ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Theoretical Substantiation Of The Device Parameters For Horizontal Continuous Measurement Of Soil Hardness In Technologies Of Coordinate Arable Farming.

Sergei Vladimirovich Mashkov[1]*, Sergei Ivanovich Vasil'yev[1], Pavel Vladimirovich Kryuchin[1], Maxim Alekseevich Mastepanenko[2], and Tatyana Sergeevna Gridneva[1].

[1]Samara State Agricultural Academy, Uchebnaya str. 2, Kinel 446442, Samara Region, Russia
[2]Stavropol State Agrarian University, Zootekhnicheskiy lane 12, Stavropol 355017, Russia

ABSTRACT

The demand for mass measurements of the hardness of the soil, with the obligatory coordination of the points at which the measurements were made, appeared because of the introduction of co-ordinate farming technologies. The existing ways of coordinating are very laborious and time consuming. We proposed to use a flat, rather than a conical tip when measuring the hardness of the soil. This makes it possible to achieve the greatest stability of the compacted soil core and the reliability of the measurement results. The relative error of measurement (up to 30%) is determined using an unprotected plunger, and the results of the studies indicate the need to protect the plunger from contact with the soil.
Keywords: coordinate agriculture, hardness, friction, soil compaction, plunger, hardness meter.

*Corresponding author

INTRODUCTION

More and more development in the world agricultural production is obtained by the technologies of coordinate and precise farming. One of the important and unsolved problems, in this case, is the need for mass measurements of the hardness of the soil, with the obligatory coordination of the points at which measurements were taken. This technology allows you to draw maps of the hardness of the field or a certain area [3].

Continuity and mass measurements of soil hardness can be achieved only by the method of its horizontal measurement, combined with any technological operation. However, the task of creating hardness meters of horizontal action is not solved.

In this regard, the purpose of the research is to develop optimal parameters of the tip, which is part of the constructive-technological scheme of the hardness meter, and also the rationale for the parameters of its placement and protection.

RESULTS AND DISCUSSION

In soil hardness, mainly cone-shaped tips are used, more rarely flat ones [4].

In the horizontal movement of the hardness tester with a tip in the soil layer, a soil compaction zone is formed in front of it with a restriction of expansion (wedging). In the process of solidimeter motion, initially, soil compression and elastic deformation, characterized by the Poisson's ratio μ, and the lateral pressure coefficient ξ [1]:

$$\mu = \frac{\xi}{1+\xi}, \qquad (1)$$

$$\xi = \frac{dq}{dp}, \qquad (2)$$

where μ – Poisson's ratio;

ξ – coefficient of lateral pressure;
dq – increment of lateral force;
dp – increment of compressive force.

With further movement of the nozzle, a compacted soil core of conical shape is formed in front of it (Figure 1).

Each elementary volume of soil in the soil core (in the compression zone) is affected by compressive forces that cause the compressive stresses σ_1, σ_2, σ_3 (Fig. 1). In this case, σ_1 is the largest principal voltage, and σ_3 is the smallest.

When the external load (force) P_{load} is increased, the tangential stress τ_α exceeds the maximum value by the strength condition, and the Elementary volume of the soil breaks down along the plane of the greatest tangential stress, located at an angle of 45 ° to the axis of the greatest principal stress [1].

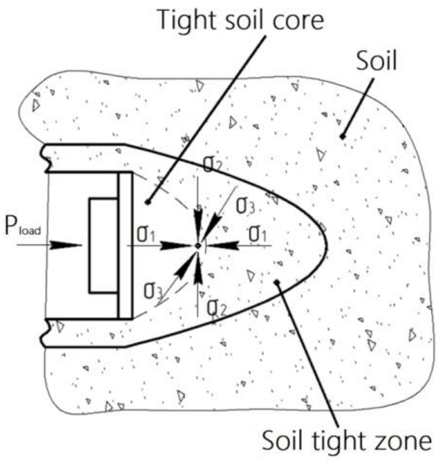


Figure 1: Scheme of the compacted soil core with normal stresses arising in it

The geometric position of the plane of destruction depends on many factors. It is necessary to take into account the fact that the soil has not only elastic, but also plastic properties and is a loose medium. The position of the plane of destruction and the operating stresses is most conveniently described by the Coulomb-Moore theory:

$$\tau = c + \sigma tg\phi_{in} = c + \sigma f_{in}, \quad \text{Pa,} \qquad (3)$$

where *c* – adhesion tension of soil aggregates, Pa;

σ – normal stress, Pa;
f_{in} – coefficient of internal friction;
φ_{in} – angle of internal friction of soil.

In this theory, the effect of the angle of internal friction of the soil ϕ_{in} and the mutual cohesion of soil aggregates *"c"* is taken into account. These parameters determine the configuration of the resulting soil core.

The interrelation of the coefficients entering into the Coulomb-Mohr law is clearly represented in the form of graphs of the dependence of the tangential stress τ on the normal stress σ (the scheme of Mohr circles) (Fig. 2).

On the basis of this theory, taking into account the angle of internal friction of the soil ϕ_{in}, the angle α_0 is determined, which characterizes the position of the plane of destruction of a single volume of soil (Figure 3):

$$\alpha_0 = 45^\circ + \frac{\phi_{in}}{2}. \qquad (4)$$

ISSN: 0975-8585

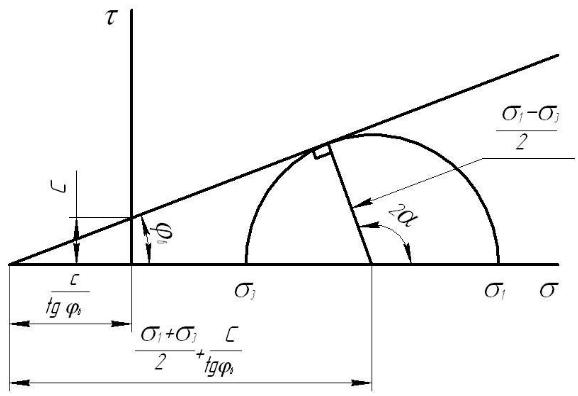


Figure 2: Circle of Mohr Circles

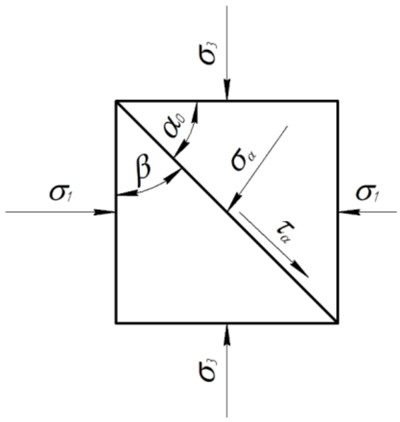


Figure 3: Scheme of the destruction plane of the soil volume under the action of external stresses

The obtained angle is located between the plane of destruction and the smallest principal stress σ_3. Of greatest interest is the angle between the plane of destruction and the largest principal stress σ_1, since its direction coincides with the direction of motion of the tip of the hardness meter.

Figure 3 shows that this angle is the angle β, which is equal to:

$$\beta = 90^\circ - \alpha_0 = 45^\circ - \frac{\phi_{in}}{2} . \qquad (5)$$

Using the theory of Coulomb-Mora, you can find the angle of internal friction of the soil in relation to the main stress. Then we get the expression:

$$\sin\phi_{in} = \frac{\dfrac{(\sigma_1 + \dfrac{c}{tg\phi_{in}}) - (\sigma_3 + \dfrac{c}{tg\phi_{in}})}{2}}{\dfrac{\sigma_1 + \sigma_3}{2} + \dfrac{c}{tg\phi_{in}}} = \frac{tg\phi_{in}(\sigma_1 - \sigma_3)}{tg\phi_{in}(\sigma_1 + \sigma_3) + 2c} . \qquad (6)$$

Given that $tg\varphi_{in} = k_{inf}$ is the coefficient of internal friction and is a characteristic of the soil. It depends on the type of soil and its state. Then we get:

ISSN: 0975-8585

$$\sin\phi_{in} = \frac{k_{\inf}(\sigma_1 - \sigma_3)}{k_{\inf}(\sigma_1 + \sigma_3) + 2c} . \qquad (7)$$

As a result of the research, the resulting compacted soil nucleus has the shape of a cone (with blunted vertex), the angle at the vertex γ_0 of which is $\gamma_0 = 2\beta$. Taking into account equations (5) and (7), we obtain the required value of the cone angle of the compacted core of the soil:

$$\gamma_0 = 90^\circ - arc\sin\frac{k_{\inf}(\sigma_1 - \sigma_3)}{k_{\inf}(\sigma_1 + \sigma_3) + 2c} . \qquad (8)$$

Since the smallest and largest principal stresses are in a reciprocal relationship determined by the condition:

$$\sigma_3 = \xi\,\sigma_1, \quad \text{Pa}, \qquad (9)$$

and the greater main tension is determined by the expression:

$$\sigma_1 = \delta\,h^{\mu}, \quad \text{Pa}, \qquad (10)$$

where δ – coefficient of volume wrinkling, N / cm^3;

h – depth of the point in question, m;
μ – parameter, depending on the type and condition of the soil.

then combining expressions (8) and (10) we obtain the required final formula for determining the angle at the vertex of the compacted soil core:

$$\gamma_0 = 90^\circ - arc\sin\frac{\delta h_n{}^{\mu} k_{\inf}(1-\xi)}{\delta h_n{}^{\mu} k_{\inf}(1+\xi) + 2c} . \qquad (11)$$

It should be remembered that the parameters included in this formula depend on the type and condition of the soil, and can vary within a significant range [5, 7]. Correspondingly, the angle γ_0 is not a constant.

If the cone-shaped tips are used in the measurement process, then three variants of interaction between the soil and the tip are possible, determined by the ratio of their parameters: $\alpha_n<\gamma_0$; $\alpha_n = \gamma_0$; $\alpha_n>\gamma_0$ (α_n – angle at the tip of the hardness nozzle (Figure 4)).

In Figure 4a, the first variant is presented, in which the angle at the vertex of the tip α_n is less than the angle γ_0. In this case, the formation of a compacted soil core does not occur. There is only a wedging of the formation of the soil with the formation of a compacted zone along the periphery of the tip. In this case, the soil moves along the surface of the tip. The force acting on the tip in this case depends on the coefficient of friction of the soil over the metal. When the moisture content of the soil changes, this force will vary in magnitude. This will lead to instability and unreliability of the testimony of the hardness meter.

In Figure 4 b, a variant is presented when $\alpha_n> \gamma_0$. In this case, a compacted soil core is formed (as it were, sticking) on the surface of the tip.

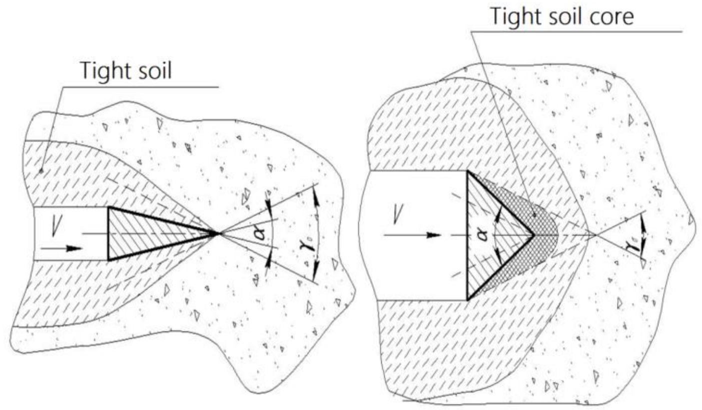
However, the soil core, supported by its base on the conical tip, is unstable. Periodically, it collapses, under the influence of large soil aggregates, and then forms again, this also leads to instability and unreliability of indications.

A third variant is also possible, in which $\alpha n = \gamma_0$. The formation of a soil compacted nucleus, as in the

ISSN: 0975-8585

first case, does not occur. In this case, there is simultaneous crushing of the soil and wedging. In addition, since the angle γ_0 varies over a wide range, this case will go either to the first or to the second variant.

Further, it is necessary to justify the geometrical arrangement of the tip and the possibility of protecting the plunger of the hardness meter.



a) b)

Figure 4: Scheme of interaction of soil with a nozzle depending on the angle at the apex: a – angle α_n less than angle γ_o; b – angle $i_n > \gamma_o$.

To do this, it is necessary to determine the force acting on the tip from the side of the soil when it moves horizontally. This force P_{load}, is formed due to the action on the frontal surface of the tip of the main stress σ_1 (Figure 1), taking into account the expression (10).

In accordance with the laws of mechanics, the force acting on the tip from the soil side

$$P_{load} = \sigma_1 S_n, \text{ N}, \qquad (11)$$

where S_n – area of the nozzle base, m^2.

For a round flat tip, the base area is:

$$S_n = \frac{\pi d_n^{\ 2}}{4}, \text{ m}^2. \qquad (12)$$

As a result, we obtain the value of the force acting on the nozzle:

$$P_{load} = \delta\, h^{\mu} \frac{\pi d_n^{\ 2}}{4}, \text{ N} \qquad (13)$$

To substantiate the constructive scheme of the hardness meter, it is necessary to solve the problem of the necessity of protecting the plunger 2 (figure 5) from the interaction with the soil. In the known hardness testers of vertical and horizontal action, the plungers are not protected and interact with the soil, which leads to significant errors in the measurements.

During the motion of the hardness meter, the soil acts on the upper and lateral surfaces (active surfaces) of the plunger. The arc of the circle surrounding the active surface is expressed by the angle α_s (Figure 6).

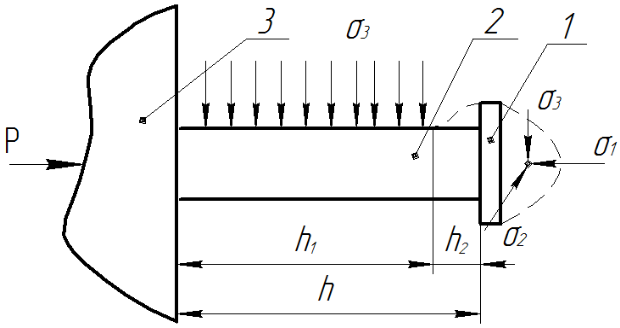


Figure 5: Scheme of active plunger surface formation

The frictional force of the soil on the surface of the plunger is determined by the formula:

$$F_{fr} = Nf \text{ , N} \qquad (14)$$

where N – normal force acting on the surface of the plunger, N;

$f = tg\varphi$ – coefficient of friction.

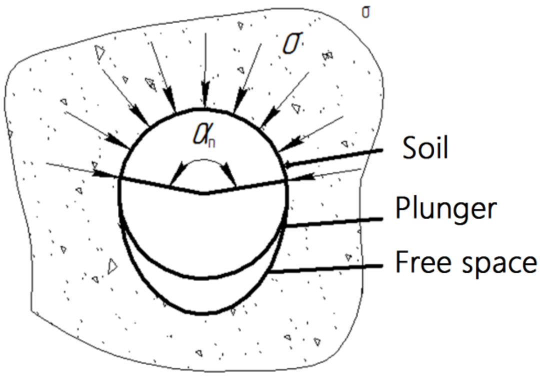


Figure 6: Cross-section of the active surface of the plunger

The force of normal pressure on the part of the soil is determined by the vertical stress arising from the soil's own weight with natural bedding [1]:

$$N = \sigma'_2 S \text{ , N.} \qquad (15)$$

The vertical normal stress σ_3', arising from the natural occurrence of the soil layers (since the soil layer has already been destroyed by the tip) is equal to:

$$\sigma_3' = \rho h \text{ , Pa} \qquad (16)$$

where ρ – soil density, g / cm^3;
h – depth of the location of the considered point, m.

The soil covers the plunger, both from the top and from the sides, where the magnitude of the stress has a different value. To account for the influence of the cohesion forces of soil aggregates *«c»* each other, the stress σ'_2 that occurs when the soil interacts with the plunger is determined. This dependence was obtained by Tokushev Zh.E. [2], from the Coulomb-Mora theory. After the conversion, it has the form:

$$\sigma'_2 = \sigma'_3 tg^2(45 - \frac{\phi_{in}}{2}) + 2ctg(45 - \frac{\phi_{in}}{2}) \text{, Pa} \qquad (17)$$

As a result of the joint solution of equations (14) to (17), we find that the frictional force acting on the active surface of the plunger on the part of the soil is:

$$F_{fr} = f\pi d_n \cdot \frac{\alpha_n}{360} \cdot \left(h - v\sqrt{\frac{d_н - d_n}{g}} \right) \cdot [\rho h \cdot tg^2(45^\circ - \frac{\phi_{in}}{2}) + 2c \cdot tg(45^\circ - \frac{\phi_{in}}{2})] \text{, N} \qquad (18)$$

Based on these results, we obtain the total force R measured by the hardness meter. It will be equal to the geometric sum of all the forces acting on the plunger and the nozzle:

$$R = P_{load} + F_{fr} \text{, N,} \qquad (19)$$

$$R = f\pi d_n \frac{\alpha_n}{360^\circ} \cdot \left(h - v\sqrt{\frac{d_н - d_n}{g}} \right) \cdot [\rho h \cdot tg^2(45^\circ - \frac{\phi_{in}}{2}) + 2c \cdot tg(45^\circ - \frac{\phi_{in}}{2})] + \delta h^\mu \frac{\pi d_н{}^2}{4}, \quad \text{N} \qquad (20)$$

The resulting expression is important because it allows us to determine the level of influence (in the form of a coefficient) of the frictional force on the reliability of the measurement. By the value of this coefficient it is possible to conclude that it is necessary to protect the plunger and the method of its constructive execution. Physically, this coefficient is a relative measurement error, it can be obtained by the formula:

$$k = \frac{F_{fr}}{R} \text{ ,} \qquad (21)$$

Taking into account the equations (18) and (20) obtained earlier, we obtain:

$$k = \frac{f\pi d_n \frac{\alpha_n}{360} \cdot \left(h - v\sqrt{\frac{d_н - d_n}{g}} \right) \cdot [\rho h \cdot tg^2(45^\circ - \frac{\phi_{in}}{2}) + 2c \cdot tg(45^\circ - \frac{\phi_{in}}{2})]}{f\pi d_n \frac{\alpha_n}{360^\circ} \cdot \left(h - v\sqrt{\frac{d_н - d_n}{g}} \right) \cdot [\rho h \cdot tg^2(45^\circ - \frac{\phi_{in}}{2}) + 2c \cdot tg(45^\circ - \frac{\phi_{in}}{2})] + \delta h^\mu \frac{\pi d_н{}^2}{4}}. \qquad (22)$$

As a result of calculations on this expression, using the average statistical parameters, it turns out that the error can be up to 30%. From this it follows that when the soil hardness is measured horizontally, it is not practical to use an open plunger, due to a high error.

The tip of the hardness tester with the plunger can be located inside the body of the hardness tester, or make it portable, but at the same time close it with a casing.

With the remote location of the tip and plunger, it is necessary to calculate the minimum distance to which the nozzle should be removed, so that it does not appear in the compacted soil zone, which is formed in front of a moving stand of the hardness meter (Figure 7). If the tip contacts or is in this zone, the instrument reading will be significantly distorted.

The tip removal distance can be found knowing the angle at the top of the cone of the soil kernel γ_0 obtained earlier.

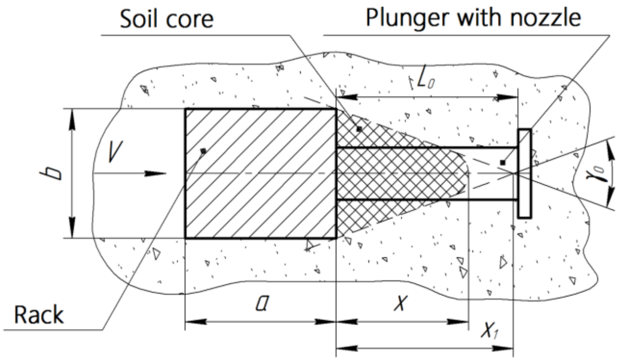


Figure 7: Scheme for determining the removal of the tip from the compaction zone

The height of the soil core is equal to X, (Fig. its apex is dulled, however, theoretically its height is higher (since there is a crushing of the soil even before the compaction zone). The total height of the seal is:

$$X_1 = \frac{b}{2\,tg\frac{\gamma_0}{2}}, \text{ m,} \qquad (23)$$

where *b* – width of the stand of the hardness meter, m.

To completely exclude the possibility of the tip entering the zone of compacted soil, the total distance L_0 must satisfy condition $L_0 \geq X_1$.

Taking into account expression (11), we obtain the final formula for determining the minimum distance of removal of the nozzle:

$$L_0 \geq \frac{b}{2tg\left[45^\circ - \frac{1}{2}arc\sin\frac{\delta h^{\mu} k_{\inf}(1-\xi)}{\delta h^{\mu} k_{\inf}(1+\xi)+2c}\right]}, \text{ m} \qquad (24)$$

CONCLUSION

On the basis of the theoretical studies, the following conclusions can be drawn:

1. When measuring the hardness of the soil, it is most expedient to use a flat, rather than a conical tip. Since this makes it possible to achieve the greatest stability of the compacted soil poison and the reliability of the measurement results. The parameters of the soil core depend on the parameters of the soil state and are determined by the expression (11).
2. An expression (13) is obtained that describes the magnitude of the force acting on the tip from the side of the soil P_{load}. This force, referred to the area of the tip section, is the measured parameter - the hardness of the soil.
3. The relative measurement error (22) is determined using an unprotected plunger. The results of the studies indicate the need to protect the plunger from contact with the soil.
4. The minimum distance (24) is determined on which it is necessary to arrange the tip to remove it from the zone of compacted soil.

REFERENCES

[1] Kulen, A. Modern agricultural mechanics / A. Kulen, H. Kuipers. - Moscow: Agropromizdat, 1986. - 349 p.

ISSN: 0975-8585

[2] Tokushev Zh.E. Technology, theory and calculation of tools for decompaction of arable and subsoil horizons of soil: Diss. Cand. tech. sciences. - M., 2003. - 215 p.
[3] Kanaev M.A., Mashkov S.V. Differentiated application of fertilizers during sowing: "Sel'skiy mekhanizator", Moscow: 2011 - № 7 - P. 22 - 23.
[4] Vasilyev S.I. Perfection of methods and technical means for horizontal measurement of soil hardness during the introduction of the technology of coordinate farming: Author's abstract. diss. Cand. tech. sciences. - Penza, 2007. -19 p.
[5] Mashkov S.V., Prokopenko V.A. Economic evaluation of agricultural machinery in the technology of crop production: monograph / S.V. Mashkov, V.A. Prokopenko. - Samara: RITS SGSKHA, 2010. - 160 p.
[6] Patent № 2608345 Russian Federation, IPC 8 G01N3 / 40. The device for horizontal continuous measurement of soil hardness / Mashkov S.V., Vasiliev S.I., Kotov D.N., Fatkhutdinov M.R. .; applicant and patent owner, the federal state budget educational institution of higher education "Samara State Agricultural Academy". No. 2015141164; claimed. September 28, 2015; publ. 01/17/2017, Byul. № 2.
[7] Gaius D. Eudoxie. Surface Hardness as an Indicator of Soil Strength of Agricultural Soils / Gaius D. Eudoxie, Dennison Phillips, Raymond Springer. // Open Journal of Soil Science, 2012. –S. 341…346.
[8] Patent № 2305267 Russian Federation, IPC G01N3 / 00. Device for continuous measurement of soil hardness / Vasiliev S.I., Nugmanov S.S. The applicant and the patent owner are the federal state budget educational institution of higher education "Samara State Agricultural Academy". No. 2005139670; claimed. 19.12.2005; publ. 27.08.2007, Bul. No. 24.