American Journal Of Agriculture And Horticulture Innovations

VOLUME Vol.05 Issue10 2025
PAGE NO. 40-44
DOI 10.37547/ajahi/Volume05Issue10-07

Stability Of Movement In The Vertical Plane Of Working Tools During Interrow Cultivation Of Vineyards On Terraces

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Received: 27 August 2025; **Accepted:** 15 September 2025; **Published:** 27 October 2025

Abstract: The difference in ΔZ values determined in this article using theoretical methods should be explained by certain assumptions made in the analytical studies (microrelief was not taken into account), as well as by errors in the experimental studies.

Keywords: Stability, plowing, cultivation, theory, equation, attachment, method.

Introduction: One of the important indicators of technological process quality is the uniformity of tillage depth, which primarily depends on the stability of the working elements' vertical movement.

The degree of stability of the working elements' movement largely depends on the unit's movement method, the relationship between the parameters of the linkage links, the machine design, the balance of the forces acting on the working element, and the stability of the unit's movement as a whole [1, 2, 3, 4].

The unit's movement on terraces is curved, which increases the traction resistance of the working elements, which increases with the curvature of the trajectory. This significantly affects the stability of the working elements' movement.

Materials and Methods

We studied a combination of an MTZ-82.1 tractor and a UK-3, UP-3 universal vineyard machine during cultivation and inter-row plowing of terraced vineyards.

For the analytical study, we will consider the mounted machine as a mechanical system subject to the action of (Figure 1):

Soil resistance forces:

$$\mathrm{P_x} = \mathrm{P_{x1}} + \mathrm{P_{x2}} + \cdots + \mathrm{P}_{xn} = n\mathrm{P_x} : \quad (1)$$

$$\mathrm{P}_z = \mathrm{P}_{z1} + \mathrm{P}_{z2} + \cdots + \mathrm{P}_{zn} = n\mathrm{P}_z. \quad (2)$$

Soil resistance forces from curvilinear movement:

$$F_{\mathrm{x}} = F_{\mathrm{x}1} + F_{\mathrm{x}2} + \cdots + F_{\mathrm{x}n} = nF_{\mathrm{x}} : \quad (3)$$

$$F_z = F_{z1} + F_{z2} + \cdots + F_{zn} = nF_z. \quad (4)$$

where n is the number of working elements.

The machine's weight forces G.

Reactions in the hinge joints attached to the tractor: A_x, A_z, B_{x1}, B_{z1}, B_{x2}, B_{z2}.

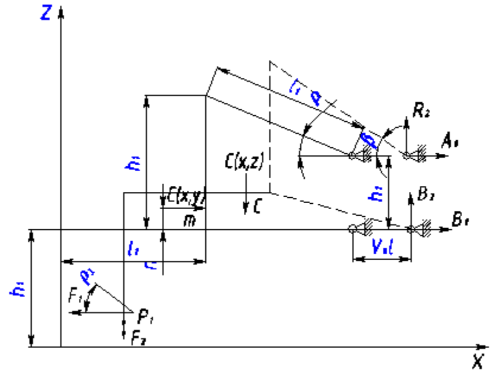

Figure. 1. Forces acting on the suspension system

Soil resistance forces Px and Pz vary significantly during operation, while FX and Fz depend on the radius of curvature of the machine's curvilinear motion.

Therefore, the equilibrium of forces acting on the working elements is periodically disrupted, causing the center of gravity of soil-cultivating machines to deviate from their initial position.

Let us determine the nature of the influence of curvilinear motion on the magnitude of the vertical deviation of the machine's center of gravity.

If the coordinates of the machine's center of gravity at the initial moment of motion are denoted by X_0 and Z_0, then

$$X_0 = l_1 - m, \quad (5)$$

$$Z_0 = h + n. \quad (6)$$

Results

Assuming uniform motion, the unit will move in the direction of motion a distance $V_n t$.

Let's assume that during this time, the machine, under the action of disturbing forces, experiences an angular displacement β. Then the coordinates of the center of gravity will shift by:

$$\mathrm{X}_1 = V_n 1 + l_1 - m + l_2 cos\beta_0 - l_2 cos(\beta_0 + \beta), \quad (7)$$

$$Z_1 = h_1 + n + l_2 sin(\beta_0 + \beta) - l_2 sin\beta_0 ; \quad (8)$$

$$\dot{X} = l_2 \dot{\beta} sin(\beta_0 + \beta); \quad (9)$$

$$\dot{Z} = l_2 \dot{\beta} cos(\beta_0 + \beta). \quad (10)$$

Using the Lagrange equation of the second kind, we will compose a differential equation of motion of a mounted machine in a vertical plane:

$$\frac{d}{dt}\left(\frac{dT}{d\beta}\right) - \frac{dT}{d\beta} = Q_\beta, \quad (11)$$

where T is the kinetic energy of the system;

Q_β is the generalized force.

The kinetic energy of the system will be:

$$\mathrm{T} = \frac{\mathrm{M}}{2}\left(\dot{\mathrm{X}}^2 + \dot{Z}^2\right) + \frac{1}{2} l_0 \beta^2. \quad (12)$$

where M is the mass of the system;

I_0 is the moment of inertia of the system relative to the axis passing through the center of gravity perpendicular to the plane of the drawing.

Taking into account expression (10) from equation (12), we express the total kinetic energy of the system as:

$$\mathrm{T} = \frac{\mathrm{M}}{2}\left[V_n^2 + 2V_n l_2 \dot{\beta} sin(\beta_0 + \beta) + l_2 \dot{\beta}^2\right] + \frac{1}{2} l_0 \beta^2 \quad (13)$$

Substituting the value $\frac{\partial T}{\partial \beta}, \frac{dt}{dt}$ and denoting (4) и обозначая $ml_2^2 + l_0 = lnp$ we obtain

$$l_{np}\dot{\beta} = Q_\beta \quad (14)$$

To determine the generalized force, we write the equation of virtual work applied to the working machine:

$$M_0\delta_\beta = Q_\beta\delta_\beta\ , \quad (15)$$

Hence, $M_0 = Q_\beta$, (16)

where M_0 is the total moment of the forces applied to the working machine relative to the point of their attachment to the tractor.

Figure 1 shows that

$$M_0 = (P_x + F_x)[h_1 + h_2 - l_2 sin(\beta_0 + \beta)] - (P_z + F_z)[l_1 + l_2 cos(\beta_0 + \beta)] -$$
$$-G[m + l_2 sin(\beta_0 + \beta) - (B_{x1} + B_{x2})]h_3. \quad (17)$$

Expression (8) can be represented as:

$$M_0 = -[(P_x + F_x)l_2 sin\beta_0 + (P_z + F_z)l_2 cos\beta_0 + Gl_2 cos\beta_0]cos\beta - [(P_x + +F_x)l_2 cos\beta_0 - (P_z + F_z)l_2 sin\beta_0 - Gl_2 sin\beta_0]sin\beta + (P_x + F_x)(h_1 + h_2) - (P_z + F_z)l_1 - Gm - (B_{x1} + B_{x2})h_3. \quad (18)$$

Let us denote

$$\dot{\beta} = \frac{d^2\beta}{dt} = y; \quad (19)$$

$$\ddot{\beta} = \frac{d^2\beta}{dt^2} = y\frac{dy}{d\beta}; \quad (20)$$

$$\frac{1}{2}\dot{y}^2 = \frac{1}{l_n}[-K_1 sin\beta + K_2 cos\beta + K_3\beta + C_1], \quad (21)$$

$$\beta^2 - 2\frac{K_3 - K_1}{K_2} = 0, \quad (22)$$

$$(P_x + F_x)l_2 sin\beta_0 + (P_z + F_z)l_2 cos\beta_0 + Gl_2 cos\beta_0 = K_1, \quad (23)$$

$$(P_x + F_x)l_2 cos\beta_0 - (P_z + F_z)l_2 sin\beta_0 - Gl_2 sin\beta_0 = K_2, \quad (24)$$

$$(P_x + F_x)(h_1 + h_2) - (P_z + F_z)l_1 - Gm - (B_{x1} + B_{x2})h_3 = K_3. \quad (25)$$

Then equation (7) takes the form:

$$l_n\ddot{\beta} = -K_1 cos\beta - K_1 sin\beta + K_3. \quad (26)$$

For integration, we introduce a new variable:

Substituting the value of β into equation (17) and integrating, we obtain:

C_1 is an arbitrary constant at $t = 0, \beta = 0, \frac{d\beta}{dt} = 0, C_1 = -K_2$.

Then the equation will take the form:

$$\dot{y}^2 = \left(\frac{d\beta}{dt}\right)^2 = \frac{2}{l_n}(-K_1 sin\beta + K_2 cos\beta + K_3\beta - K_2). \quad (27)$$

Since the angle β is small, we can take:

$$sin\beta; cos\beta = 1 - \frac{\beta^2}{2}. \quad (28)$$

At the maximum value of the angle ρ, the angular velocity β = 0. Then from equation (10) we find:

$$\beta^2 - 2\frac{K_3 - K_1}{K_2}\beta = 0, \quad (29)$$

from here

$$\beta = 0; \beta = 2\frac{K_3 - K_1}{K_2}, \quad (30)$$

Taking into account expression (12), equation (10) can be written as:

$$\dot{\beta} = \sqrt{\frac{K_2}{l_n}}\sqrt{2\frac{k_3 - k_1}{k_2}\beta - \beta^2}, \quad (31)$$

where $t = \sqrt{\frac{l_n}{k_2}}\int\frac{d\beta}{\sqrt{2\frac{k_3 - k_1}{k_2}\beta - \beta^2}}$. (32)

After integrating, we obtain:

$$t = \sqrt{\frac{l_n}{k_2}} arcsin\left[\frac{k_2\beta-(k_3-k_1)}{k_3-k_1}\right] + C_2, \quad (33)$$

where C_2 is an arbitrary constant t=0, β=0.

$$C_2 = \sqrt{\frac{l_n}{k_2}}\sin(-1) = \frac{3}{2}\pi\sqrt{\frac{l_n}{k_2}}, \quad (34)$$

Having solved equation (34) for β, we obtain:

$$\beta = \frac{k_3-k_1}{k_2}(1 - cos\sqrt{\frac{k_2}{l_n}}t) . \quad (35)$$

Having the values β=f(t), we determine the vertical displacement ΔZ of the center of gravity of the working machine, that is, the analytical change in the processing depth

$$\Delta Z = l_2\sin(\beta_0+\beta) - l_2\sin\beta = l_2\sin\beta(cos\beta - 1) + l_2\cos\beta_0 sin\beta. \quad (36)$$

Taking into account expression (18), we obtain

$$\Delta Z = l_2(\beta\cos\beta_0 - \frac{\beta^2}{2}sin\beta_0). \quad (36)$$

Substituting the value of expression (8) into equation (36), we can write:

$$\Delta Z = l_2\left\{\frac{K_3-K_1}{K_2}\left(1-cos\sqrt{\frac{k_2}{l_n}}t\right)\cos\beta_0 - \left[\frac{K_3-K_1}{K_2}\left(1-cos\sqrt{\frac{k_2}{l_n}}t\right)\right]^2\frac{sin\beta_0}{2}\right\}$$

Since the coefficients k1, k2, and k3 depend on the forces acting on the mechanical system, and the forces depend on the radius of curvature of the movement, then, by substituting the average traction characteristic of tillage at different curvatures of movement, we obtain the theoretical dependence of the change in depth on the curvature of movement.

Given the following data: h1 = 62 cm, h2 = 58 cm, h3 = 36 cm, l1 = 84 cm, l2 = 76 cm, β0 = 170, G = 500 kg, m = 8 cm, we plot the graphs of the function ΔZ = f(t) (Figures 2 and 3).

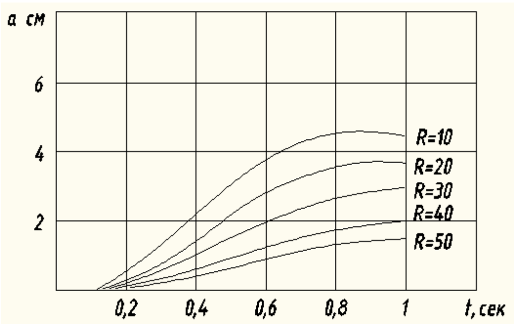

Figure. 2. Changes in ΔZ over time depending on the radius of curvature of the trajectory of movement during cultivation.

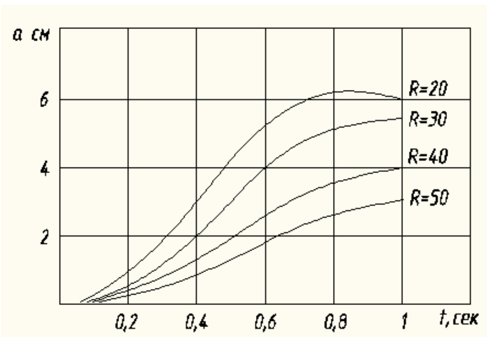

Figure 3. Change in ΔZ over time depending on the radius of curvature of the trajectory of movement during plowing.

During field testing of the unit, the change in depth from the radius of curvature of the trajectory of movement has the following form [4-12] (Figure 4).

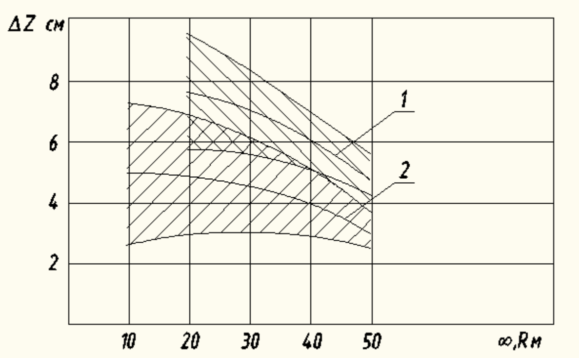

Figure 4. Change in average tillage depth and confidence intervals (0.8) from the radius of curvature:

1. Plowing h = 25 cm; v=l.75
2. Cultivation h = 15 cm; v = 3,49.

It can be seen from the graph that the analytical and experimental dependences of the change in depth on the radius of curvature almost coincide..

Conclusions

The difference in ΔZ values should be explained by some assumptions made in the analytical studies (microrelief was not taken into account), as well as errors in the experimental studies..

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