SZENT ISTVÁN UNIVERSITY

EVALUATION OF TILLAGE EFFECTS WITH PHYSICAL PARAMETERS IN DURATION EXPERIMENTS AND ON THE FIELD

Ph. D. Thesis

MÓNIKA GECSE

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Doctoral School

Name: Plant Sciences Doctoral School

Scientific branch: 4.1. Plant Production and Horticultural Sciences

School leader: Dr. Ferenc Virányi
University professor, doctor of the Hungarian Academy of Sciences

Thesis leader: Dr. Márta Birkás
University professor, doctor of the Hungarian Academy of Sciences

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Approval of school leader Approval of thesis leader

1. INTRODUCTION, OBJECTS OF THE RESEARCH

Soil is the most important natural resource of Hungary and it is going to be in the future, too. Its wise use and protection, to sustain its multifunctionality is a featured task of environmental protection.

In Hungary natural resources provide much better possibilities for agricultural production than in Western European countries, in member states of the OECD or in the World average.

Hungary joined the European Union in 2004. It is not hopeless but surely hard work to stay competitive against the high level machinery and highly subsidized agricultural production of the EU.

Our obvious advantage is the low chemical contamination of the soil. Industrialization and chemical fertilizers caused smaller damages on our soils. Physical degradation did not avoid Hungarian soils either. During the survey of the degradation processes (*ISRIC* 1988), five types of physical degradation were recognized:

- Surface crusting,
- Compaction,
- Soil structure destruction caused by salinization,
- Threat of surface water,
- Water and wind erosion.

In my work I evaluated the reason and consequences of compaction in various tillage methods. My research tasks can be described as follows:

1. To evaluate the effect of tillage systems at the same depth and with the same method based on the parameters of soil resilience and air permeability.
2. To determine the relation of air permeability and soil resilience.
3. To evaluate the effects of tillage methods as a function of penetration resilience used in crop change on soil state in private farms.
4. To evaluate the costs of used technological methods in the examined private farms, based on the publication prepared by the Machinary Evaluating Association of Public Utility (Ministry of Agriculture).
5. To evaluate the technological methods based on No. 3. and 4.

2. MATERIALS AND METHODS

Measurements were done on four sites with different agroecological properties, on three farms and on the Research Site of the Plant Production Institute, Agricultural University of Gödöllő (today: Szent István University).

In 1994, on the Research field of Gödöllő we set up a two variant, small parcel duration experiments on an eroded brown forest soil. The area of the Aranykorona Kft. of Bicsérd is a brown forest soil with thick humus layer and the technology is modern and production is well organized. The research site at Agárd has high quality soil (loamy with thick humus layer) where owners are ready to accept and use technical and technological updates. The farm in Besenyszög is family run where weak soil properties, lack of input and low technological background are limiting the requested technological developments.

2.1. Methods of measuring soil resilience

One of the methods of qualifying the soil physical state is the measurements of the soil penetration resilience. I used mechanical spring penetrometer, pushing probe for my measurements which is the tool for finding soil compaction in the tilled soil layer. The equipment is consisted of a probe with calibration, a spring force-meter and a force measuring scale on the handle. The screen of the equipment shows the soil resilience in KPa. On my figures it appears in MPa.

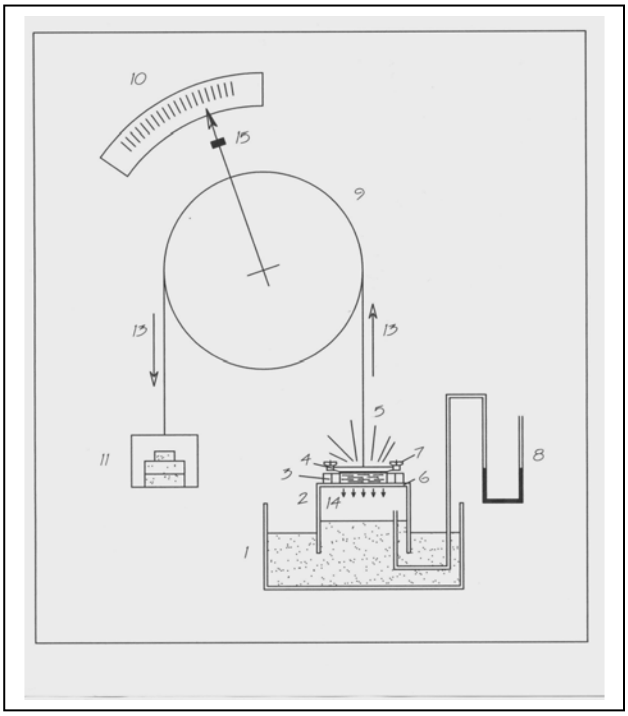
The base area of the probe is 1 cm^2, its angle is 60 degree. It can be used down to 50 cm depth. My measurements were done down to 40 cm depth, at every 10 cm until the deepest tilled layer.

2.2. Method of soil moisture measurements in weight percentage

The given soil moisture content has a big effect on soil resilience, so it must be measured in order to understand and have a correct figure for soil resilience. I took samples for soil moisture measurements at the place where I used the penetrometer. For taking the samples, I used a hand equipment with a cartridge. From the surface of the soil I took samples at every 10 cm until 30 cm depth. The undisturbed samples were oven-dried at 105 ^{o}C until weight equivalence then I calculated the difference between the wet and the dried soil sample.

2.3. Method of air permeability measurements

I did the soil air permeability measurements in Kiel (Germany), at the Institute of "Pflanzenernährung und Bodenkunde" University of Christian Albrecht, in spring of 2001. The equipment I used can be seen on Figure 1.



1. water holding tank
2. float
3. clamp ring
4. perforated clamp metal slab
5. soil sample
6. joint ring
7. wing nut
8. U tube
9. leader disc
10. normalized scale
11. weight holder
12. way of air
13. way of movement
14. inner space for the float
15. compensatory weight

Figure 1. Schematic drawing of the equipment used for soil air permeability measurements

The showed equipment let 1500 cm^3 air evenly through the soil sample. The time necessary for the air to go through must be measured manually. Altogether 2000 cm^3 air can go through, from the lowest calibration of the float to the highest calibration, through the soil sample. From the measured data I used the LOTUS program of the University to calculate the soil air permeability coefficient values and I was working with these values in Windows Excel program.

2.4. Method of cost calculations

The calculations of the costs of soil management (in HUF), based on the applied technologies were calculated according to the bulletin of the Agricultural Machinery Institute – Gödöllő Office, Ministry of Agriculture. I divided these figures by the gas prices (from the manual). This way I received the necessary gas-quantity-equivalence. Burning of one liter diesel fuel produces $40,79 \times 10^6$ Joule energy. I used this figure to evaluate the technological methods of the examined farms.

3. RESULTS

3.1. Changes in soil resilience as a function of soil humidity

3.1.1. Results of the Gödöllő site

At the Gödöllő location 5 year long term field experiment started off in 1994 the effects of 5 types of soil cultivation methods are evaluated on the penetration resilience parameter as a function of humidity. Soil as a natural media can function properly if the ratio of three phases (solid, air and liquid) in it is at present in an appropriate way. Soil is disadvantageously hit by compaction if its volume exceeds 1,5 $g \cdot cm^{-3}$ and the value of its resilience exceeds 2,5-3,0 MPa (in our case with low cohesion 3Mpa).

Table 1. Significance results of soil resilience values between treatment pairs, Gödöllő

	1994.				1996.				1997.				2000.				2001.			
	0-10 cm $SzD_{5\%}$=1,86				0-10 cm $SzD_{1\%}$=1,07				0-10 cm $SzD_{5\%}$=1,80				0-10 cm $SzD_{1\%}$=0,97				0-10 cm $SzD_{1\%}$=0,83			
	Dv	T	Sz	LT	Dv	T	Sz	LT	Dv	T	Sz	LT	Dv	T	Sz	LT	Dv	T	Sz	LT
T	2,41				1,48				2,25				0,29				0,23			
Sz	2,91	0,50			2,31	0,83			0,71	2,96			2,18	2,47			1,60	1,37		
LT	2,09	0,32	0,82		1,80	0,32	0,51		0,45	2,70	0,26		1,55	1,84	0,63		0,83	0,60	0,77	
LSz	2,50	0,09	0,40	0,41	2,18	0,70	0,13	0,38	0,98	3,23	0,27	0,53	2,31	2,60	0,13	0,76	1,60	1,37	0	0,77
	10-20 cm $SD_{1\%}$=0,83				10-20 cm $SD_{5\%}$=2,53				10-20cm $SD_{10\%}$=2,96				10-20cm $SD_{10\%}$=2,43				10-20cm $SD_{1\%}$=1,32			
T	1,55				2,00				2,19				1,17				0,33			
Sz	1,60	0,05			3,05	1,05			1,13	3,32			1,40	2,57			2,53	2,2		
LT	1,26	0,29	0,34		3,35	1,35	0,30		0,38	2,57	0,75		0,48	1,65	0,92		1,67	1,33	0,87	
LSz	2,61	1,06	0,79	1,37	4,19	2,19	1,14	0,84	2,13	4,32	1,00	1,75	1,74	3,39	0,82	1,74	2,8	2,47	0,26	1,13
	20-30 cm $SD_{5\%}$=0,99				20-30cm $SD_{5\%}$=1,51				20-30 cm $SD_{5\%}$=2,56				20-30 cm $SD_{5\%}$=1,73				20-30 cm $SD_{10\%}$=1,33			
T	0,86				0,76				0,98				1,30				0,17			
Sz	1,02	0,16			0,95	0,19			0,77	1,75			0,08	1,38			1,07	0,90		
LT	1,28	0,43	0,27		1,64	0,88	0,69		0,31	1,29	0,46		0,02	1,32	0,06		0,70	0,53	0,37	
LSz	1,63	0,77	0,61	0,34	1,75	0,99	0,80	0,11	2,00	2,98	1,23	1,69	0,60	1,90	0,52	0,58	0,53	0,37	0,53	0,17
	30-40 cm $SD_{1\%}$=0,36				30-40 cm $SD_{5\%}$=0,77				30-40 cm $SD_{5\%}$=1,72				30-40 cm $SD_{5\%}$=0,88				30-40 cm $SD_{10\%}$=1,03			
T	0,70				0,72				0,78				0,72				0,30			
Sz	0,24	0,46			0,32	0,40			0,16	0,94			0,30	0,42			0,33	0,37		
LT	0,93	0,23	0,69		0,57	0,15	0,25		0,13	0,91	0,03		0,74	1,46	1,04		0,7	0,67	1,03	
LSz	0,86	0,16	0,62	0,07	0,69	0,03	0,37	0,12	1,23	2,01	1,07	1,10	0,47	1,19	0,77	0,27	0,36	0,40	0,03	1,06

= significant difference between treatment pairs

Legend: DV = Direct sowing; T = Discing (16-20 cm); Sz = Ploughing (22-25 cm); LT = Loosening (35-40 cm)+discing (16-20 cm); LSz = Loosening (35-40 cm)+ploughing (22-25 cm)

Based on the data from the 8 year long field experiment of comparing cultivation methods the following the results are the following:

As comparison of *direct sowing* and *discing* it is observed that there was significant difference among the soil resilience values, already in the first year, both in the layers of 0-10 and 10-20 cm. The soil condition typical for direct sowing is compacted with 20,75 % in the uppermost layer, and compacted with 30 % in the 10-20 cm layer than the soil that has been disced. In the third and fourth year there was only difference in upper 10 cm layer . In the other layers and other years the effect of the two cultivation methods are similar.

When examining the resilience values of the soil conditions a result of *ploughing* (rotation method) and *discing* (non-rotation method) it is concluded that the significant difference of the starting years is only observed under the cultivations in the 30-40 cm layers. In the fourth year (1997) difference with 5% probability of error was detected between the two cultivation methods in the uppermost 0-10 cm layer and the 10-20 cm layer beneath it.

Soil resilience measured in the layer 10-20 cm (4,43 MPa) as a result of discing was 66,6 % higher than in soil with ploughing (1,46 MPa).

When comparing *discing* (shallow operation) and *loosening+ploughing* (deep operation) it is concluded that by the fourth year in all examined layers the difference between soil resilience values are significance. This means that the favourable effect of loosening is also proved by the measured values. The differences between soil conditions that characterise the two cultivation methods are more articulated from the fourth year. The compaction effect of shallow cultivation has increased. However, the deep cultivation combined with loosening after relief in the initial soil condition deficiencies has maintained the favourable loose status. In the seventh and eighth years (2000-2001) difference was only detected in the upper 20 cm soil layer. In 2001 soil resilience values under direct sowing and discing showed significant difference with rotation methods, both with ploughing and ploughing+loosening treatments.

1.2. Results from examinations of other sites

At the Bicsérd site soil condition evaluation was carried out after the same cultivation method each time in the same field. It is concluded that as a result of the reduced cultivation when compared to the traditional ploughing had not resulted in differing or adverse compaction values in the upper 10 cm layer of the soil that would have affected production.

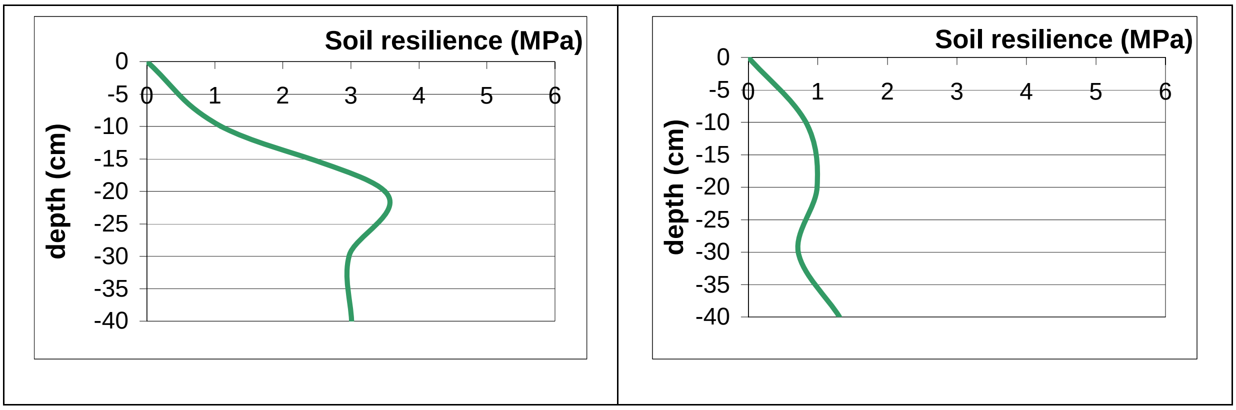


Figure 2. Soil resilience affected by ploughing (a), and regular loosening (b) in Bicsérd.

This observation is also true for the 10-20 cm depth, where in the second year of the experiment the soil resilience values in effect of direct sowing and combined cultivation have remained below those after ploughing. Major differences were measured in the 20-30 cm layer, below the layer of ploughing in particular, where in the cultivation period of the third year the plough sole is considered damaging (Figure 2.a). There was a different phenomenon observable as a result of loosening basic cultivation. Although soil is settling and compacting but its resilience remains below the plough sole (Figure 2.b).

Related to the measurements near **Agárd** we can tell on the conditions of the long term field conditions that the owners endeavour to choose the crop structure and also related cultivation systems in order to steadily secure good soil status for the crops.

When comparing the soil resilience values (Figures 3.a and 3.b) that are resulted by the technology operations applied for the production of different crops it is concluded that both the rotary cultivator use and ploughing in 1998 also provided loosened, favourable soil conditions for both winter wheat and peas.

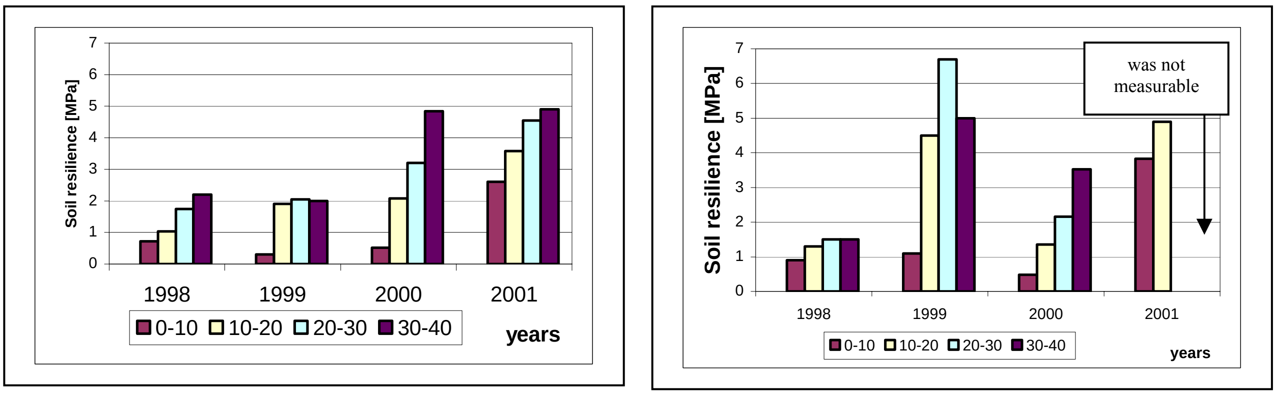


Figure 3. Soil resilience in fields 059.(a) and 101. (b) as function of years and cultivation methods

Field No.	**059**	**101**
1997.	peas	mustard
1998.	winter wheat	peas
1999.	mustard	winter wheat
2000.	peas	Peas
2001.	rape	winter wheat

Technology operations	
✓ Winter wheat	disc + rotary cultivator
✓ Mustard	disc + ploughing
✓ Peas	disc + ploughing
✓ Rape	cultivator + rotary cultivator

Figure 4. Succession of crops and technology operations in Agárdon

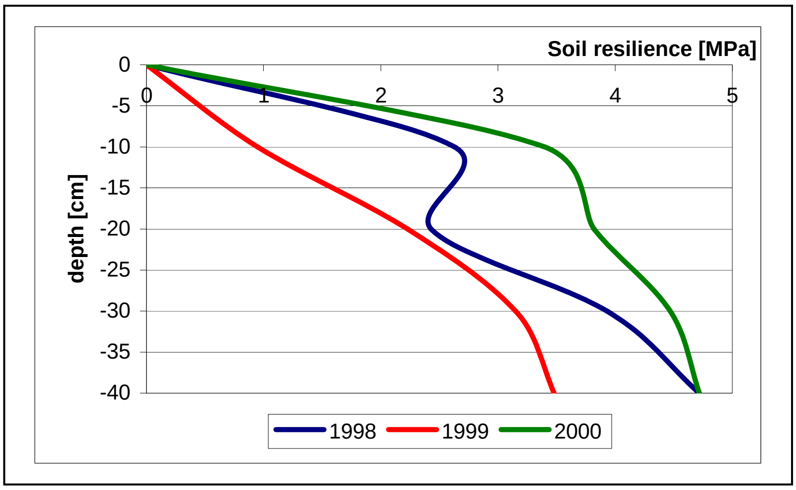
However, despite of the relatively high values of soil humidity, 30-40 cm below the rotary cultivator operation a tendency referring to initial compaction was observed. As an effect to the non-rotational cultivation applied to under winter wheat in 1999 soil resilience values were very high in the 10-40 cm layer. I deduct the reasons to the basic cultivation carried out in a much more humid status of the soil than the optimum. Due to the required draught power high performance, high self-weight power machinery and implement were used hence compaction was unavoidable.

In 2000 peas were sown in both fields and the soil was prepared with autumn ploughing. The soil resilience changes are similar by layers. The difference in the maximums measured by the layers allude to cultivation carried out among ideal soil humidity in field No.101, while in the case of field No. 59 it refers to compaction caused by cultivation in humidity state of the soil higher than the optimum.

The measurements in 2001 were also carried out followed by the autumn basic cultivation. From the soil resilience values of both fields one can see the increase of the faults caused in the previous year. While in 2000 we registered worse status in the field No. 59, in 2001 the worse status was observed in the field No. 101.

The explanation in the case of the previous field lies in the improvement effect of the cultivator basic soil preparation applied to under rape. In the case of the other field the explanation is related to the rotary cultivation operation requiring high motor power.

Examining soil resilience as a function of years it is concluded that in **Besenyszög** the disc cultivation has created favourably loosened status in the upper 20 cm soil layer in 1998 (Figure 5.).



Technology operations

- ✓ Winter wheat: no stubble breaking, basic cultivation with cultivator
- ✓ sunflower: ploughing + basic cultivation with cultivator
- ✓ sorghum: stubble breaking with disk + disking twice as basic cultivation

Figure 5. Soil resilience in the field 'Gólyás' in Besenyszög, as a function of years and cultivation methods. Succession of crops: 1997. sugarbeet, 1998. sorghum, 1999. sunflower, 2000. w.wheat

The effect of discing is detectable in the 20-40 cm layer, it has seemingly increased the otherwise compacted status to which the machinery trampling on humid soil during sugar beet harvest also contributed. In 1999 the cultivator based soil preparation moderated the difference in compactness between the layers. As a result the maximum soil resilience did not reach 3,5 MPa that means an improvement by 26,3 % in the 30-40 cm layer. The results measured in autumn sown winter wheat did not show improving tendency despite of the basic soil preparation carried out with cultivator. The reason might be found in the improper status of maturity of the soil. Winter frost could not exert its beneficial clod breaking effect on the autumn cultivation therefore the average values of soil resilience are 40,2 % higher in 2000 compared to 1999.

3.2. Changes of the air permeability coefficient in the soil of the Gödöllő Experimental field as a function of the cultivation methods and soil depth

Samples were taken into 236 cm^3 volume sampling cylinders on 28 March 2001 from 3 and 4 depths of the cultivation variations at the long term experiment Gödöllő site „B". The examined layers where chosen, in accommodation to the cultivation depth of the cultivation machinery, as follows:

- 16-22 cm   cultivation depth of direct sowing and discing
- 25-35 cm   depth of ploughing
- 35-45 cm   depth of likely compaction directly beneath ploughing

- 65-70 cm untouched layer below cultivation depth (samples from direct sowing and loosening+ploughing operations).

Denomination of cultivation methods is the following:

A1 – direct sowing, **A2** - discing, **A3** – ploughing, **A4** – loosening + discing, **A5** – loosening + ploughing.

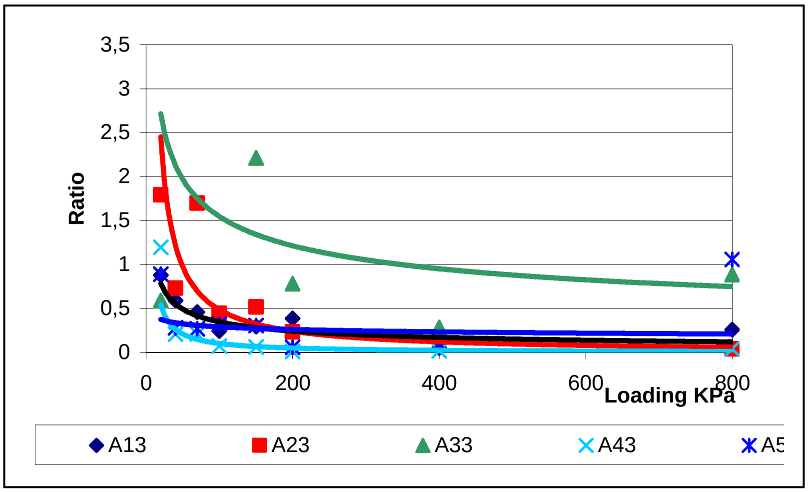
From the 8 unmixed soil samples per layer I carried out air permeability measuring three times in the Soil Mechanical Laboratory of the Christian Albrecht University (Germany, Kiel). First, on unmixed samples kept air tight, then after humidity extraction at -60 hPa pressure examinations were carried out with 20 kPa, 40 kPa, 70 kPa, 100 kPa, 150 kPa, 200 kPa, 400 kPa and 800 kPa.

I could put 8 samples at the same time into the computer controlled appliance that work based on the principle of oedometer. I divided the air-permeability value measured after the load with the air-permeability value measured before the load of the respective sample. Then I plotted resulted quotients in rectangulate coordinate system and fitted an exponential function to them. From the functions I present here the results of examinations carried out on the samples taken from the 35-45 cm soil layer.

On 20 kPa the highest value in 35-45 cm layer is taken by the function of ploughing that is followed by the function of discing. The curve of ploughing runs close to the value of 1 within the examined 800 kPa range while the curve of discing converges towards 0. The soil resilience of the two treatments are high, but the air-permeability of the unmixed samples are favourable at discing and show a very low value in the case of ploughing (Figure 6.).

The curve of ploughing has smaller reactions to higher pressures, which alludes to pore poor, compacted soil structure and plough sole. The disced soil is also compacted although it structure is rich in air permeable pores. Based on the air diffusion values the negative effect of ploughing and discing is detectable in the 35-45 cm and 16-22 cm layer respectively.

The curve of the direct sowing and discing combined with loosening starts from a value under 1 and converges towards zero at 20 kPa. The form of the curve indicates a soil with good pore composition, in stabile, ideally compacted condition.



A13	$Y=3,6092X^{-0,5091}$	r=0,7228**	n=8
A23	$Y=49,981X^{-1,0062}$	r=0,9209***	n=7
A33	$Y=7,7397X^{-0,3497}$	r=0,4031	n=8
A43	$Y=12,156X^{-1,0382}$	r=0,8352***	n=8
A53	$Y=0,602X^{-0,158}$	r=0,1929	n=8

$P_{(10\%)}$ * ; $P_{(5\%)}$ ** ; $P_{(1\%)}$ *** ; $P_{(0,1\%)}$ ****

Figure 6. L_U/kL_E quotient values as a function of loading by cultivation methods in the 35-45 cm layers.

The fitted curve of the treatment 'loosening +ploughing' take values between 0,37 and 0,21 in effect to the treatment at pressure 20-800 kPa. The flat almost even curve at ploughing in the same depth follows the already discussed tendency that reflects compact structure. The soil sample unlike ploughing neither react susceptibly to loading in the low pressure range. This feature makes it similar to the discing+loosening treatment in the 25-35 cm layer.

4. NEW SCIENTIFIC RESULTS

My new scientific results based on my examinations in the field of "**Evaluation of tillage effects with physical parameters in duration experiments and on the field"** between 1998-2003are as follows:

1. On the brown forest soils of Gödöllő, in the duration tillage experiments I found tight relation between the yearly repeating tillage effects and the penetration resilience measured in the various layers of the soil. Based on the results, I made and defined groups of the tillage operations from a new viewpoint: soil state decreasing, soil state sustaining and soil state improving operations.
2. On the brown forest soils of Gödöllő, in the duration tillage experiments I made groups from the used tillage operations based on their effects on the soil moisture regime and I established unfavorable, favorable, improving and sustaining categories.
3. Based on the continuous examination of the 0-40cm soil layer I stated that in case the loose layer where the plants live is getting narrower, the harmful drought is increasing (1996, 1997). Based on the examination of the soil moisture values it can be stated that the sustaining of the loosed layer until the deeper layers it is not only the infiltration capacity that improves but the water loss is decreasing dependably.
4. I completed the soil state examinations with soil air permeability experiments that are rarely used in Hungary. The absolute value of this permeability parameter helped me to describe soil structure, capillary air- and water retention capacity.
5. Based on the change in the soil air permeability values I detected precisely the presence of the water sealing layers and the expanse of the loosed layer in the upper part of the soil.
6. Based on the use of the power function fitted on the coefficients of the soil air permeability values before and after the 20-800 kPa load I found a new parameter to evaluate the physical state of the soils. The given reaction in various pressure ranges give information on the quantity of the depression and the direction of the change in the soil besides the absolute values of soil compaction and air permeability.
7. During field experiments in Bicsérd, Agárd and Besenyszög I detected basic parameters of soil state deterioration and improvement, and their causing effects.

5. CONCLUSIONS, SUGGESTIONS

Based on the **Gödöllő** measurements, with the help of soil resilience I qualified the management methods as follows: decrease-, sustain or increase the state of the soil. I precisely described the connecting definitions. Based on the soil moisture measurements at the Gödöllő site, I defined more groups for managements methods: unfavorable for soil moisture regime, adequate for soil moisture regime and sustainable/improver of soil moisture regime.

In **Bicsérd** I stated that decreased tillage caused no change compared to plowing in the upper 20cm layer. At the depth of 20-30cm, following the 3rd year, reduced tillage caused harmful tillage compaction. Moreover I stated that amount and duration of the precipitation of the tillage period had great effects on tillage quality, on the state of tilled layers and the layers below it. In wet soil the least damage is under direct sowing, the plow and disc cause compaction and loosening effect is decreasing.

In **Agárd** (loamy Chernozem soil) – with appropriate soil moisture content – viability of loosening combined with soil cutting tillage method can be proved because of the low soil compaction damage. In case of higher soil moisture content base tillage methods with lower towing efficiency requirements are favorable concerning the moderate compaction effect.

In **Besenyszög** the safety of production can be sustained by base tillage without plowing causing little compaction or by the loosening of the compacted layers every 2-4 years on the shallow, loamy and clayey soils with low infiltration capacity, threatened by salinization.

During the soil air penetrability examinations, from its absolute value I made conclusions on soil structure, capillary air and water retention capability. The change of air permeability might refer possible upper water sealing layers and on their air permeability. Comparing soil resilience and soil air permeability values it can be generally stated that with the growth of soil compaction, soil air permeability decreases, and these two parameters generally have a reverse relation.

Based on the measurements in Gödöllő I could not establish a direct figure that describes the relationship of the examined parameters. My conclusion is that tendencies might turn backwards because it is influenced by soil structure, soil moisture content, and its so called "culture state". The (individual or combined) effects of these parameters can be followed by the air permeability.

Following the water withdrawal handling at -60 hPa, soil samples were set under various pressures that caused change in soil air permeability capability. I used the values from before and after the handling. It can be stated that the curve of the power function, fitted for the results mean a new parameter for the description of the soil physical state. Reactions, caused by the various

pressure sections, besides the absolute values of compaction and soil air permeability gave answers on the direction and value of the depression in the soil.
I calculated the costs of tillage based on the applied technological versions for winter wheat production. My conclusion is that the cost of using more expensive machinery with the required higher towing capacity need of the contracted tillage machinery is paying back in mid range by the cease of soil faults, and keeping the costs of plant protection low. Data proved that the amount of production is higher on soils having no tillage compaction and good water and nutrient management, than on fertile soils with soil faults.

Results of the examinations on four research sites strengthen that soil management and tillage dependent soil state have important role on infiltration, soil moister regime and water use efficiency, regardless the amount of precipitation. These three parameters have extreme importance when the climate – likewise in the future more frequently – is extreme. A soil state should be prepared and maintained that is able to admit, carry and hold the precipitation reaching the surface.

6. PUBLIKATIONS

6.1. Scientific articles

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5. Takács-György, K., **Gecse M.** (2001). Some agricultural and economic aspects of energy saving production technologies of maize. Journal of Central European Agriculture, 2. 3-4. 183-190.

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