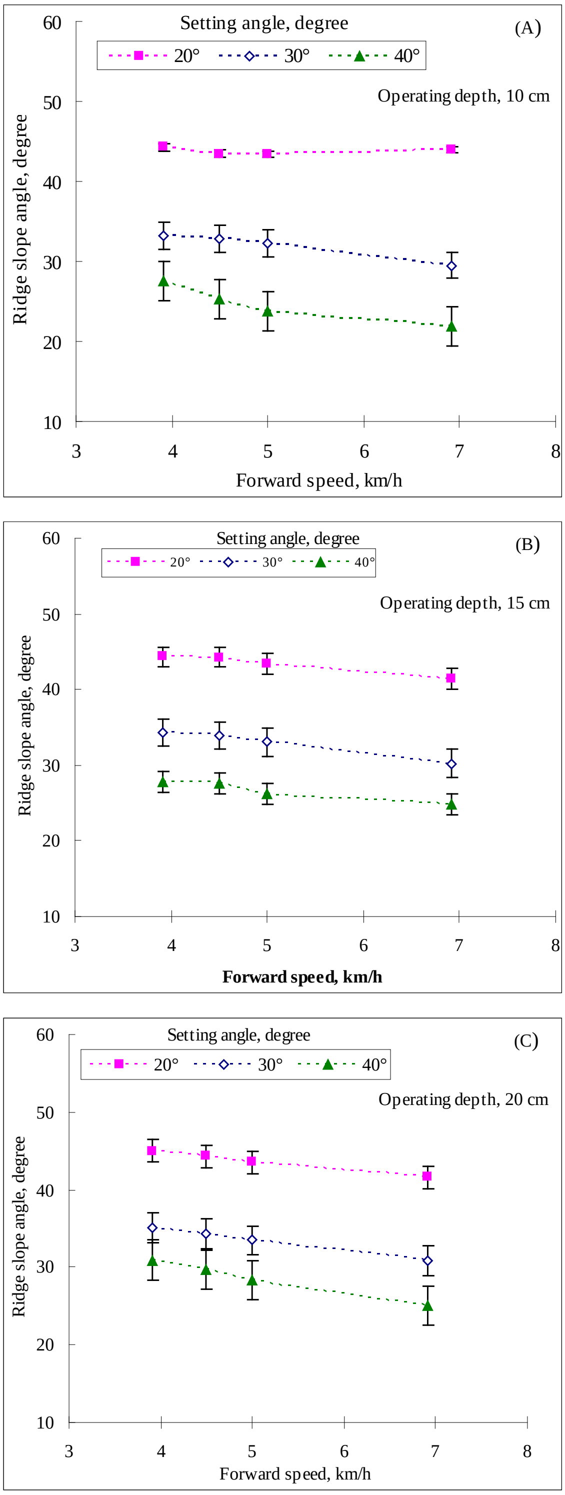


Fig. 7: Effect of forward speed on ridge slope angle

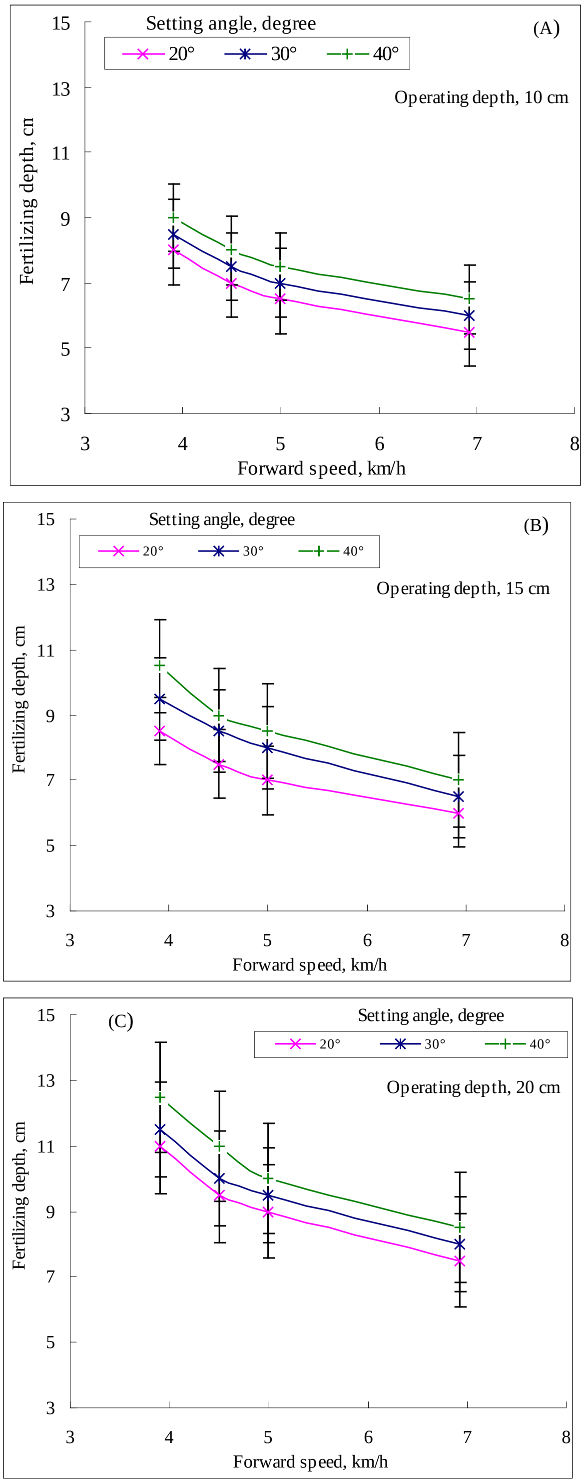


Fig. 8: Effect of forward speed on fertilizing depth

The Fertilizing Depth:

The fertilizer depth relative to the independent variables is illustrated in Fig. (8). Lowest fertilizing depth "5.5 cm" is recorded at using forward speed of 6.9 km/h, operational depth of 10 cm and setting angle of 20°. However, Fig. (8-C) cleared that using the setting angle of 40°, operational depth of 20 cm and forward speed of 3.9 km.h-1 gave maximum value "12.5 cm". This result may be attributed to the ridge accumulation of soil layers occurred by using shallow operating depth and a small setting angle with high forward speed. Consequently, affecting the amounts of rack soil, this was translated too little fertilizing depth. On the other hand, slow forward speed and deep operating work at a large setting angle encourage more accumulation of a soil slice.

The Cross Section Area Of Bed Profile:

The data as shown in (Table 1) indicated a high significant difference between the levels of the three experimental factors and the interaction between all levels of three factors except. the interaction between the forward speed and operational depth. The cross section area of ridge profile is decreased 37.82 % by increasing the forward speed from 3.9 to 6.9 km.h^{-1}. This trend may be attributed to the effect of increment of forward speed on preventing the wide ridge former shares to penetrate in soil, and not encourage more soil layers to accumulate and constructing a big cross section area of ridge profile.

The setting angle of α_3 = 40° is more effective on the cross section area of ridge profile increased by 26.57 % (Table 1). It may be due to the increment of cutting width of a soil slices so more soil layers accumulate and constructed a highest cross section area. And also increasing the operational depth from 10 to 20 cm, the cross section area increased by 13.63% (Table 1), because there are more soil layers translated to change in the amounts of rack soil lead to a positive increasing in the cross section area of bed profile.

Table 1: Effect of setting angle on cross-section area of bed profile

Forward speed, V_m, km/h	N	Mean, cm^2	t Grouping
V_{m1} = 3.9	27	1294.639	A
V_{m2} = 4.5	27	1125.648	B
V_{m3} = 5	27	1035.639	C
V_{m4} = 6.9	27	939.361	D
Least significant difference		14.095	
Setting angle, α, deg	N	Mean, cm^2	t Grouping
(3 = 40	36	1277.604	A
(2 = 30	36	1080.729	B
(1 = 20	36	938.132	C
Least significant difference		12.207	
Operating depth, d, cm	N	Mean, cm2	t Grouping
d3 = 20	36	1180.688	A
d2 =15	36	1096.063	B
d1 = 10	36	1019.715	C
Least significant difference		12.207	

N.B.:

$$The\ \ percentage\ \ of\ \ ridge\ \ profile\ \ crosssetion\ \ area = \frac{V_{m1} - V_{m4}}{V_{m1}} \times 100$$

$$at\ \ V_m\ \ \ from\ \ 3.9\ \ to\ \ 6.9\ \ m/s$$

Conclusions:

* Increasing setting angle from 20^o to 40^o the raised beds height increased by 16.6 %, while the upper width decreased from 42 to 20 cm and so the wall bed sloping angle "θ" decreased by about 59.3 % also the cross section area increased by 37.4 %.

* The cross section area of bed profile is decreased by 37.82 % by increasing the forward speed from 3.9 to 6.9 km.h^{-1} and also, the highest value of ridge profile upper width of 51 cm was achieved at operational depth of 10 cm, setting angle of 20° and forward speed of 6.9 km.h^{-1}.

* The increase in forward speed from 3.9 to 6.9 km/h decrease the fertilizing depth of the raised profile by 31.6 %. While increasing the setting angle from 20° to 40° increases the fertilizing depth of the bed profile by about 22.2 %, because the distance between the two terminal ends of the two opposing moldboard decrease with increasing the setting angle and encourage more soil layers to accumulate and constructed a highest covering.

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