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Justification of running and perspective standards which will secure ploughed up soils against physical degradation

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The purpose. To justify the list and the contents of standards, capable to norm mechanical load on soil — the important cause of physical degradation. **Methods.** Field and office probes of influence of techniques and instruments of cultivation on physical properties of soils. On the basis of digitalized maps the squares of areas with degradation processes are calculated. **Results.** Destructure (formation of lumps and dust), augmentation of equilibrium firmness and negative transformation of pore space in ploughed up soils are the consequence of non-normed load of modern machine-tractor assembly units and instruments. The supervisory control of execution of the running standard of allowable pressure of road systems on soil, implementation and observance of new standards — that is an actual problem for adjustment of modern farming agriculture. **Conclusions.** Monitoring of physical properties of ploughed up soils and mechanical load during growing and harvesting crops should become obligatory. By use of standards it should be made impossible plastic deformation, formation of lumps, excessive crushing of soils, their overstocking in subseed layer and in plough base surface.

Key words: *physical degradation, admissible mechanical load, designs of the newest standards.*

In Ukraine (where agricultural technologies are characterized with elevated mechanical loading-pressure on soil and domination of intensive plough- cultivation traditions), agro-arable soils are prone to physical degradation (especially by soil-over-compaction, deterioration in quality of structural soil-aggregates; occurrence of heavy clods, crust and cracks in topsoil-layer, and formation of a dense plown-bed in the bottomsoil-layer.

Diagnostically, the soil-degradation is manifested by downgrade of structural morphology and porosity-space-texture; stable rise of steady-state density; decrease of inter- (and, especially, intra-) aggregate porosity; formation of preferential moisture-water flows (which is not typical to natural features of soil).

The major cause of physical soil-degradation is an excessive mechanical loading-pressure on soil-cover -surface, which makes recovery of required soil-structure parameters, properties and regimes near to impossible. Physical soil-degradation is followed by numerous negative eco-genetic and agro-productive consequences. In realm of soil-science and practice, a wide variety of methods to prevent and terminate this evil have been developed, but strength and scope of physical degradation intensity of proliferation still remain strong factors as yet.

Purpose of the study: to emphasize a necessity of adhering to the now-valid Standard on values of allowable loading-pressure on soil-cover by agro-machinery systems, and introducing principally novel standards that would limit the negative impact on soil by mechanical loading (as major factor of physical degradation spread-out in soils).

Objects and methods of research. Results of long-term field- and cameral- studies for structural composition and density; water-physical properties and certain other features of Ukrainian agro-soils (alongside the "Properties of Soils of Ukraine" database [1]) have been used. All parameters were measured by aid of standard and common-use research techniques. Authors used quantitative values and indicators of: soil-degradation, negative natural arable-soil- phenomena, and spread-out of degradation-affected arable land-areas, from materials of their previous studies and topical bibliography; and made corresponding calculations aground the digitized map sources [2].

Research outcomes. Generalization of Ukrainian arable soils' status per natural and machinery-caused negative aspects (Table-1) proves an actual urgency of resolute activities for rational use and protection of agro-soils.

Especially anxious is the state-of-matters in elaboration of soil-conservation standards. In fact, only a single one out of series of innovative Standards on permissible soil-loading had been approved in Ukraine [3]; but still today, it is regretfully neglected by the agro-practitioners.

1. Areas of soil-degradation phenomena- spread-out, and threats of their impact on fertile properties of Ukrainian arable soils

Indications of degradation or other threats/ risk to arable soil- properties	Quantitative threat characteristics	Spread-out area	
		a*	b*
formation of thick soil-lumps	> 10% >10 mm- sized lumps within tilth-layer	3.8	12.1
soil loosening down to dusty powder	> 10% to <0.25 mm-sized fractions	14.1	44.1
soil-abrasive plough-steel wear- loss	> 70 g/ ha metal-loss	6.9	21.6
soil-cover over-compaction	> 1.25 g/cm3 within tilth-layer	17.3	54.1
soil dispergation	> 8% per Kaczynski factor	5.8	18.1
deficit of productive soil- moisture in spring time	<20 mm in 0-20 cm soil-layer	6.9	21.6
deficit of soil- moisture during crop- plants' genesis	<100 mm in a 0 to 100 cm layer	21.3	66.6
deviation of soil-moisturization values from physical soil-maturity normatives	between >22% and <13% in spring time	9.5	29.7
critical shortage of time in spring season when amount of moisture is sufficient for soil to get crumbled into particles	<5 days	1.5	0.05
shortage of autumn moisture- supply time for optimal for soil-crumbling	<5 days	11.0	34.3
excessive values of specific soil-resistance to tillage/ plowing	> 0.6 kgf/ cm2	9.1	28.4
deficit in amount of agronomically usable soil- aggregates	<50 per cent of 10 to 0.25 mm-sized aggregates	14.1	44.1
very low index of soil- aggregates' water- stability	<40 per cent of >0.25 mm aggregates	8.4	26.2
very low total steady-state porosity index	<50 per cent in arable layers	11.1	34.7
(*) NOTES	***(a)* : upon degradation-affected land-areas (mio ha)*** ***(b)*: per cent of the total agro-land areal (over 32.000.000 ha)***		

Major criteria that were used to justify the now-valid standard, included:

• variation of physical soil-water properties under impact by mechanical pressure on soil-cover (because loading by heavy soil-tillage agro-machinery systems results in threats to structural- density and soil-aeration conditions);

• capability of compaction-affected soils to crumble into well-tillable particles (because pressure by heavy soil-tillage machinery results in critical amount of heavy soil-clods);

• depth of soil-compaction spread-out down the bottomsoil layer (because soil-compaction beyond the boundaries of arable layer is not admissible);

• depth of wheel-track sinkage into topsoil (which is harmful to the quality of sowing procedures);

• admissible loading pressure by heavy agro-machinery on soil-cover (whose value must: be equal to the sum of [soil-rupture-strength] + [soil-shear-resistance] factors, and avoid plastic soil-deformation impact (because soil discompation goes on very slowly (if any at all);

• factor of time required for soil to dispergate into required size of particles (because prior to every springtime seeding campaign, the compaction-affected soil-density must be re-conditioned back to its natural state).

Aground numerous field and laboratory model-studies for soil-loading-pressure and soil-moisture factors (whose parameters undergo gradual variation), a relevant novel Standard has been instituted officially (Table- 2).

2. Normative values of maximum admissible loading-pressure on arable soils of medium- to heavy- particles'size, structural density and soil- moisture indices being affected after every passage/ run by agro- tillage machinery

(a)*	Maximum permissible pressure-loading on [0 to 10 cm-thick] Soil-layer by agro- tillage machinery, kPa			
	In springtime		In summer through autumn	
	(b)*	(c)*	(d)*	(e)*
>0.9	40	50	60	80
0.7-0.9	50	60	80	100
0.6-0.7	60	100	120	140
0.5-0.6	80	120	140	180
0.4-0.5	120	160	180	210
(*) NOTES:	***(a) Soil moisture in minimally wetted soil-fractions within 0 - 30 cm-layer (b) at loose (<0.9 g/cm3) structure (c) at moderately compacted structure (0.9 - 1.0 g/cm3) (d) at moderately compacted structure (1.1 - 1.2 g/cm3) (e) at steady-state structure (1.2 - 1.3 g/cm3)***			

While analyzing the normatively-admissible soil-loading pressure-values, focus should be laid on urgency to prohibit involvement of the category of heavy soil-tillage machinery whose specific pressure on soil-cover exceeds values presented in Table-2 (especially in springtime, regarding the soil-layers compacted between loose and medium degrees); and anywhere else when amount of soil-moisture either complies with, or lags behind the soil- maturity stage.

This novel Standard, formulated with participation of Ukrainian soil-scientists and adopted officially in the USSR, was the first ever attempt in the world to limit values of mechanical loading-pressure on arable soil-cover [8]. In 2007, this Standard was revised, reedited and approved for service in Ukraine. In their studies, the Standard-developers noted that from a certain degree of soil compaction, its recovery back to inherently natural state goes on but too slowly, since the compacted soil- density remains stable for a long age ahead. This novel Standard is to eliminate any possibility of structural soil- bondage and intra-granular porosity- pattern decomposition, thus supporting the soil's ability to rejuvenate its agronomically usable structure. Moisture (that penetrates into soil-aggregates) enables a recovery of needed soil-structure and density parameters, owing to soil-volume-changes (caused by soil-drying or freezing), crops' root- system- genesis, and microbiological activity in soil).

The most imperative points of this Standard concern chernozems typical (as the most agronomically valuable soil species). Since this category is characterized with its best structure-aggregation capability, chernozems' pre-sowing density-values are usually minimal. Owing to this feature, chernozems are more readily prone to over-compaction than all other soil types. Hopefully, the agro-machinery designers and practitioners would reasonably comprehend and adhere to these novel agrotechnical requirements (alongside their fully argumented commanding style of formulation), and thus, would make every effort possible in quest for the most plausible design & technology solutions aimed at combat against the over-compaction phenomena that endanger the most precious Ukrainian agro-land assets.

To this end, relevant values of soil-admissible loading pressure are currently under discussion by soil-scientist in Germany, Netherlands, Sweden [4-10]. In these countries (plus Canada, USA and several others as well), the soil-practitioners operate their agro-vehicles of duplicated and even triplicated low-pressure pneumatic-tyre options.

Yet regretfully, this Standard could only restrict vertically-applied average loading- pressure values, whereas other kinds of soil-deformation that arise from the field-travel by heavy agro-machinery, were left over beyond attention. In particular, excessive deformation occurs through tractor-wheels spin-skidding in moist weather; soil-cover tear- scutch by sharp-edge tyre-tread-lugs; treatment of over-moisturized soils etc., whereafter thus damaged soil-cover can not recover back to normal state for a very long time. Due to non-uniform loading pressure-distribution over the field-surface, critical values of pressures imposed on soil-cover by wheeled agro-vehicles can amount to average 500 kPa. After all, even higher loading-rates (up to 800 - 1000 kPa) can occur due to contact pressure caused by plough-cutter and plowing-tools engaged in service after “Flat-Wedge” principle [2]. It is the very type of soil-cover loading- pressure that creates the heavy plown- bottomsoil bed and stone-dense soil-lumps.

Moreover, despite the exceptional importance of the Standard as a legal soil protection instrument, it has not become a full-power stop-degradation barrier as yet. Generally speaking, its effect is aimed actually at only would-be types of future agro-machinery to by designed, while today (and for many years ahead), a huge army of soil-treatment field-monsters has been missioned across the fields, whose specific loading pressure is by far in excess of the Standard-asserted normatives. That is why the definite urgent efforts to mitigate the impact on soil-cover by heavyweight tillage systems are urgently required today.

By the way, the soil-treatment technologies being in common use in Ukraine today, are mostly unable to comply with this Standard-positions, since in springtime seasons, the soil-treatment is executed almost completely by the wheel tractor park, instead of caterpillar haulers, at almost total absence of 2- or 3-tyre wheeled soil-treatment vehicles.

It's worth while mentionening that low-pressure pneumatic tyres made by the national Agro-Tyre Plant “Dniproshina” in Dnipro-city (intended specifically for spring-campaign operations) and such purpose agro-devices that would promise an ideal solution of the above problems, are regretfully still not popular among Ukrainian farmers.

Moreover, it is desirable to regulate officially values of summarized soil-cover loading-pressures by agro-machinery during crops' growing period. Attempts to continue the non-controlled traffic of field-treatment vehicles must be prohibited.

Calculations for ***summarized length of field-treks run across the whole crop-land by agro-machines a year***, multiplied by ***consolidated weight of_all agro-machinery systems engaged in routine soil-treatment operations***, may produce a convincible informative indicator of soil-oppression intensity.

3. Such an index could be expressed either as a [ton- km/ ha/ yr] formula or worded out via such descriptive assessment:

	Character of impact
<50	Weak
50 to 100	Permissible
100 to 150	Conditionally permissible
150 to 200	Non-admissible
>200	Absolutely non-acceptable

Compliance with this Standard is only possible under conditions that:

• ***a strictlly controlled order of agro-vehicles' traffic/ runs across the crop-fields shall be institutioned mandatorily;***

• ***a relevant field-traffic routing system shall be introduced; whereby efficiency of traffic-routing procedures must be proven by successful results in stop-degradation efforts; shrinkage of degradation- affected field-areas, and enhanced crop-yields' indications.***

Analysis of present-day technologies shows that only grain crops are grown fruitfully on fields of admittable soil-compaction values, provided that only light- and medium-weight tractors shall be used in spring field-work. Otherwise, the "dirty finger-prints" left over by soil-safety violators on fertile properties of soils and future harvest-yield rates, shall be inavoidable.

No less important is compliance with now-valid relevant Standard in relation to design of soil-tillage implement. Generally speaking, wedging pressure by soil- cutting-blade of such agro-purpose tools must never exceed the cohesive strength of agronomically usable-size soil-aggregates. Authors have analyzed lots of corresponding information on wedging pressure parameter, and revealed a wide range of its values' scatter in dependence on: genesis of soil, soils' granulometric composition and soil-moisture at tillage-period. However, values of wedging pressure on soil by cutting blade of present-day soil-tillage tools can vary between several kPa to several dozens, and sometimes come up to hundreds of kPa.

Such the overburden on soil-body becomes more noticeable with increase of angle of attack of the tiller cutting blade, especially with several such working blades in one unit altogether. Unfortunately, the creative vision of present-day soil-tillage machinery & tools' design engineers is driven ahead by an erratic assumption that soil is a solid (or a semi-solid) inert mass that can undergo physical deformation or cutting intrusion with no restrictions to worry. Since most of Ukrainian soils belong to the joint category of medium- to heavy-grain granulometric composition, there during physical soil-maturity period is no need for unnecessary cutting blade force application (because soil-lumps are loosening quite readily themselves). Under favorable soil-moisture conditions, soil-resistance to shear-failure (to be overcome by a routine soil-tillage cutter), typically does not exceed 1 to 3 kg/cm^2 depending on load, whereby coefficient of internal friction is 0.2 to 2.5 kg/cm^2, soil-granular cohesive strength is 1.0 kg/cm^2, and [soil-metal] friction- coefficient is in the range of 0.5 to 5.0 kg/cm^2. Above these values, physical properties of soils are subject to inevitable deterioration.

Thus conducted studies enabled authors to substantiate the purpose of certain future Standards that would restrict values of mechanical loading- pressure on soil; reduce probabilities of physical soil degradation, and optimize conditions for prolific genesis of all parts of crop- plants, in a manner that:

- values of angle- of- attack and quantity of cutting surfaces of soil-tillage tools (which induce contact-pressure on soil at cultivation process) **must correspond** to mechanical properties of agronomically usable-size soil-aggregates, such as: structural cohesion, texture strength, cohesion strength and resistance to shear-failure;

- a future Standard intended to determine data on force applied on soil by soil-tillage cutting blades **must not exceed** values of resistance to soil-crumbling and shear-failure resistance, at tillage of soil being at stage of physical maturity:

- a future Standard intended to determine data on force applied on soil either by field-vehicles' wheel-tyre tread-lugs, or by soil-tillage cutting blades, **must not exceed** values of soil-resistance to crush & squash forces;

- future regional Standards on normatives to admissible soil-moisture values **must take** in account types and granulometric composition of soils, in order to comply with optimal soil-crumbling pre-conditions at minimal guaranteed cost of resources for soil- cultivation;

- regional Standards on sub-seed layer-density **must envisage** crop plants' physiological needs to justify efforts required for eliberation of sub-seed soil-layer from compaction;

- regional Standards on values of soil-hardness in the plown bottomsoil- bed **must justify** the demand for soil- loosening;

- regional Standards on values of soil crust-strength parameters **must provide** for optimal selection of appropriate soil-crust-ruining agro- tools;

- future Standards on structural composition **must assume** for optimal ratio of agronomically usable-sized soil- aggregates within seed-layer in order to accelerate seeds' germination and crop-plant-roots' in-depth propagation;

- regional future Standards of optimal density of the seed layer structure **must take** in account type of soils, their granulometric composition and physiological crop -plant needs.

Conclusions

An importance of adhering to the Standard on admissible loading pressure on soil -coverby agro-tillage systems has been emphasized; and an urgency of mandatory introduction of innovative Standards has been substantiated.

Major sense of future Standards altogether is that after passage/run by soil-tillage vehicles across the cultivated fields, the soil-cover capability to recover back to its natural state must be maintained with no severe residual deformations that might lead to a long age of soil-cover rejuvenation.

An impact on soil-cover by soil-tillage tools must not exceed its structural stability limits.

Thus proposed measures shall promote a creative convergence between soil scientists, agronomists and agro-mechanical engineers in their outlook of the problem, and in solution of many existing challenges in their mutually fruitful relationship.

Account of actual soil-technological conditions at soil-tillage systems' design and future operation would undoubtedly contribute to ecologization of agro-industry that implies harmonization of soil - tools linkage-relations, and reduced threats of fertile soils' degradation due to agro-machinery involvement.

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