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FEATURES OF PHYSICAL DEGRADATION IN SOIL PLOUGHED UP

V.V. Medvedev, I.V. Plisko

NSC "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky"
(vvmedvedev@ukr.net)

As a result of research of 6 fields to Polissya, Forest-Steppe and Steppe of Ukraine are established attributes of physical degradation – blocks in a superficial layer and overcompaction in an arable layer and in plow pan. Physical degradation diagnosed in relation to the optimum, modal and maximum permissible parameters received accordingly in modelling experiences, on the basis of mass definitions and settlement way. The blocks is shown everywhere, that testifies to deterioration of process of structurization on an arable land. Overcompaction is shown at edges of fields and in their downturn where influence of running systems of mashine-tractor units more affects more often. Tillage of fields should be carried out on technology of precise agriculture as blocks and overcompaction in an arable layer and in plow pan have no continuous character.

Key words: *blocky, bulk density, physical degradation*

Introduction. General cause of the soils` overcompaction is the mechanical stress exceeding the soils` capacity of restoring their modal (most probable) parameters of the bulk density in equilibrium [14]. The typical heavy-loam chernozem compactized in autumn to the density higher then 1,3-1,4 g/sm^3 was not restored in the next spring, and that condition lasted for 6 years [20]. Cases are reported in publications when overcompaction lasted even much longer, that is for 10 or even 20 years [8, 30, 31]. Most of all the overcompaction is undesirable for the soil aggregates because it makes them impenetrable for the roots which diminish the soils live space at the expense of the in-aggregate porosity inside which the water-mineral plant nutrition is mostly being performed [10, 26, 27]. Also the increase in the inter-aggregate porosity observed at the same time accelerates aridization in spring [10, 16].

As a result of but small overcompaction the soil loses its capacity for adequate crumbling even in the physically ripe condition (18). In our opinion it was the overcompaction of the tilled soils that caused the widespread lumpiness on the ploughed-up fields. Some prognostic assessments esteem the part of general-cultivated land where the lumpiness exceeds the permissible rate of 30 % as 12 % of the tilled area in the country, while in case of the pre-sowing cultivation when the lumps must not exist at all 83 % of the tilled land have more or less lumpy surface [15].

Due to the deficient field soil-physical observations and consequent absence of direct proofs to the affect, the overcompaction and lumpiness of the tilled soils are underestimated in practice. The standard [7] that limits the tractor assembly carriage's soil pressure and runs number practically does not work though in was adopted in 2007 already. The agriculture machines` over-field "routization" is not in use while it allows reducing the overcompaction 2 or even 3 times [19, 28 and 29]. Also other overcompaction reducing techniques are not adopted in practice, including tire-coupling which became widespread over American continent and in Europe. It is only typical that in recently issued agriculture recommendations prepared by NAASU [21] practically none of the physical degradation reducing techniques are mentioned at all.

Object of this publication is to define the real signs of physical degradation concerning structure and bulk density inside the arable layer on the ground of the field researches on the six sites of long-termed tillage situated in the general nature zones of the country. The physical conditions will be assessed against the optimal values of corresponding characteristics which were obtained before through the modeling experiments [17], also against the modal characteristics taken from the soil database [9] and against the calculated limits [6]. Such use of several reference points for the soils comparison and assessment makes it possible, as we had shown, [13], to obtain more accurate a characterization of the present soil status and work out an efficient strategy for its amelioration.

Subjects and methods. General research method used in this work was the geostatic method. For this the elementary sites regular net has been laid in the field, every one of those 5x5 m in size. The sites were geopositioned for the coordinated sampling and yield registration. Measuring of bulk density in the arable and under-arable layers (the ring method, ring volume 100 sm^3, 5 replica) and penetration resistance down to the 35 sm depth (by Reviakin (*Ревякин*) method, plunger of the flat type, 10 replica), and soil water content at the same depths as bulk density (drying at 105 ^oC, 5 replica) and sampling for lumpiness were carried out in the field. Terms for the field works were 2-2,5 months after the last cultivation, that is in time to characterize the soil physical status in equilibrium [22, 17]. The crops yields were determined in the field, per 1 m^2, 5 replica.

Measuring of the lumps content (by Savvinov (*Саввинов*) method, 4 replica) and statistical and geostatistical data processing were carried out in the laboratory. The results of the processing which shows statistically significant varieties of the soils are reported in details in [11]. In this work main consideration will be given to the 2-D-diagramms analyzing and placing of the lumpiness and bulk density parametrical contours upon the fields under research. For the processing the standard program of Surfer and interpolation technique of Kriging were used.

For sizing the negative impact upon the soils structure and composition and their possible degradation the data obtained were compared with the optimal, modal and limit values as it was mentioned before.

As the subjects 6 fields were used, three of those situated in the Wooded District (Romaniv, Kolky, Vediltsy) and two in Forest Steppe (Korotych, Kommunar) and one in Steppe (Donetsk).

Romaniv. Volyn Region. In the soil cover the grey podzolized and, derno-podzolic and meadow gleyzated soils dominate. Relief is leveled. Texture is light loamy. Field size is 63 ha, 35 elementary sites. The crops are grains and fodder. The cultivating techniques are not differentiated in spite of the obvious inside-field diversity.

Kolky. Volyn Region. The soil cover is complex of the derno-podzolic gleyic and derno-gley and meadow-marsh soils. Relief is leveled. Texture is clayish-sand. Field size is 11 ha, 27 sites. The crops (outside the marshy part) are fodder. The field is drained with the open net of canals, partly out of use to our regret. Researches were carried out outside the marshy part only. Cultivating techniques are not differentiated throughout the field.

Vediltsy. Chernigiv Region. Derno-middlepodzolic loamy sand soils. Relief is leveled. Field size is 105 ha, part of the field grassed, number of sites on the un-grassed part – 117. The crops are grains and fodder.

Korotych. Kharkiv Region. Dark-grey podzolized hard-loamy soil dominates. Relief is slightly sloped. Field size is 31 ha. Sites number – 35. The crops are grains and fodder with cultivating techniques traditional for the Forest Steppe.

Kommunar. Kharkiv Region. Typical low-humus leached hard-loamy chernozem. Relief is leveled. Field size is 30 ha. Sites number – 26. The crops are grains and industrial.

Donetsk. Donetsk Region. Ordinary hard-loamy chernozem. Relief is leveled. Field size is 105 ha, the net of sites (51) were laid on the 50 ha area of the field. The crops are grains and industrial.

Of the results obtained before only those will be shown here which concerns spatial variability of the studied fields physical characteristic from which their average and high diversity follows (table 1)

1. Spatial variability coefficients of physical characteristics for soils of the studied fields

Field	Lumps in the surface layer	Equilibrium bulk density in the arable layer	Penetration resistance	
			arable layer	plough pan
Kolky	-	0,06	0,18	0,19
Vediltsy	0,64	0,05	0,27	0,10
Kommunar	0,70	0,05	0,16	0,14
Korotych	0,57	0,08	0,19	0,18
Donetsk	0,43	0,10	-	-

Results and discussion. The physical degradation means soils physical characteristics and regimes constantly getting worse with the consequence of losses in fertility and crops yield. In the draw of the National Standard of Ukraine [2] the physical degradation is proposed to be assessed through the agronomically efficient structure content, its water-tightness and bulk density in equilibrium. The rate of degradation is estimated as the rate of divergence of any of those characteristics from its initial or reference value. For example if the divergence of the bulk density in equilibrium is less then 10 % the degradation is considered absent. Every next 10 % means higher rate of degradation, and when the divergence is more then 40 % the degradation is estimated to be catastrophic. As the reference point the soil with its initial (before use) characteristics is implied, while the soil which has gained some new and worse characteristics after any period of use is considered degraded. It is significant that the new characteristics must be stable. In other words, the soil which is able to regain its natural physical characteristics cannot be termed degraded.

When assessing for degradation it is important to know those initial physical characteristics which are naturally inherent to the soil together with their possible changing with land use and also the soil's capacity of regaining its initial parameters or to fix them on some new level after the anthropogenic impact. The most adequate methodic approach would be to register the soil's status in the beginning of its use and monitor possible changes of the characteristics along with the use. In other words, the accurate diagnostics of degradation needs monitoring of the soil's status both on the virgin land and under cultivating techniques of varied intensity. Regrettably, this can not always be accomplished because the physical properties had been included neither in the large-scale soil survey nor in the fields' agrichemical certification, nor, as a rule, in any other survey of the soil cover. Practically, physical characteristics are not included in monitoring in the most part of the European countries, even in those where monitoring have a long history and high development – such as Germany and Austria and Sweden [13].

Besides, due to the fact of practically whole area of the Ukrainian soils being tilled out, it is difficult enough to find suitable virgin land for comparison. Because of this other approaches are necessary. For example, modal (the most frequently observed characteristics of soils physical status) may by found and used as reference levels. In other cases the initial observations over the soil may be useful. For example it is applicable when laying a field stationary. Testing of the soil in an artificially created condition under (as a rule) increased loads (that is modeling) is possible and in some cases very useful. This approach permits to obtain values of the inadmissible loads leading to the irreversible physical degradation of the soil. That is, for example, under very high vertical pressure imitating the soil pressure of the mobile agriculture assemblies' carriages [14].

In some cases it is necessary to assess the process opposite to degradation, namely the process of the soil cultivating, when the soil becomes better as a result of applying some ameliorating techniques. For this the key physical parameters in equilibrium must be found (usually those are the agronomically efficient structure, its water-tightness and bulk density) and compared to the ones optimal for the crops most widespread in the zone. The comparison will show how efficient the ameliorating techniques were and whether any other measures are necessary to hinder the soils physical degradation.

The important methodical point of revealing physically degraded soil is term of measurement, for both of the key agriphysical properties (structure and density) are dynamic characteristics. For this reason it is quiet necessary to measure them when in equilibrium that is approximately 0,5-2,0 months after the last cultivation. Regrettably, the time of the soils physical status equilibration is not yet studied enough. So the terms mentioned above are but rough. They are based on our researches only, which were carried out on the chernozems of various textures. A short time of soils equilibration (relaxation time) goes with the light soil texture, more prolonged period – with the heavy one.

So, the soil must be acknowledged as degraded when its physical characteristics are irretrievably worsened in comparison with its natural analogue or virgin land, or long time untilled layland (or renaturalized variety of the similar soil). When such comparable data is not available it is permissible (though for the rough assessment only) to use average characteristics of the similar tilled soil in the nature-climatic and agricultural conditions (modal parameters) similar with those of the reference point.

Using the approaches stated above, we determine here optimal, modal and maximum permissible levels of the soils physical characteristics concerning the fields of research. Only the comparison between the characteristics obtained and the real observed levels will render possibility to assess the soils present physical characteristics and their level of degradation or cultivation. To achieve that we use following data:

- optimal compactization characteristics are determined (or rather extrapolated) on the ground of the data of specialized small-site field experiments which we had carried out before [16]. From almost 90 of our experiments processed those are selected which were carried out on the soils similar to our fields and having same texture, though under headed grains (tables 2, 4 and 5);

- modal parameters of lump content in the surface layer, bulk density and penetration resistance both in the arable layer and in the plough pan are the average levels for corresponding depths obtained from measuring on the fields under research (table.3). For the reason that the clay-sandy and light loamy soils' lumpiness is negligible such fields were not taken into account;

- maximal permissible bulk density value is a calculated parameter obtained with regard to the condition that the soil air content must be less then 15 % while water content is on the most likely level for tillage, that is near 0,6-0,7 of the minimum soil water capacity (table 2,4,5);

- maximal permissible penetration resistance value in the arable layer (that is practically in the under-seed layer where it restricts the first roots' forming) as well as in the surface layer (where it restricts the seeds' shooting) and in the plough pad (where it restricts the roots' penetration into deeper layers, thus hindering crops' adaptation to insufficient water supply) is based on the great number of national and foreign publications including our ones, which are summed up in the book [13], (tables 4,5);

- maximal permissible lumpiness value is based on the requirements to the seeding layer [1], publications [3] and [4], (table 3).

The maximal permissible characteristics of the physical properties based on the air content 15 % and lumpiness 35 %, are extremely tight. As a matter of fact, such conditions restrict aerobic microorganisms activity, hinder mineralization processes and root nutrition, neutralize the advantages of the structurized soil completely [4, 6, 17]. So, such levels are rather to be hold as impermissible, and soil with such characteristics is to be estimated as degraded and put out of tillage altogether .

2. Optimal (under headed grains), modal in equilibrium and maximal permissible bulk density in the arable layer in soils of various texture

Density	Bulk density, g/sm^3 in soils of various texture		
	Sandy, clayish-sandy and light loamy (mostly soils of the Poles'e zone)	Light-, middle- and heavy-loamy (mostly soils of the Forest Steppe zone)	Heavy-loamy and light clay (mostly soils of the Steppe zone)
Optimal	1,35-1,45	1,10-1,25	1.15-1,30
Modal in equilibrium	1,50-1,55	1,10-1,30	1,20-1,35
Maximal permissible	1,65	1,35	1,40

3. Optimal, modal in equilibrium and maximal permissible content of lumps >10 mm in the seed (arable) layer of the fields under research (for the most widespread soils)

Field	Lumps content, %		
	optimal	modal	maximal permissible
Vediltsy	0 (5)	16,6	10 (35)
Kommunar	0 (5)	16,9	10 (35)
Korotych	0 (5)	18,3	10 (35)
Donet	0 (5)	22.6	10 (35)

4. Optimal, modal in equilibrium and maximal permissible bulk density and penetration resistance in the arable layer of the fields researched (for the most widespread soils)

Field	Bulk density, g/sm^3, and penetration resistance (in brackets), kgf/sm^2		
	optimal	modal in equilibrium	maximal permissible
Kolky	<1,45 (<20)	1,47 (21)	1,65 (20)
Romaniv	<1,35 (<20)	1,19 (18)	1,60 (20)
Vediltsy	<1,40 (<20)	1,40 (23)	1,60 (30)
Kommunar	<1,25 (<20)	1,30 (21)	1,35 (30)
Korotych	<1,25 (<20)	1,31 (11)	1,35 (30)
Donetsk	<1,30 (<20)	1,16 (-)	1,40 (30)

5. Optimal, modal in equilibrium and maximal permissible bulk density and penetration resistance in the plough pan of the fields researched (for the most widespread soils)

Field	Density, g/sm^3, and penetration resistance (in brackets), kgf/sm^2		
	optimal	modal in equilibrium	maximal permissible
Kolky	<1,45 (<30)	1,49 (32)	1,50 (40)
Romaniv	<1,40 (<30)	1,38 (29)	1,40 (40)
Vediltsy	<1,45 (<30)	- (39)	1,45 (40)
Kommunar	<1,30 (<30)	1,27 (37)	1,35 (40)
Korotych	<1,30 (<30)	1,50 (24)	1,35 (40)
Donetsk	<1,30 (<30)	1,36 (-)	1,30 (40)

When comparing the modal values of physical characteristics to their optimal and maximal permissible values, the most unfavorable situation is obviously the one concerning lumpiness. Though lumps under sowing are not permissible at all, they are present in great quantities on every field. Also the fact must be emphasized of the modal bulk density on the 3 fields of 6 exciding the optimal level, which is known to limit the use of the minimal tillage technique. Moreover, that last circumstance affects even the chernozems on which the possibilities of minimization are considered the greatest [22]. But the most alarming is the proximity of the modal values on the part of the fields to the maximal permissible ones, because (along with the obvious signs of lumpiness) it reveals clearly the unfavorable tendency of the soil-formation processes in the soils of long tillage with most possible development of the physical degradation.

Now on the ground of the spatial observation of lumpiness and density and penetration resistance upon the fields under research and also of the 2-D-diagrams obtained as a result of the geostatical processing (as shown in the publication [11]) and assessment parameters shown in the tables from 3 to 5 we shall find those areas of the fields where the real parameters exceeds optimal or modal or maximal permissible levels (table 6). It appeared that the contour areas where parameters exceed optimal and modal values are large. It is but those areas where the levels are higher then maximal permissible ones that are mostly insignificant.

6. Contour areas inside the fields researched where the parameters exceeds optimal or modal or maximal permissible levels of the physical characteristics

Fields	Content of lumps >10 mm in the surface layer after tillage		Bulk density in equilibrium inside the arable layer		Plough pan			
					bulk density		penetration resistance	
	ha	%	ha	%	ha	%	ha	%
Exceeding optimal values								
Kolky	-	-	6	55	8	77	11	100
Romaniv	-	-	4	6	2	3	51	81
Vediltsy	2	2	14	13	-	-	96	91
Kommunar	5	16	3	91	-	-	28	93
Korotych	0,3	1	22	71	-	-	5	15
Donetsk	49	97	1	2	38	77	15	30
Exceeding modal values								
Kolky	-	-	5	46	5	47	6,2	56
Romaniv	-	-	2	3.5	15	24	24	38
Vediltsy	45	43	45	43	-	-	65	62
Kommunar	12	39	8	27	-	-	15	49
Korotych	14	45	14	44	-	-	16	52
Donetsk	22	45	24	48	32	63	18	37
Exceeding maximal permissible values								
Kolky	-	-	0	0	5	47	0	0
Romaniv	-	-	0	0	13	2	0,3	0,5
Vediltsy	0,2	0,2	0	0	-	-	60	57

Kommunar	1.2	4.1	2	6	-	-	3	10
Korotych	0,2	0,5	4	12	-	-	0	0
Donetsk	0,3	0,6	1	2	8	15	6	10

We are inclined to think that on the part of the fields where real physical characteristics of the soils exceeds the modal ones such processes are developing which may lead to the physical degradation. As for the part of the fields where physical characteristics exceeds the maximal permissible ones, there the physical degradation is undoubtedly present already. Moreover, when comparing modal parameters of physical properties of those soils (at least of the chernozems which are deeply studied in this aspect) to the similar parameters on the virgin land [14], the statement concerning partial degradation of the fields under research becomes even more substantiated. Significant areas (57 % that is 60 ha) with penetration resistance exceeding maximal permissible values in the Vediltsy field are accounted for by the layer being not a plough pan already but a beginning of a very hard illuvial horizon. At such a place the deepening of tillage is exceedingly undesirable, and if it is unavoidable the evolving of the horizon inside the arable layer must be accomplished along with some suitable complex of ameliorative measures only.

It must be emphasized that the statement on the degradation of some of the fields is rather hypothetic, for we dispose of no prolonged observation data and therefore have no ground to claim stability of the obtained parameters. Probably, those fields would be more correctly called temporary degraded. For some cases are known when renaturalization of such fields or putting them under constant grassing leads to restoring their characteristics back to virgin land [14].

If we attempt to make an integrated assessment of soils' physical degradation on the fields under research then according to S.A. Baliuk (С.А. Балюк) et al. [2] it may be called low or temperate. Most probably that parts of the fields must be taken as degraded the parameters of which lays between modal level and impermissible one. However, that uncertainty can be removed by more researches only. Therefore we state once more that in the absence of prolonged after-effect research results the physical degradation found here is to be more correctly assessed as temporal one.

When analyzing the spatial distribution of physical characteristics upon the fields under research on the 2-D-diagrams combined with the topographic maps, our attention was attracted by the fact of the density and penetration resistance of arable layer changing regularly along with the height of the place and technical details of the machine/tractor operations. The data were divided into 3 following groups:

- on the elevations of the fields;
- at the brim where the tractor assemblies accomplish roundabout turns and loading and reloading of the seeders' or fertilizer-applicators' or combines' bunkers;
- on the hollows upon the fields.

The results of the analysis are shown on the table 7. It distinctly shows the characteristics of density and penetration resistance in equilibrium increasing at the brim of the fields and in small hollows. Besides, in small hollows density and penetration resistance increase even against those of the fields brim. The cause seems obvious: the greater number of the machine/tractor assemblies' runs in the first case and again the carriages pressure under impact of the higher moisture in the other. For the height divergences causing moisture varieties were significant enough on all the fields under research. For example in Romaniv it was up to 10 m, on the other fields – 6-8 m.

7. Bulk density and penetration resistance in various parts of the fields under research

Field	On the elevations of the field		On the brim of the field where machine/tractor assemblies turn		In the small hollows	
	density, g/sm^3	penetration resistance, kgs/sm^2	density g/sm^3	penetration resistance, kgs/sm^2	density, g/sm^3	penetration resistance, kgs/sm^2
Kolky	1,35	16	1,60	24	1,52	27
Romaniv	1,15	15	1,25	22	1,30	26
Vedivtsy	1,25	20	1,42	28	1,47	31
Kommunar	1,20	23	1,36	26	1,40	27
Korotych	1,20	15	1,35	20	1,46	18
Donetsk	1,05	10	1,25	14	1.30	14

The spatial variability of the density and penetration resistance is the cause of the yield variegation over the field [23-25]. The features of the yield data variability on the fields under our research had been analyzed before [11]. Here we stress the point of the physical characteristics being the cause of yield variegation, those including lumpiness, density and penetration resistance. That is confirmed with the data shown in the table 8.

8. Coefficients of the binary correlation between the crops yield and the soils physical characteristics

Soils characteristics	Soil layer, sm	Correlation coefficient
Lumps content	0-10	- 0,57
Bulk density	0-5 10-15 20-25 30-35	- 0,68 - 0,70 - 0,60 - 0,48
Penetration resistance	0-10 10-20 20-30 30-40	- 0,79 - 0,77 - 0,70 - 0,64

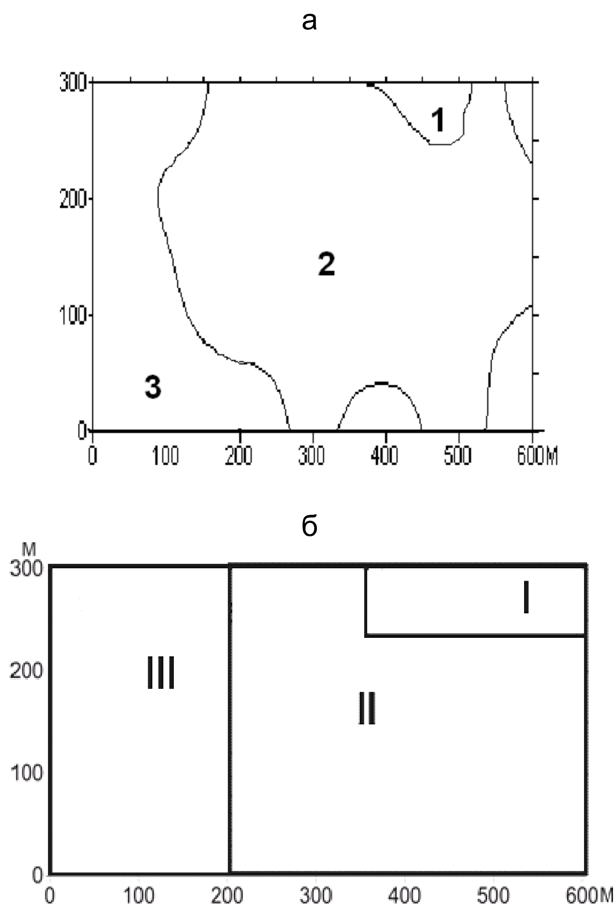
Of course, such a distinct variegation throughout the fields in the form of regular change of lumpiness and density and penetration resistance all of those being quite soundly looked upon as the indices for the type and intensity of agriculture technique required [11] shows necessity for a spatial differentiation for that technique. Such fields must be a subject of the accurate agriculture for which the economic and soil-protection advantages are proved by foreign and national practice [12].

Our data concerning the features of the soils' physical characteristics modal levels in comparison with its' optimal and maximal permissible ones give ground for parcellization (dividing into small parts) fields to apply variegated agriculture techniques. Where lumpiness is absent while density meets approximately the requirements of the crop and penetration resistance does not exceed the permissible level for roots growing and seeds concurrent shooting no technique is really necessary as the Latin America countries' experience [12] have successfully demonstrated. V.P. Gordienko (В.П. Гордиенко) et al. [5] had shown a possibility of managing without any pre-sowing treatment in such a case too. On the contrary, at the parts of the fields where the characteristics are worst the agriculture technique must be applied according to every zonal recommendation with indispensable combining the treatment with other ameliorating techniques. Lastly, where the modal characteristics are dominating the minimalization of general treatment is possible (table 9).

9. The percentage of areas with pre-sawing treatment varied in accordance with the spatial features of the soils physical characteristics upon the fields under research

Field	Area, %		
	Treatment technique		
	no treatment (direct sowing)	minimal general	zonal treatment + soil amelioration techniques
Vediltsy	10	50	40
Romaniv	60	30	10
Kolky	25	40	35
Korotych	50	40	10
Kommunar	70	25	5
Donetsk	75	22	3

Here the proceeding is shown for the choosing of the soil treatment with the Kommunar field as an example. Depending on the lumpiness in the surface layer the number of hoeings is determined (fig.1). According to the calculations using MapInfo program 2,6 % (0,8 ha) of the field need no pre-sowing treatment or after-plough hoeing while 71,8 % (21,5 ha) need pre-sowing hoeing and 25,7 % (7,7 ha) need both intense pre-sowing and intense after-plough hoeing. For the convenient technical operations the sites must be separated out inside the field (fig.1б).



1(I)- lumpiness <5 %, no need in pre-sowing tillage or after-plough hoeing;

2 (II) – lumpiness 5-20 %, pre-sowing hoeing is needed;
3 (III) – lumpiness >20 %, intense pre-sowing hoeing is needed as well as the after-plough one.

Fig.1. Lump content in soil of the Kommunar field after tillage:
a) after combining the contours according to standards;
b) after straightening the contours

Conclusions. With the use of the method of overlaying by net of elementary sites the spatial variability and also modal and optimal and maximal permissible values are found for soils lumpiness, bulk density and penetration resistance on the six soils of the Wooded District, Forest Steppe and Steppe of Ukraine.

The soils physical characteristics parameters upon part of the fields exceeds the modal and maximal permissible levels which gives ground to assert the development of the physical degradation processes or the presence of the physical degradation already developed. Soils physical degradation is placed with the brims of the fields and with the hollows; it affects the crops yield significantly.

The use of the characteristics under research as guides for choosing the soil treatment technique and intensity gave possibility to accomplish parcellization (dividing into small parts) of the fields and to ground the fields use techniques differentiation according to the concept of accurate land use.

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