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Abstract

EFFECTS OF CULTIVATION ON CLOD FORMATION OF SOILS AND ENERGETIC RELATIONSHIPS IN BREAKAGE OF CLODS

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1. INTRODUCTION AND AIMS OF RESEARCH

If profitability of plant cultivation and protection of environment is to be ensured one has to strive to preserve or possibly to increase the fertility of soils as well as to decrease the limiting factors of fertility by reasonable use of soil.

The "quality assurance" in the soil cultivation is rather problematic even if all the necessary knowledge and technologies are available.

During the growing season several factors should be available simultaneously to be able to ensure the best soil conditions for the produced plants without having too serious soil degrading side-effects.

It can be stated that both from the side of soil and from the side of the tool optimum conditions are needed if the farmer wants excellent results from the cultivation or from the whole cycle of production.

The good workability depends on soil conditions and among them the humidity content of soil. It is known exactly which tool of tillage offers good quality work at which soil cohesiveness and humidity range.

In general the humidity content of the cultivated layer of soil is lower at the end of summer and in autumn than the tillage optimum, or more exactly the interval of optimum tillage is very short. On heavy soils the drying causes the increase of soil resistance, therefore on such soils the quality of autumn seedbeds does not correspond to the demands. The problem is aggravated by the intense clodding which results in the increase of number of tilling processes and as a result the increase of energy demand. In such a situation the traditional tilling technologies and equipment should be reconsidered as the otherwise well-utilizable tilling technologies may not offer the same quality in case of drier, more droughty weather. We have to pay much more attention to the preservation of humidity, i.e. to the prevention of drying of soil, not depending on the development of other technological elements.

A possible way of adaptation is to introduce such soil tilling processes and technologies which ensure confirmably safe production even besides drier climate (minimum tillage, row-tillage, no tillage, dry farming and other methods). The development of equipment may be another way of solution. The work quality of our tilling machines is strongly dependent on the soil quality. By the change of the construction parameters and structural solutions it is possible to reach that the tools would ensure good quality work even in case of lower humidity content, or – if the dry cultivation cannot be ensured by traditional tools – new solutions should be elaborated.

Several studies were carried out for the identification of problems of seedbed preparation and for the disclosure of reasons and possibilities in some farms around town Szarvas. The results of cropland analyses urged the studies on the theoretical questions of clod breaking and the energy balance of tilling machines in more details. Finally I have started to construct a new tool which demands low amount of energy and offers good work quality in dry conditions as well.

The aims of research were the following:

- Justification of actuality of the research subject by surveying the foreign and Hungarian technical literature with special respect to the economical use of energy and the soil saving cultivation methods and implements.
- Evaluation of clod breaking effect of traditional soil cultivation methods on the basis of the main physical effects resulting in breakage.
- Comparison of clod forming effects of primary tillage and soil cultivating implements on the basis of literature data and results of clod fraction analyses in croplands carried out mainly on heavy, dry soils.
- Elaboration of the testing method of clod breaking, as well as determination of breaking energy for soil clods of different humidity content, cohesiveness and diameter.
- Studies on the principle of forced clod breaking, determination of theoretical relationships and design basic data.
- Completion of the experimental tool functioning on the principle of continuous forced breaking, and elaboration of method of measurements needed for the exact determination of specific energy demand of clod breaking, as well as construction of the measuring system.
- Determination of specific energy demand of compulsory clod breaking for soil samples of different cohesiveness and humidity content, as well as research on quality of forced breaking and functional suitability of the experimental tool.
- Evaluation of results of measurements by the methods of mathematical statistics, and identification of relationships between the studied parameters.

2. MATERIALS AND METHODS

2.1. Cropland investigations

As it is known the reasons of clod formation are manifold. The most important ones are the structure and cohesiveness of soil, its humidity content at the time of tilling as well as the applied soil cultivation tools, thus my studies have been focussed on these influencing factors. The direct aim of the studies was to determine the characteristic clod size (characteristic clod diameter, D_j) and the distribution of clod fraction after applying different soil cultivation processes on the soils of clayey loam (Arany's number of cohesiveness, K_A = 43-50) and clay (K_A = 51-60) which are characteristic in the region of Szarvas. Based on the mentioned characteristics the process can be followed, and having the data the results of a planned seedbed preparation technology can be forecasted.

On the selected plots 10 samples were taken on each measuring point from the upper 10 cm layer after the tillage processes, and photographs were taken about the soil surface chosen by random selection by using a 1 m^2 frame of 10 cm marking.

For determination of the characteristic clod diameter the following relation was applied:

$$D_j = \frac{\sum_{i=1}^{n} (n_i \cdot D_i)}{\sum_{i=1}^{n} n_i} \quad [mm]$$

where

n_i - mass percent of clod fraction i

D_i – average diameter of clod fraction.

2.2. Studies on clod breaking

The aim of clod breaking studies was to determine the breaking force demand of clods characteristic to the soil conditions after the primary tillage in the humidity range utilizable for cultivation. In the course of the measurements the actually needed breaking force and the breaking energy values were determined, based on which it was possible to define the breaking energy of soil cultivating machines. This latter energy is surely higher as the cultivation machines – based on their operation principle – cause smaller or bigger deformations of soil which occur together with energy absorption. After recognizing these two kinds of energy my purpose was to characterize the efficiency of soil cultivating tools.

Before the analyses clod samples were taken from the upper 0-20 cm cultivated layer of the soil (20 samples at each sampling point). The analysed diameter of clods was between 15-65 mm. The clod samples were taken by such a way that they would represent as various humidity contents as possible. After finishing the taking of samples the cohesiveness and soil humidity of clods were determined by the well-known methods.

The energetic measurements were carried out by the help of the clod breaking tool prepared exclusively for this purpose and by applying two different methods (**Figure 1**):

a. by rigid support of clods and
b. by clods embedded in the soil simulating the conditions of the natural clod breaking.

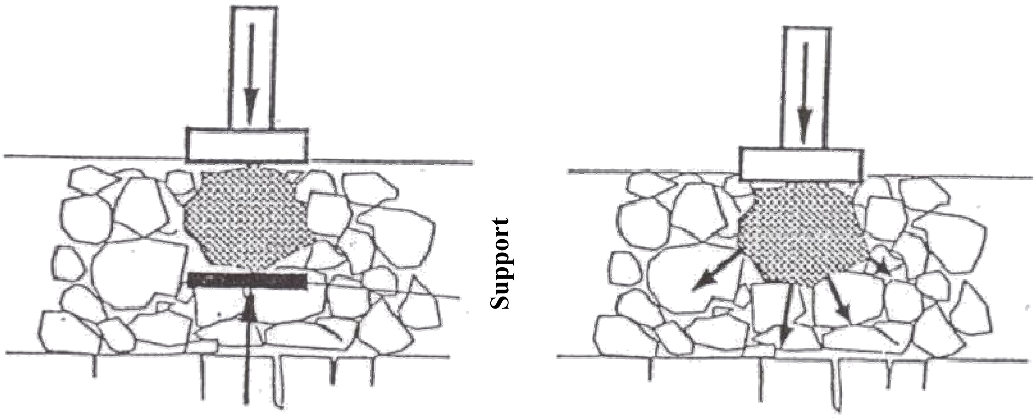


Figure 1 **The two methods of clod breaking for the determination of breaking energy**

The clod breaking tool records the changes in the breaking force as a function of deformation, or more exactly draws the diagram of breaking which makes possible the definition of the total energy demand of clod breaking.

2.3. Studies on the experimental tool working on the principle of forced breaking

2.3.1. Structure and operation of the experimental tool

The experimental tool was constructed on the basis of theoretical relationships and considerations described in paragraph 3.3 (**Figure 2**).

The two main parts of the tool are the feeder and the breaking unit (**Figure 3**).

Figure 2 **Structure of the experimental device**

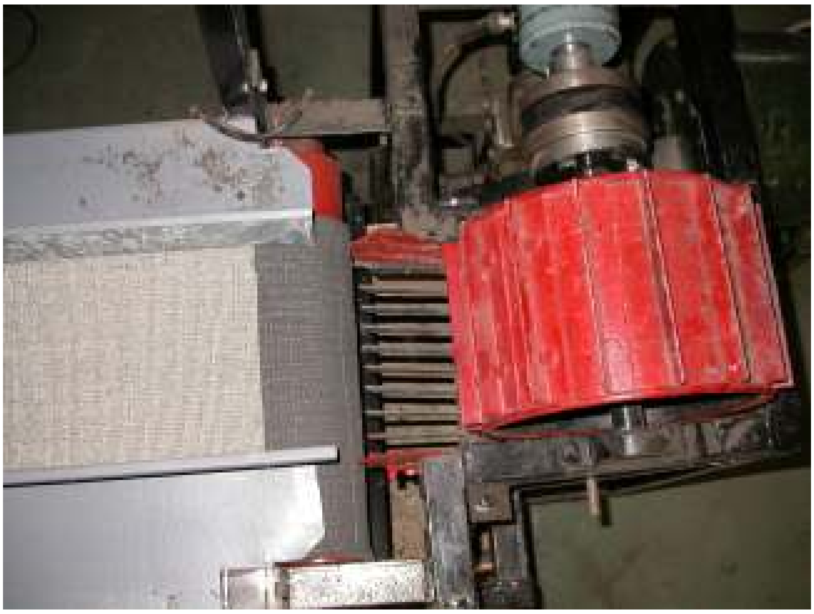


Figure 3 **Parts of the feeder and the breaking unit**

Main technical data:

Breaking unit:

- Diameter of breaking drum: D = 7 0.32 m
- Number of teeth: k = 16
- Height of teeth: z = 20 mm
- Peripheral speed of breaking drum: v_k = 1.68 m/s

- Revolution number of driving engine: n_m = 1428 l/min
- Inlet of breaking channel: h_1 = 120 mm
- Outlet of breaking channel: h_2 = 25 mm
- Angle of breaking grid: $\alpha = 15°$
- Grid spacing: a = 15 mm

Feeding unit:
- Revolution number of driving engine: n_m = 940 l/min
- Speed of conveyor belt: v_{sz} =1.4 m/s
- Length of conveyor belt: l = 1.4 m
- Width of cradle feeder: b = 200 mm

2.3.2. Method and course of analyses

- **Collecting samples**
  The soil samples needed for he energetic analyses were collected in farms around Szarvas and Békésszentandrás in the end of summer and in autumn of the year 2003. The samples were always taken from the upper 10 cm cultivated layer of the soil. Each sample weighed 25 kg.
- **Determination of Arany's cohesiveness and humidity content:**
  The cohesiveness of soil samples was determined by the well-known method. The samples of identical or very similar cohesiveness were grouped generating five classes of cohesiveness. Each class contained six samples of the same cohesiveness, while the humidity content of samples was identified starting from the air-dry condition (w = 5 mass %) to w = 22 mass % increasing it gradually. The wetting was carried out by spraying of water onto the extended samples watching the uniformity and distribution of water intake carefully.
  Table 1 demonstrates the serial number and humidity content of soil samples in each class of cohesiveness.

Table 1

Serial number and humidity content of soil samples in each class of cohesiveness

Number of samples	Humidity content (mass %)				
	I. $K_A = 36$	II. $K_A = 42$	III. $K_A = 46$	IV. $K_A = 49$	V. $K_A = 52$
1.	5	5	5	5	5
2.	10	10	10	10	10
3.	13	13	13	13	13
4.	16	16	16	16	16
5.	19	19	19	19	19
6.	22	22	22	22	22

- **Analyses of clod fractions**

  The clod fraction analyses were carried out both before and after the breaking. The aim of this work was to determine the new surface formed in the course of breaking.

  For the purpose of these analyses a set of screens has been made ($d_1>10$, $d_2>6$, $d_3>4$, $d_4>2$, $d_5>1$, $d_6>0{,}5$ and $d_7<0{,}5$ cm) creating seven different classes of diameter.

  The masses of each class of diameter were weighed and the total surface of each sample before breaking ($A_ö$) and after breaking ($A_ö$) was calculated by the use of the following equations:

- Total surface (cm^2) of fraction of n_i samples:

$$A_i = \frac{6 \cdot m_i}{\rho \cdot d_i} \quad \left[cm^2\right]$$

where m_i – mass per fraction (gr)

ρ – density of soil (gr/cm^3)

d_i – characteristic diameter of the fraction (can be calculated from the set of screens)

- Total surface before breaking:

$$A_ö = \sum_{i=1}^{j} A_i \quad \left[cm^2\right]$$

where j = number of fractions

The total surface after breaking can be calculated by the same method.

- The new surface formed in the course of breaking:

$$A_u = A_{ö}' - A_{ö} \quad \left[cm^2\right]$$

- **Energetic measurements**

  The breaking of prepared samples and the energetic measurements were carried out by the use of the experimental tool. The units of the measuring system (torque meter, signal oscillator of revolutions) register the momentary values of force and revolution number by a signal frequency of 50 Hz.

  The voltage signals of torque meter and tacho-dynamo are collected on the data collection unit of a measuring computer through a connecting panel. The further processing of data was carried out by the help of a computer.

  Based on the force - time diagrams the average values of force and number of revolutions were calculated, and the breaking times were read (Δt).

  On the basis of the collected data the following calculations were made:

- Performance needed for breaking:

$$P = \overline{M} \cdot \overline{\omega} = \overline{M} \cdot 2\pi \cdot \overline{n} \quad [W]$$

where $\overline{M}$ - force average of breaking drum (Nm)

$\overline{n}$ - average of revolutions of breaking drum (1/s)

- Energy needed for breaking:

$$E = P \cdot \Delta t \quad [J]$$

where Δt - duration of breakings (s

- Specific energy demand of breaking:

$$E_f = \frac{E}{A_u} \quad \left[\frac{J}{m^2}\right]$$

where: A_u - the new surface formed in the course of breaking (m^2)

3. RESULTS OF STUDIES

3.1. Results of cropland analyses

The severe lack of rainfall before the period of measuring and the drought connected to it resulted in such a drying of soil that there was no significant difference in the humidity content in the cultivated layer.

On the border of the cultivated layer (25-28 cm) we could measure 10-12 mass %, while on the soil surface 5-8 mass %, therefore the soil humidity as an influencing parameter could be neglected concerning the effects of different processes.

In **Figures 1 and 2** the results of analyses of soil surface clod fraction distribution are demonstrated after four different cultivation processes. However these are only accidentally chosen data, they demonstrate the regional conditions very well.

The clod fraction structure of soil surface after ploughing (**Figure 4**) has shown relatively favourable results (D_j= 110-120 mm) even on clay soils (K_A= 50-52). It can be explained by the fact that in the course of drying of soil the decrease of volume is accompanied by the severe cracking of the soil layer, thus the breaking force of the plough can get on as a result of large number of micro-crackings.

After disking with a heavy disk-harrow the characteristic clod diameter was 81 mm. The harrow plates crumbled only the clods bigger than 100 mm diameter. Because of the low humidity content the crumbling was minimal.

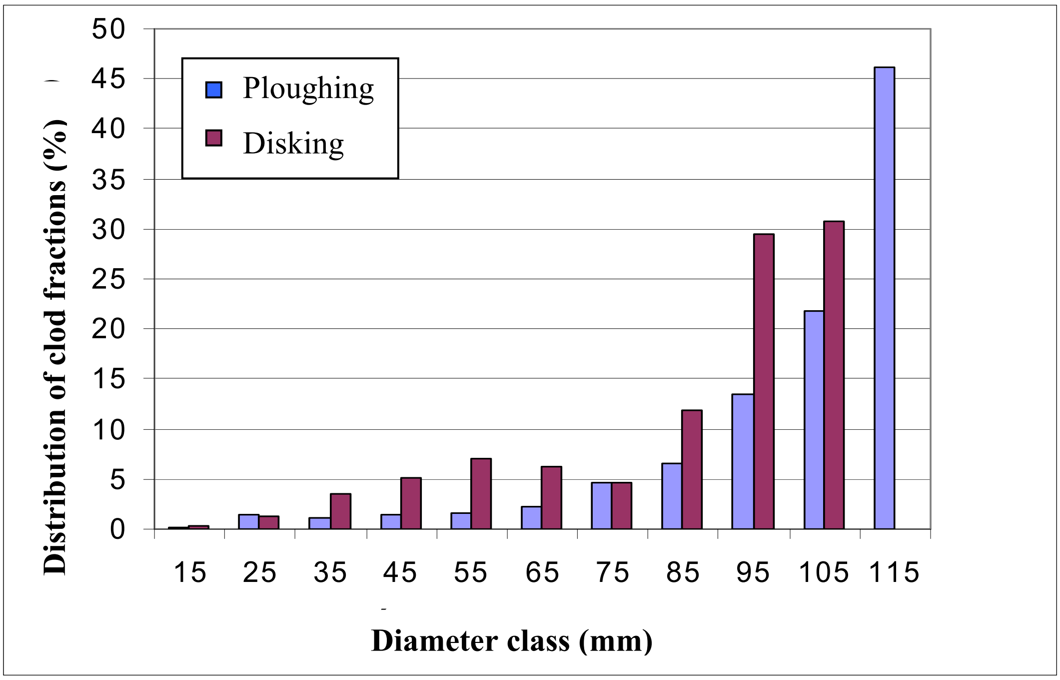


Figure 4 **Distribution of the surface clod fraction after ploughing and disking**

Table 5 demonstrates the clod fraction distribution after the second and third passes of seedbed preparation carried out by a heavy cultivator. The characteristic clod diameter after the second pass is 55 mm, while after the third pass it is about 37 mm. The size of most of the clods was between 25-55 mm, and significant difference was found only between the bigger size grades.

The clod fraction distribution after the third pass of seedbed preparation is characteristic to the heavy soils in the given conditions. On the basis of these analyses it can be stated that more favourable seedbed cannot be made by the traditional tools and by the increase of number of passes. The rough composition of the surface layer influences the quality of sowing, the germination and the initial development of plants unfavourably.

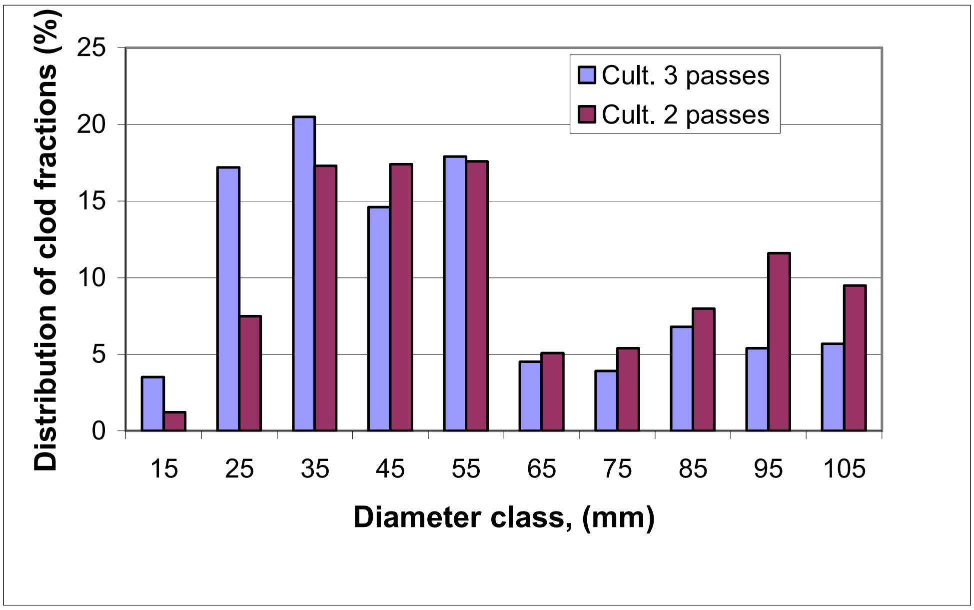


Figure 5 **Distribution of surface clod fractions after preparation of seedbed with heavy cultivator**

3.2. The results of clod breaking analyses

Figure 6 shows the breaking diagrams of clods originating from a medium heavy (K_A = 43) and a heavy soil (K_A = 57) at different humidity contents. The experiments were carried out by using supported clods.

In the figure it is visible that the heavier clods are crashed as an affection of a bigger breaking force and the deformation phase is longer than in breaking of less heavy clods. Accordingly the energy demand under the curves will be bigger for every humidity content.

Based on the breaking diagrams it also can be stated that the conditions of breaking improve if the humidity content increases.

In case of w = 22 mass % humidity content the energy needed for breaking is 2.5 - 3 times lower than in dry clods containing w = 5 mass % humidity.

If the clod breaking experiments are carried out with clods embedded in the soil, the development of the deformation zone needed for the supporting makes the breaking diagram protracted.

Thus the energy needed for the clod breaking ($E_Á$) will be 2.5 – 3 times higher – depending on the cohesiveness and the humidity content - than the energy value measured at the rigid support.

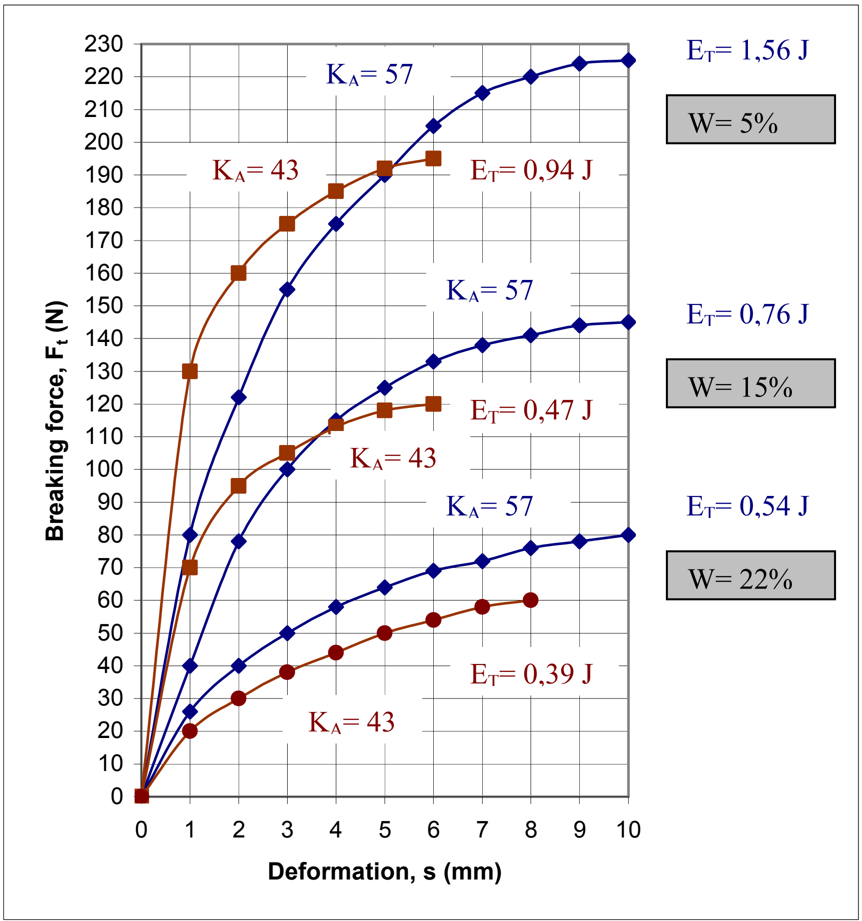


Figure 6 **Breaking diagram of supported clods**

In **Figure 7** the breaking diagrams of clods originating from heavy (K_A = 57) and medium heavy (K_A = 57) soils of w = 5 and 22 mass % humidity content are shown together with their breaking energy values ($E_Á$).

The energy demand – humidity content functions were determined for the clods of diameter D_j = 50 mm which was the most characteristic size after the preparation of the seedbed

(**Figure 8**). As a result of the regression analyses close positive connection was found between the studied parameters which can be described by a power function.

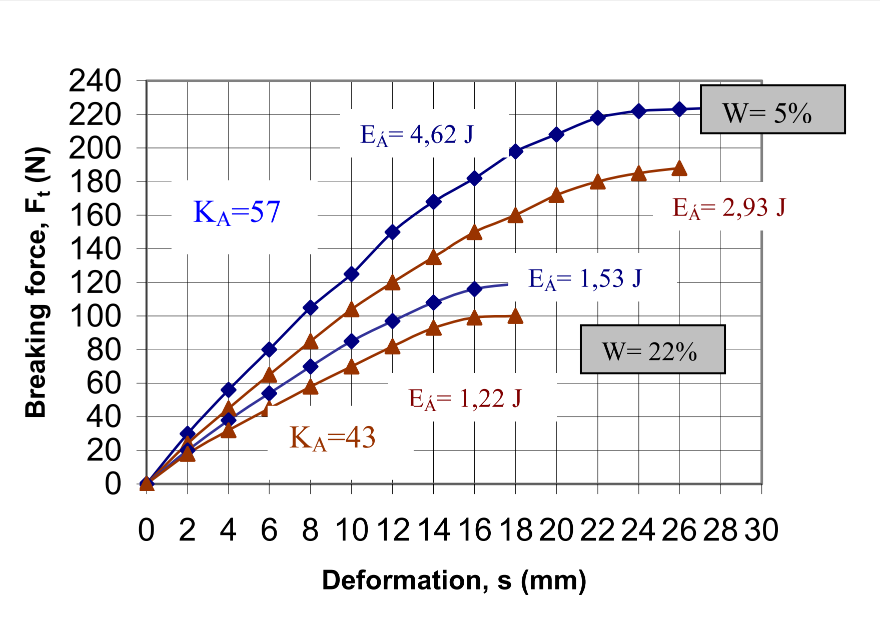


Figure 7 **Breaking diagram of clods embedded in the soil**

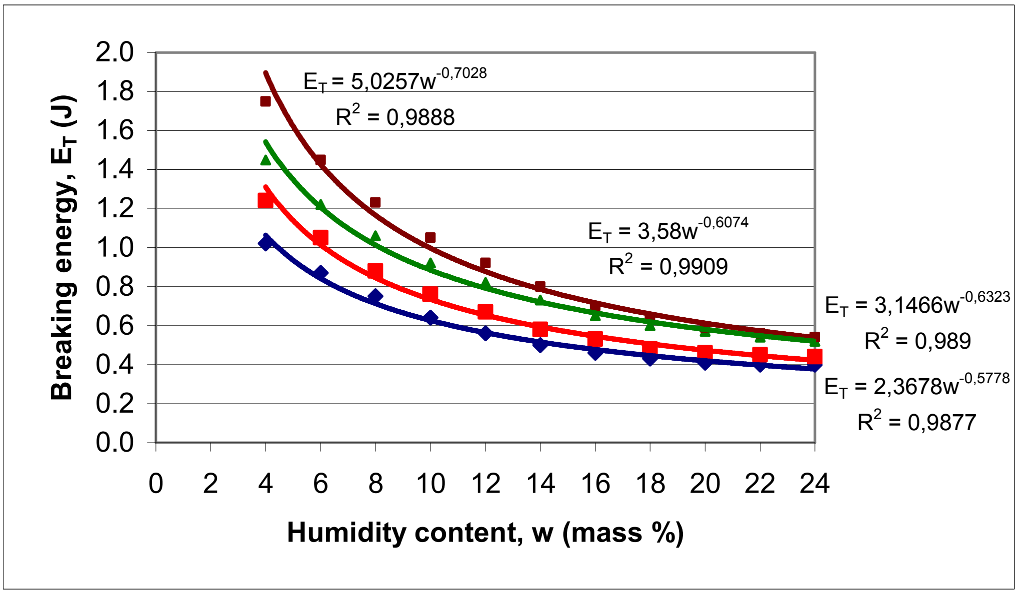


Figure 8 **Changes in the breaking energy as a function of humidity content at the different levels of cohesiveness**

It was found that the conditions of clod breaking worsened by the decrease of humidity content and the increase of cohesiveness, and the clod breaking could be carried out only by use of bigger energy.

3.3. Methodology results of principle of forced clod breaking

If the described principle of supported clod breaking is made continuous, a two-element model of forced breaking is obtained which consists of a driven rotating unit (breaking cylinder) and a perforated surface supporting unit (breaking grid) (**Figure 9**).

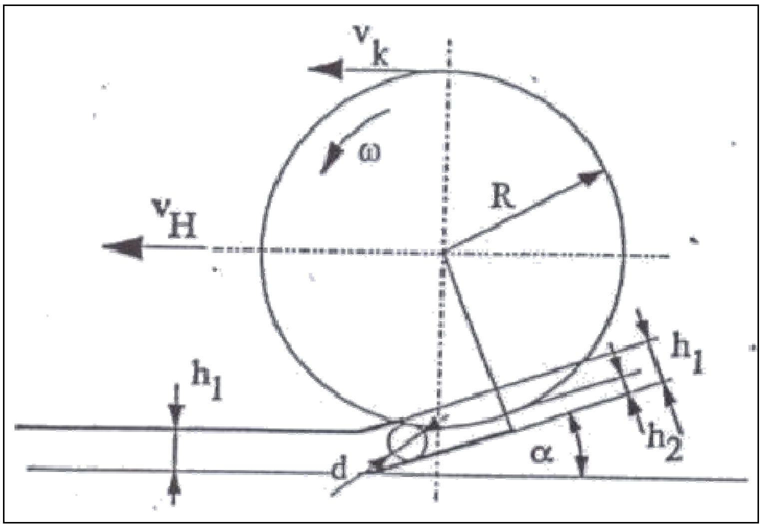


Figure 9 **Model of a two-unit plain breaking grid**

Before the preparation of the planned experimental tool the theoretical relationships of forced clod breaking as well as the most favourable values of construction factors influencing the clod breaking were identified. They were taken into consideration at the planning and manufacturing as well. These theoretical relationships and construction factors are the following:

- When the breaking cylinder is moved on the soil surface, the soil profile determined by the breaking grid enters the narrowing gap. The advancement of the soil layer is assisted by the pushing force (p_t) originating from the velocity V_H and the rotating motion (V_k) of the breaking cylinder, if the assumption $v_K>v_H$ exists.

  As the pushing force is strongly limited by the rate of travel, the advancement of the soil layer (and as a result, the breakage) should be enforced by the teething of the drum and the breaking grid (**Figure 10**).

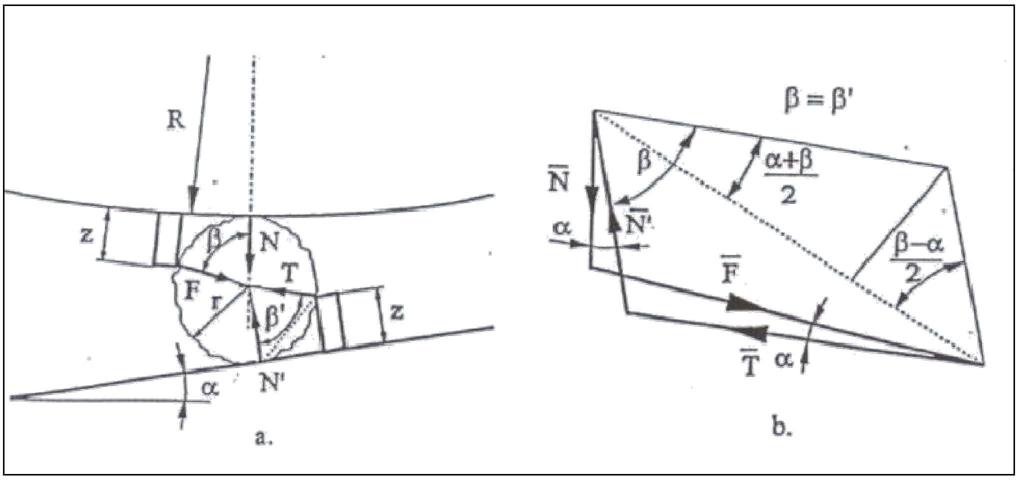


Figure 10 **The principle of force feed and the stress conditions**

- In the course of studies of stress conditions the C proportionality factor was determined. It can be described as a function of the construction factors (z/d) influencing the stress and breaking conditions and α (z/d = relationship between height of teeth and clod diameter, α = angle of breaking grid).
  It was found that from point of view of breaking uniformity the value C = 1 would be favourable which can be reached by the increasing ratio $\frac{z}{d}$ as well as the small angle of breaking grid (α) (**Figure 11**).
  The breaking uniformity of the studied theoretical model is less sensitive for the height of teeth if the angle of breaking grid is small (e.g. if $\alpha = 10^\circ$, the C value is above 0.8 even if $\frac{z}{d} = 0.3$), but the uniformity of breaking decreases dramatically if the angle of breaking grid is increased.
- As a result of narrowing of the breaking gap the clods entering the channel may go through several breakings depending on their original size, the gap geometry, the height of teeth, the form and size of screen surface etc. until it leaves the breaking channel or the perforation of the supporting breaking grid or at the end of the channel.
  The clod fraction distribution of the soil layer going through the forced breaking can be decisively influenced by the perforation of the breaking grid (size, form), as well as by the height of outlet gap (h_2). The height of teeth and the breaking cylinder – as it could be seen - influence mainly the uniformity of breaking.
- The quality of breaking is affected by the peripheral speed of the breaking cylinder. As a result of breaking effect of the cylinder rotating with too big peripheral speed, the ratio of

the unwanted dust fraction increases in the cultivated layer, therefore the number of revolutions should be increased only up to the level of safe feeding of the material.

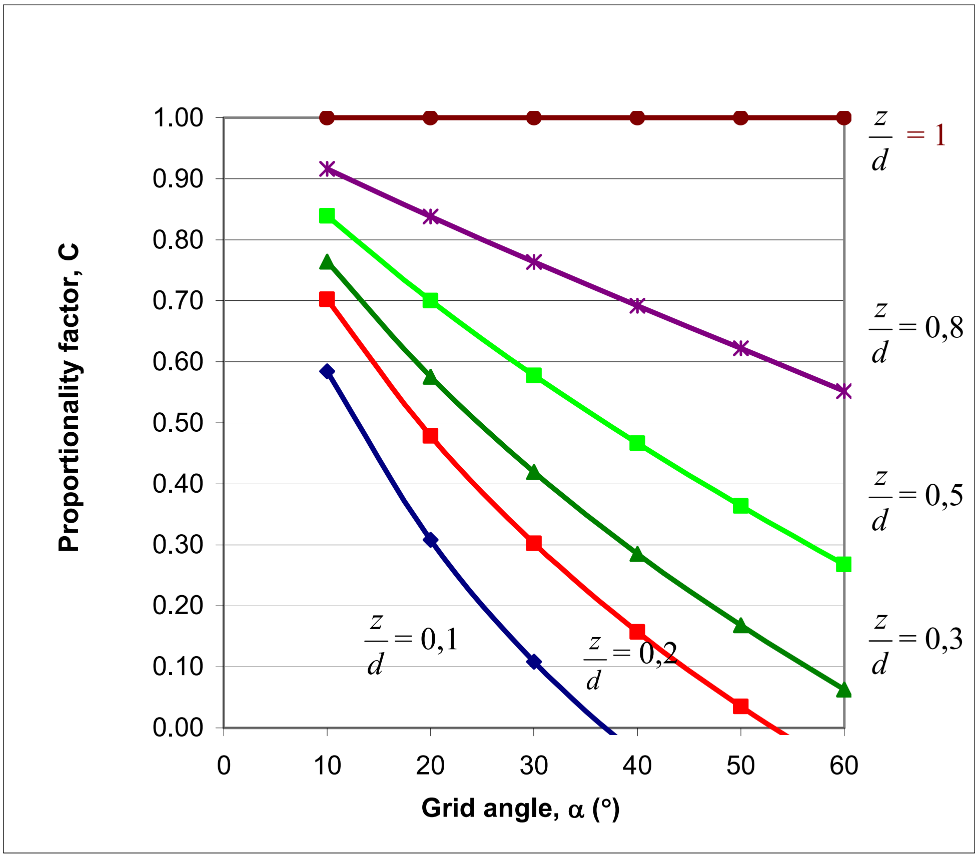


Figure 11 **Effect of grid angle on clod breaking at different z/d values**

Based on **Figure 12** the following relationship was derived from the studies of flow and velocity conditions and the application of continuity rule:

$$v_K \geq 1{,}5\, v_H$$

where v_K – the peripheral speed of breaking cylinder

v_H – the rate of travel

Analysing the gap function it can be stated that the speed conditions can not be chosen too big because of the dust. Therefore the following value is suggested: $\frac{v_K}{v_H} = 1{,}2$.

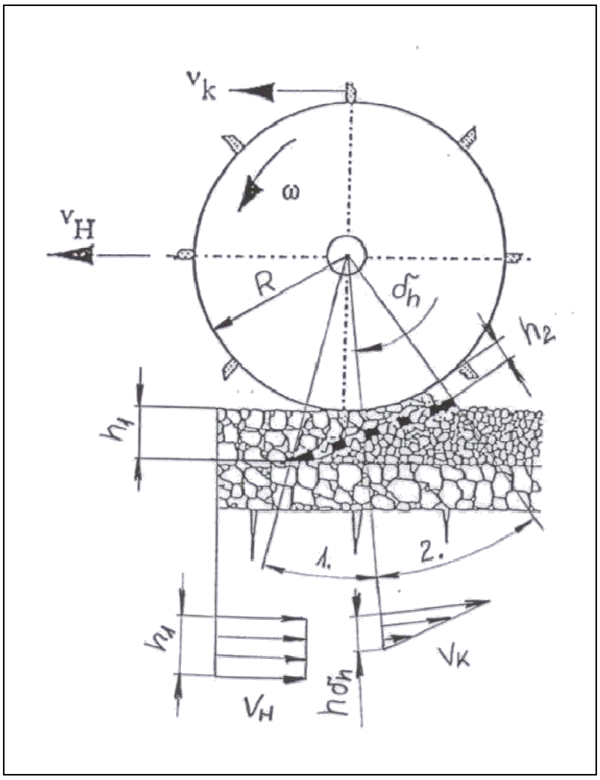


Figure 12 **A nalysis of flow and velocity conditions**

3.4. Clod fraction analyses

Based on the clod sizes and fraction masses characteristic to the soil conditions before and after the breaking, the scale of breaking and the new surface got in the course of the breaking were determined for each soil sample. These two parameters can be used both for the qualification of soil conditions and for the evaluation of clod breaking work of the tool. On the basis of data shown in **Table 2** it can be stated that the breaking is 2-4 times higher depending on the cohesiveness of soil and the humidity content, or in some cases it is even higher. Considerable breaking was found in those samples in which the ratio of 8 cm size or bigger clods was the highest (e.g. in samples IV/1 and IV/6). As a result of breaking (increase of surface area) the ratio of the different clod fractions has changed considerably. Before the breaking the clod fractions of 4 cm or bigger size were prevailing in each soil sample, but after the breaking the ratio of 2 cm clod fractions became predominant (**Figure 13**).

Table 2

Cumulated results of clod fraction analyses

No. of samples	Average of cohesiveness K_A (-)	Humidity content w (mass %)	Total surface before breaking $A_ö(cm^2)$	Total surface after breaking $A_ö$' (cm^2)	New surface A_u (m^2)	Break-up $A_ö{}^{'}/A_ö(-)$
I/1	36	5	29798	89249	5,94	2,99
I/2		10	26425	89980	6,35	3,40
I/3		13	33797	90903	5,71	2,68
I/4		16	21620	84043	6,24	3,88
I/5		19	30897	107584	7,66	3,48
I/6		22	37118	122016	8,48	3,28
II/1	42	5	36856	90919	5,4	2,46
II/2		10	43926	106376	6,24	2,42
II/3		13	22438	85848	6,34	3,82
II/4		16	52506	114328	6,18	2,17
II/5		19	40692	102576	6,18	2,52
II/6		22	49872	114720	6,48	2,3
III/1	46	5	25067	92722	6,76	3,69
III/2		10	40163	77166	3,70	1,92
III/3		13	32364	84488	5,21	2,60
III/4		16	22022	82404	6,03	3,74
III/5		19	43271	90202	4,69	2,08
III/6		22	25547	93734	6,81	3,66
IV/1	48	5	21019	88972	6,79	4,23
IV/2		10	30004	76083	4,60	2,53
IV/3		13	23228	78784	5,56	3,39
IV/4		16	32334	80568	4,82	2,49
IV/5		19	43850	113514	6,96	2,58
IV/6		22	15382	81873	6,65	5,30
V/1	52	5	15404	63728	4,83	4,13
V/2		10	38320	80067	4,17	2,08
V/3		13	25278	83678	5,84	3,3
V/4		16	29983	91118	6,11	3,03
V/5		19	29206	87238	5,8	2,98
V/6		22	29650	71636	4,19	2,41

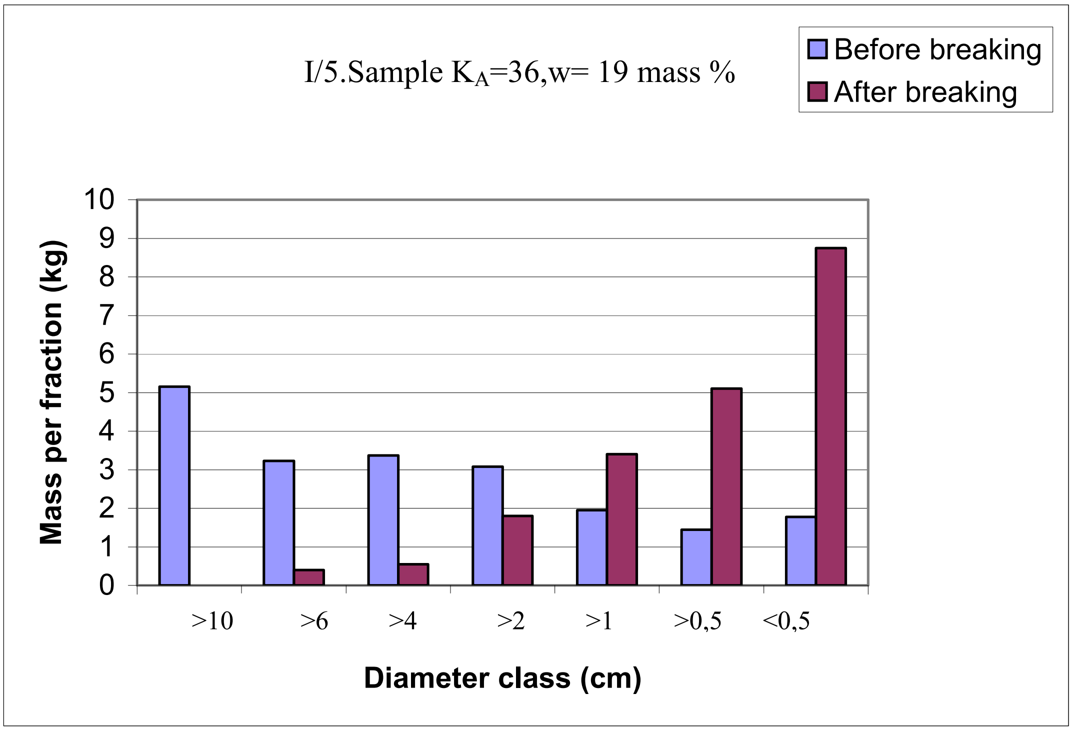
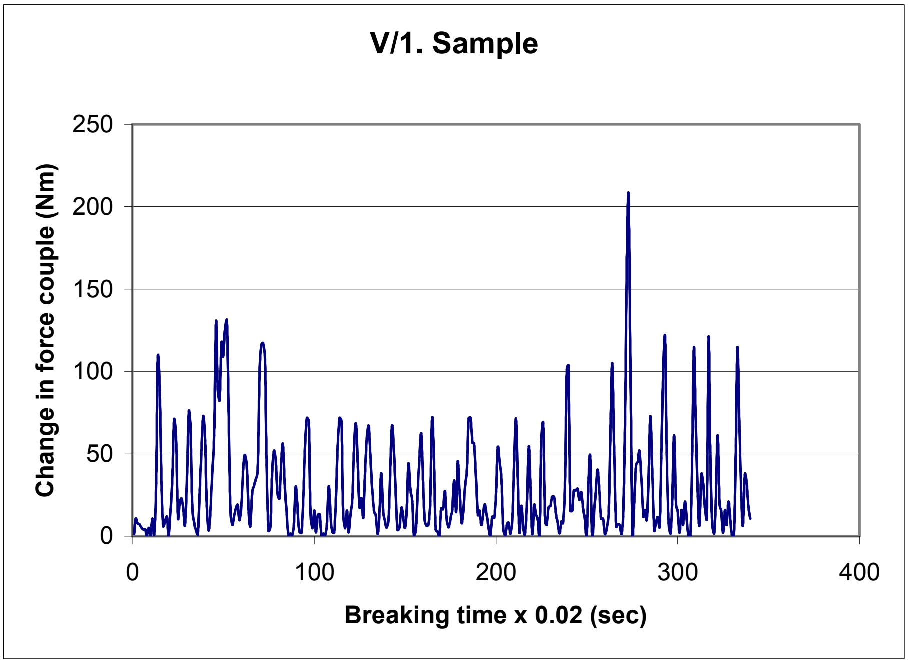


Figure 13 **Changes in distribution of clod fractions in the course of breaking**

3.5. Energetic analyses

After finishing the measurements the force-time diagrams were evaluated. In **Figure 14** the force and time diagrams of soil samples of two different cohesivenesses and humidity contents are shown. It is visible that in the drier and heavier soil samples high force-peaks occurred (the average force was the highest here) and the time needed for the breaking was also longer. Accordingly the highest breaking energy was also measured in this sample.



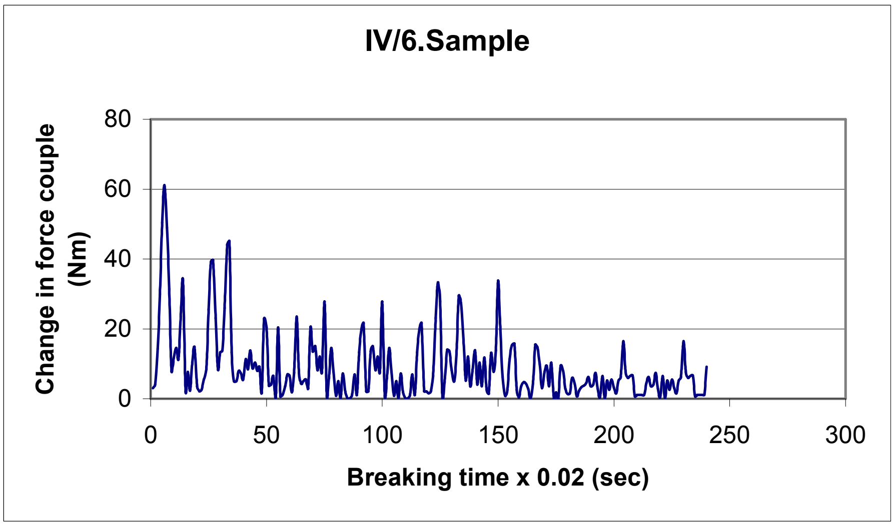


Figure 14 **Force and time diagrams**

The cumulated results of energetic analyses are summarized in **Table 3**. Besides these studies the changes in specific energy as a function of soil cohesiveness and humidity content were also analysed. As a result a very close positive relationship was found between the specific energy and the humidity content. The connection between the two variables can be described by an exponential function (**Figure 15**). The determination coefficient (R^2) was between 0.91 and 0.99 for each analysed cohesiveness. The connection is extremely close in the soil sample of $K_A = 52$ where R^2 is nearly 1.

Table 3

Cumulated results of energetic analyses

No. of samples	Average of cohesiveness K_{-A}(-)	Soil humidity W (%)	New surface A_u (m^2)	Energy E (J)	Specific energy E_f(J/m^2)
I/1	36	5	5,94	684,94	115,31
I/2		10	6,35	715,83	112,73
I/3		13	5,71	371,52	65,06
I/4		16	6,24	306,04	49,04
I/5		19	7,66	305,47	39,88
I/6		22	8,48	313,75	37,00
II/1	42	5	5,4	942,09	174,46
II/2		10	6,24	1030,62	165,16
II/3		13	6,34	584,26	92,15
II/4		16	6,18	482,29	78,04
II/5		19	6,18	406,52	65,78
II/6		22	6,48	313,34	48,36
III/1	46	5	6,76	1322,46	195,63
III/2		10	3,70	617,22	166,82
III/3		13	5,21	576,80	110,71
III/4		16	6,03	659,36	109,35
III/5		19	4,69	301,63	64,31
III/6		22	6,81	373,57	54,86
IV/1	48	5	6,79	1771,24	260,86
IV/2		10	4,60	972,67	211,45
IV/3		13	5,56	745,63	134,11
IV/4		16	4,82	548,77	113,85
IV/5		19	6,96	595,58	85,57
IV/6		22	6,65	462,85	69,60
V/1	52	5	4,83	2091,71	433,07
V/2		10	4,17	1121,78	269,01
V/3		13	5,84	1059,96	181,50
V/4		16	6,11	921,07	150,75
V/5		19	5,8	543,68	93,74
V/6		22	4,19	354,40	84,58

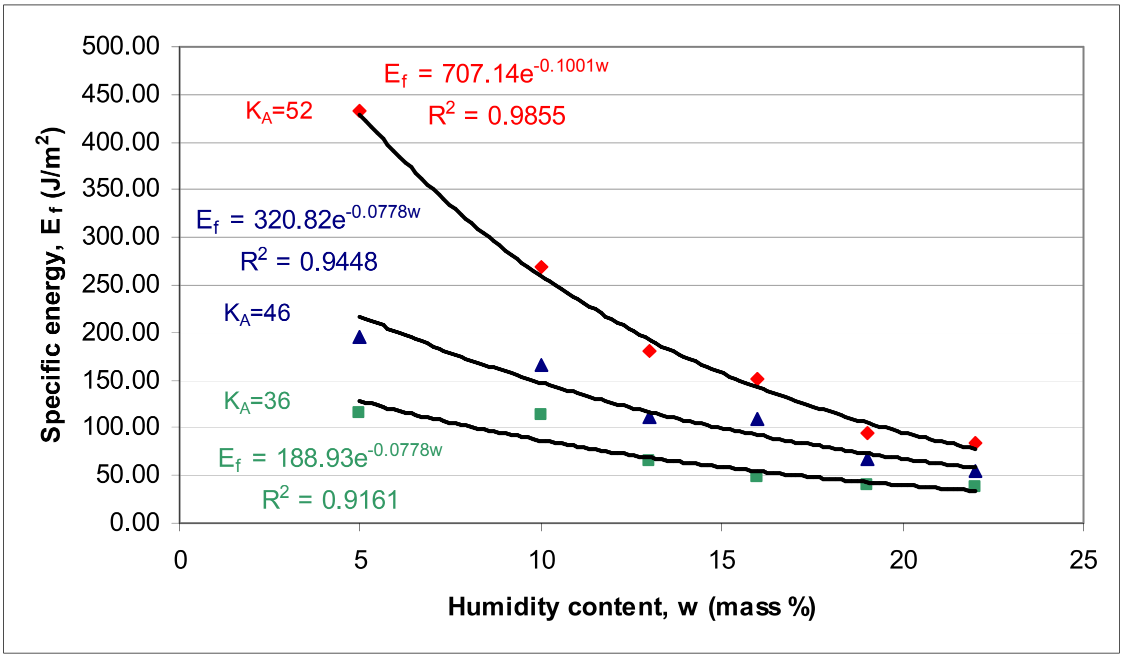


Figure 15 **Change of specific energy as a function of humidity content at different cohesivenesses**

The relationship between the specific energy and the soil cohesiveness was also studied. As a result of the regression analysis a very close positive connection was found here as well. It can be described by an exponential equation (**Figure 16**).

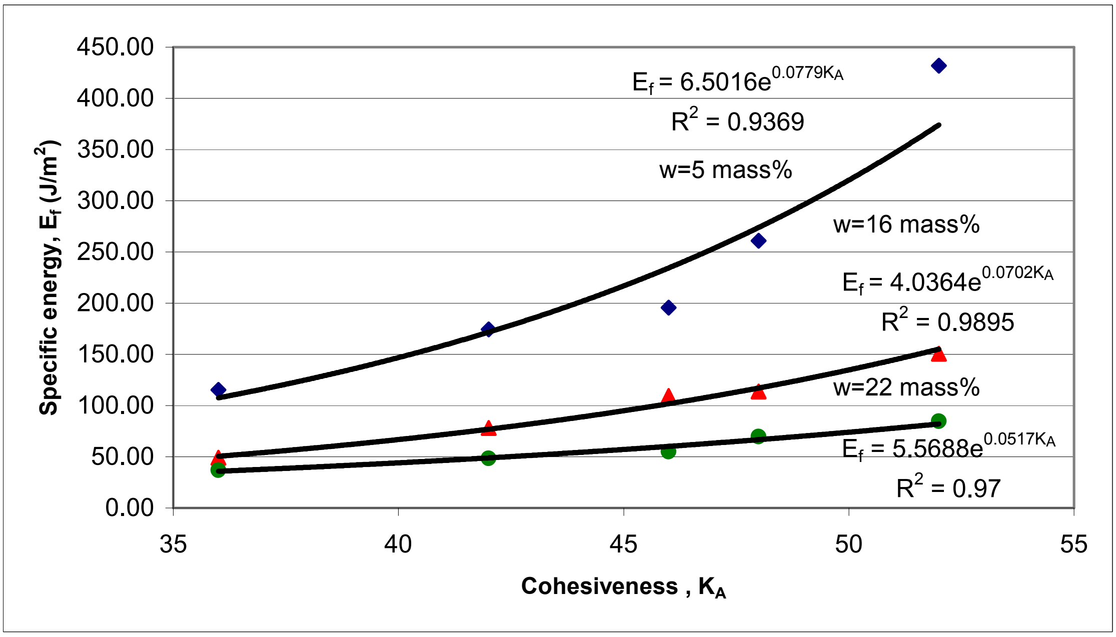


Figure 16 **Change of specific energy as a function of soil cohesiveness at different humidity contents**

In this case the determination coefficient (R^2) was also higher than 0.9. Moreover in case when the humidity content was 16 mass % it reached 1, on the basis of which it is supposed that there is a linear connection between the studied parameters.

The joint effect of the two independent variables is demonstrated by the dimensional diagram shown in **Figure 17**. From this diagram the actual values of specific energy can be read at different soil cohesivenesses and humidity contents.

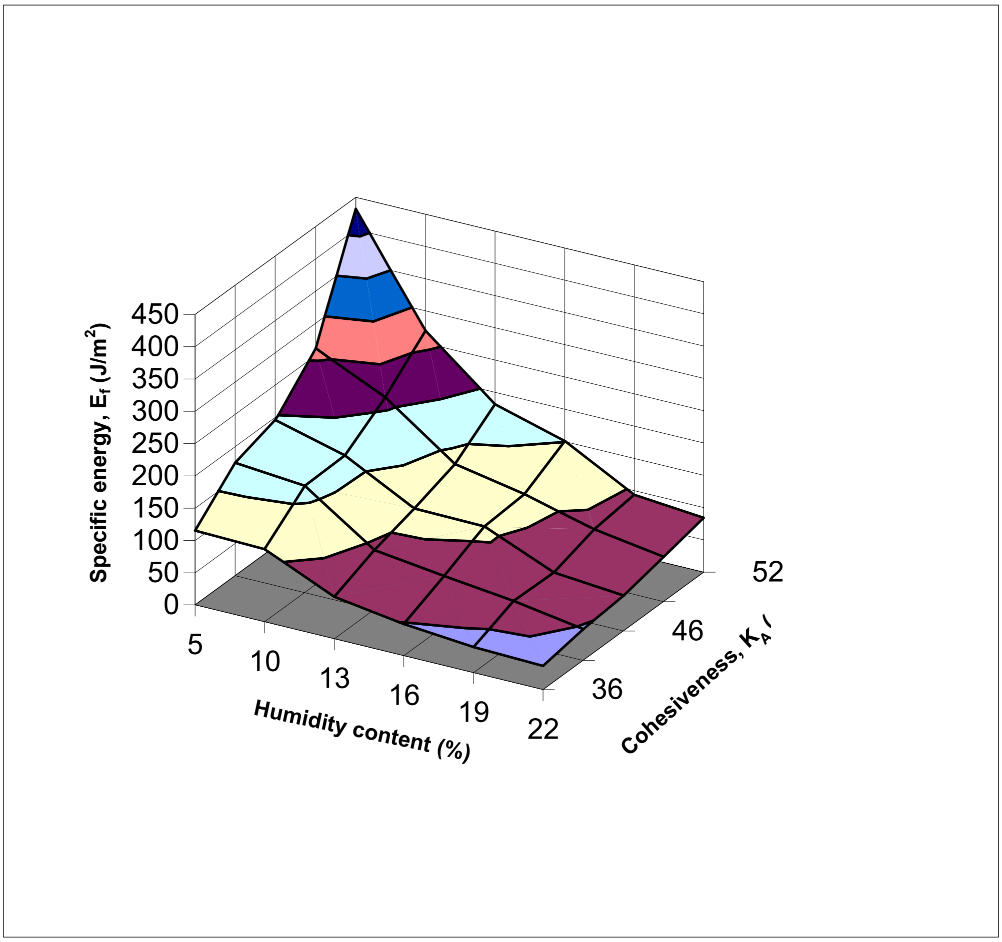


Figure 17 **Variations in the specific energy as a function of cohesiveness and humidity of soil**

For the determination of joint effects of the two variables multiple linear regression analyses have been applied. Based on the described linear equation and the multiple determination coefficients (R2) it was stated that the joint effect of humidity content and soil cohesiveness influence the change of specific energy. The described relationship was significant on P = 0.1 % on the basis of the statistical test (F-probe). From the two independent variables the effect of the humidity content is about 1.5-times higher to the specific energy than that of the cohesiveness of soil. If the values of independent and dependent variables are drawn in a three dimension coordinate system, a spatial plain surface is gained which determines the connected values of the studied parameters within the ranges of examination (**Figure 18**).

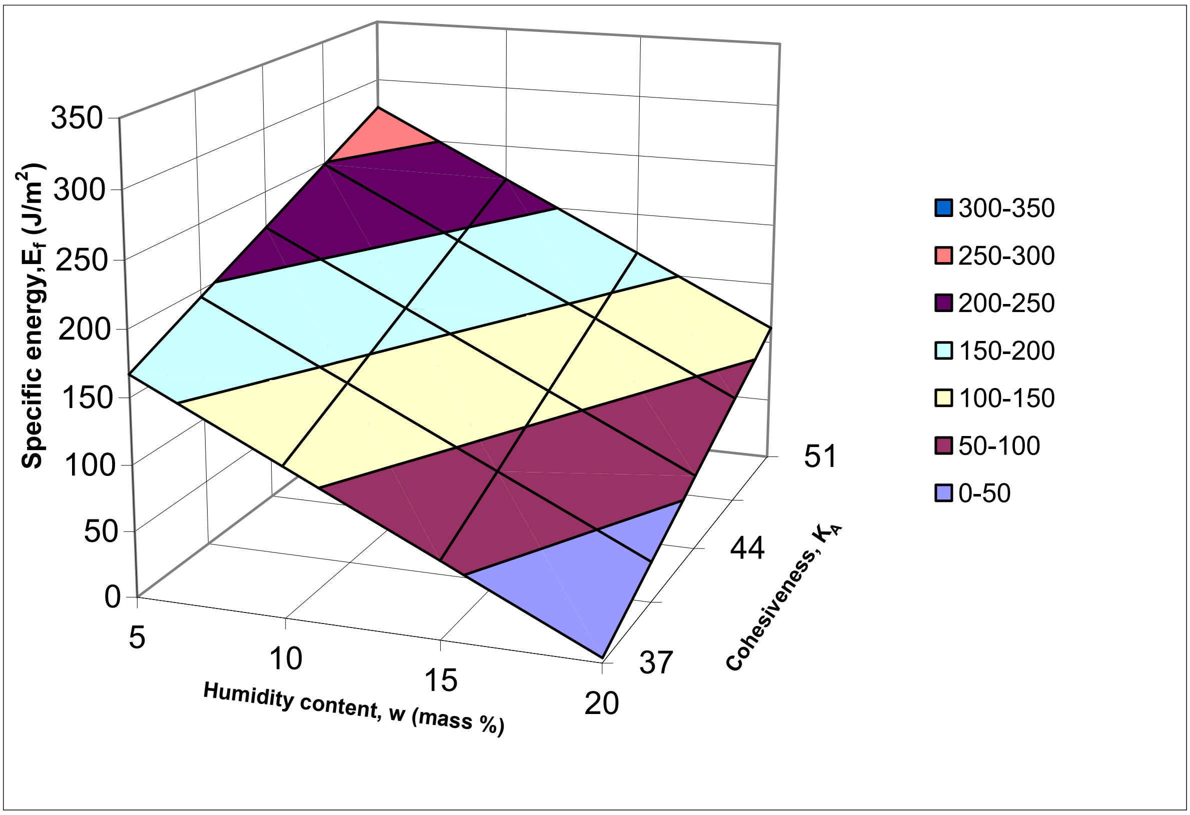


Figure 18 **Linear efficiency surface with two independent variables in the range KA = 37-51 of soil cohesiveness and in the range w = 5-20 mass % humidity content**

Based on the spatial diagram it can be stated that the use of the studied tool can be suggested only in the ranges w_{max} = 21 mass % humidity content and K_{Amin} = 37 soil cohesiveness. In case of other soil conditions – higher humidity and less cohesiveness – the energy demand of clod breaking is low, and the tillage can be carried out by the traditional equipment.

4. SCIENTIFIC RESULTS

1. As a first step of research the breaking energy of different humidity content and soil cohesiveness clods was determined using clods of 50 mm diameter representing the soil conditions well after the autumn seedbed preparation. As a result of the regression analysis a very close positive connection was identified between the breaking energy and

the humidity content in each type of cohesiveness. The regression relationship between the two variables can be described by a power function as follows:

$$E = a \cdot w^{-b} \qquad R^2>0{,}91$$

where

E – breaking energy (J)

w – humidity content of the soil (mass percent)

The determination coefficient (R^2) is higher than 0.91 for each soil cohesiveness which refers to a very close relationship between the studied parameters.

2. The principle of forced breaking was analysed in details for such a tool in which the clod breaking is carried out by a rotating active unit (breaking cylinder) and a passive supporting unit (breaking grid).

   In the course of these studies the following theoretical relationships and suggestions were elaborated:

   - The clod breaking and the uniform flow of material should be forced by the teeth of the breaking drum and breaking grid (by forced feeding).
   - The form of the breaking channel (gap and teeth geometry) may influence the quality of breaking and the distribution of clod fractions after breaking decisively.
   - The construction factors determining the power and breaking conditions have been described by the following equation:

     $$C = \frac{\sqrt{\frac{z}{d}} \cdot \cos\frac{\alpha}{2} - \sqrt{1-\frac{z}{d}} \cdot \sin\frac{\alpha}{2}}{\sqrt{\frac{z}{d}} \cos\frac{\alpha}{2} + \sqrt{1-\frac{z}{d}} \cdot \sin\frac{\alpha}{2}}$$

     where

     C – proportionality factor (the uniformity of breaking is the most favourable at C=1)

     z/d – ratio of height of teeth and clod diameter

     α – angle of breaking grid

- The velocity conditions (v_D/v_H) should be chosen according to the needs of flow of material and clod breaking by such a way that the breaking would be gentle i.e. it should not result in bigger amount of dust. The suggested value of velocity conditions is $v_D/v_H = 1.2$.

3. Based on the theoretical relationships and the design basic data such an experimental tool was constructed which is suitable for determination of breaking energy of different cohesiveness and humidity content soils in 10 kg samples. The experimental tool functioning on the principle of forced breaking together with the measuring technique built into the tool is available for determination of accurate net energy demand of the breaking process.

4. Studies were carried out for the determination of energy demand of breaking in different heaviness and humidity content soils as well as for the determination of specific energy demand of breaking. The specific energy means the net energy needed for the formation of a unit of new surface in the course of breaking. This can be described by the following equation:

   $$E_f = \frac{E}{A_u} \quad \left(\frac{J}{m^2}\right)$$

   where

   A_u – the new surface formed in the course of breaking, and was determined from the clod fraction analyses

5. Based on the research results a regression analysis was carried out for the determination of the relationship between the studied parameters.

   The specific energy – humidity content function can be described by an exponential equation.

   The equation is the following:

   $$E_f = a \cdot c^{-c \cdot w} \qquad R^2 \rangle 0{,}91$$

   Between the specific energy and the cohesiveness of soil a similarly close positive connection was found. The regression equation can be described also by an exponential function:

$$E_f = a \cdot e^{c \cdot K_A} \qquad R^2 \rangle 0{,}93$$

The determination coefficient (R^2) was bigger in both cases than 0.9 which has proven the close connection between the specific energy demand and the studied parameters of soil physics.

6. The joint effect of soil cohesiveness and humidity content on the demand of specific breaking energy was proved by multiple linear regression analyses. The two linear equations with the independent variables were the following:

$$E_f = 7{,}77 \cdot K_A - 10{,}9\, w - 65{,}67$$

where: E_f –specific energy demand of clod breaking (-J/m^2)

K_A – soil cohesiveness

w – soil humidity (mass %)

The multiple correlation coefficient is R = 0.89 which means a significant connection within the range of the analysed cohesiveness and humidity content.

It has been stated that the effect of humidity content is 1.5-times bigger to the specific energy demand than that of the cohesiveness according to the ratio of regression constants $\left(\frac{10{,}9}{7{,}77} \approx 1{,}5\right)$.

5. PRACTICAL USE OF RESULTS

Studying the physical interaction between the cultivation tools and the clods it can be stated that the clod breaking effect dramatically decreases if the humidity content of soil drops (especially on heavy soils). Considerable extra energy is needed for the breaking, which is used for the generally superfluous motion.

The principle of forced breaking offers a possibility for the decrease of extra energy as well as for the improvement of conditions of breaking.

The novelty of the method and the studied experimental tool is that they can create an easily controlled and manipulated clod / crumb structure in the cultivated layer in contrast with the traditional cultivation tools. All this is done in one pass, i.e. with low specific energy demand, thus it is possible to create a cultivation tool which offers good work quality at low energy demand.

The construction of tool (the form of breaking drum and breaking grid, the method of assembly and the selection of driving units) offered in my thesis, can be manifold. It can be elaborated in the course of the further development.

The cultivation tool based on the principle of forced breaking can be used for the following tasks, although with some limitations and modifications:

- It can be used as a separate seedbed preparation tool with narrow working width (max. 2-2.5 m) for croplands, in conditions when precise seedbeds should be made (e.g. vegetable production on arable lands).
- It can be used for one pass seedbed preparation on well-cultivated soils connected to the basic drilling tool (e.g. heavy cultivator).
- It can also be used connected to a seed drill with narrow working width. In such a case the seedbed preparation on the total surface can be neglected after the basic cultivation. The seedbed is prepared precisely only in the plant rows, while the surface of the spacings may remain rough (but blocked). By the help of this tool considerable cultivation costs can be saved and the over-cultivation of soils can be eliminated.

Of course the utilization of the tool might be much wider similarly to the variable forms and sizes of units of the breaking tool. These parameters should be elaborated taking into account the soil conditions (cohesiveness, humidity content etc.), the planned connection of machines and the seedbed needed for the given plant.

The clod breaking and energetic data gained in the course of the research can be useful for the possible practical use of forced breaking which can be an alternative for the traditional soil cultivation and seedbed preparation tools.

6. PUBLICATIONS IN THE SUBJECT OF THE THESIS

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