SZENT ISTVÁN UNIVERSITY

GÖDÖLLŐ

STUBBLE MAINTENANCE USING TILLING AND BIOLOGICAL METHODS

Ph.D thesis of

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1. BACKGROUND AND OBJECTIVES

For a long while the potential fertility was the primary concern when assessing the type of soil and the given area for bearing crops, it was only later that quality standards appeared such as in the context of climate change, the great significance of water reservoirs, or relating to environmental protection, the crucial aspect of – the effect of stress and land overload – resistance (buffering) capability.

Soil is conditionally a renewable natural resource, however, the renewability is dependent on certain conditions and activities which can be insured by rational land use, agricultural techniques and soil conservation (Várallyay 2012).

In the 1990s the changes in land ownership created a new situation in the field of soil and environmental protection which was caused mainly by the appearance of small plots and the low-key expenditures, as well as the new landowners' deficient professional expertise, and the unavailability of machine technology.

At the same time however, at the beginning of the 20th century both the American and European continents were striving to mitigate the damages of climate change. The emerging new cultivation trends either directly or indirectly aimed at improving the quality of the soil and the environment. Based on the projected scenarios of global climate change Birkás (2009) emphasizes the need for the purpose of tillage to adapt to climate change, therefore he named the era spanning from the year 2000 to the present day period the so called climate-oriented cultivation era since the objective of cultivation is to be responsible for reducing climate damage through improving the quality of the soil.

The implementation of the so-called climate oriented tillage should start with the stubble of harvested crops; at this time when the soil is ready to regenerate and renew itself it is the most exposed to the elements and extremities of the weather. This contradiction must be resolved with the reevaluation of the most controversial summer time tillage, to which modern machine technology is available, but our store of knowledge on the matter needs to be expanded.

My research objectives as seen above were the following:

1. The comparison of stubble tillage methods based on the properties of the state of the soil.

2. The study of the methods of drilling cover crop onto stubble taking into consideration the mitigation of climate impact and sparing the structure of the soil.

3. A new concept of stubble management, and clarification of the role of stubble management relating to soil protection and the reduction of climate damage.

The timeliness on stubble management has been brought forward in recent years due to extreme climate, and there is a need to focus attention on reducing moisture loss as well as regulating moisture. During harvest and stubble maintenance (or previously) we need to promote regeneration of the soil using physics and biological methods. Besides the reduction of soil organic material and moisture loss, there appears a new objective to save the structure and surface protection, of which the length of time, and the method of establishing a way of stubble management are such open questions to which the topic of my thesis may bring us closer.

In the more agriculturally developed countries as early as the 1960s and onwards the stubble residues were used for protection, we used these one decade later. The influence of mulch and cover crops showed positive characteristics in the condition of the soil, which was confirmed by a number of domestic and foreign authors. After harvesting, the amount of straw and crop residue left on the surface decreases depending on the conditions of decomposition, its function can be taken over by the role of green cover, and for a regulated period of time of weeds and volunteers.

The specific research topic is particularly timely since in 2015 among the EU direct payments a new one was introduced known as „greening" whose main activity was to designate areas of ecological significance. The requirements of the ecological aim of the second seeding can be met by sowing cover or green manure crop during the period between the two main crops.

2. MATERIALS AND METHODS

2.1. Conditions of research

The experiments took place between 2008-2009 near Hatvan, and were conducted in the Szent István University Józsefmajor Experimental Farm.

The annual average temperature is 9.5 to 10 ° C, during the time of vegetation 16.3 to 16.8 ° C; an average temperature of above 10 ° C for 183 days measured between 13 April and 13 November.

The area is characterized by precipitation during the average of many years (Fenyőharaszt, 1965 to 1995). Annual rainfall is 580 mm, of which 323 mm falls during the vegetation period. In November, May and June most of the rainfall is expected (Figure 1).

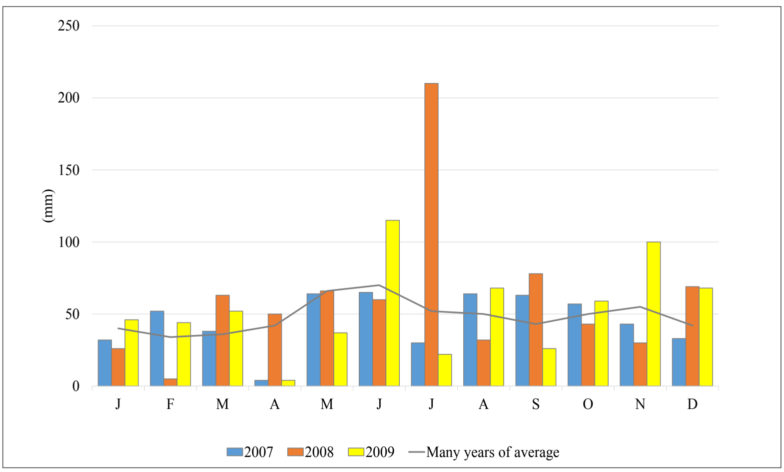

Figure 1. Many years of average rainfall and years of experimental data

The experimental area soil type is lime coated chernozem (Calcic Chernozem), according to the physicality of the soil it is adobe. The PH is slightly acidic. Mean organic matter content in the 0-40 cm layer is 2.83%. The soil characteristics are shown in Table 1.

Table 1. The experimental area of soil properties in different layers (Geoderma Bt., 2006)

Nomination	0–10 cm	10–20 cm	20–30 cm	30–40 cm
K_A	40	39	39	40
pH_{KCl}	5.48	5.50	5.66	5.76
Humus %	3.965	3.353	3.119	2.650
NH_4-N mg/100g	5.19	4.73	4.41	3.58
NO_3-N mg/100g	3.46	2.37	2.65	1.88
NH_4+NO_3 mg/100g	8.65	7.1	7.06	5.46
Összes N %	0.198	0.168	0.156	0.134
C org%	2.23	1.93	1.829	1.575
C:N	11.36	11.56	11.69	11.90
AL-P_2O_5 mg/kg	128	95	85	58
AL-K_2O mg/kg	231	166	162	170

2.2. Presentation of the experiment

2.2.1. Introducing the stubble tillage experiment

The stubble cultivation experiment was set to 11 treatments from 12-13 July 2008. The area is almost flat. One treatment area: 10 m × 180 m (1800 m^2). The plots direction has a deviation from a straight line by 45°. Within the treated spaces, we randomly selected 4-4 permanent sections for the measurements. Arable stubble management treatments of the experiment are summarized in Table 2.

Table 2. The stubble cultivation treatments and nominations

Nomination	**Depth (cm)**	**Marking**	**Soil surface**
Untilled, control	0	HN	*undisturbed, covered*
Flat disc tillage	6 – 9	SP	*disturbed, consolidated, covered*
Tilled with a stubble cultivator	6 – 9	K	*disturbed, consolidated, covered*
Traditional heavy disc harrow	9 – 12	HT	*disturbed, unconsolidated*
Traditional heavy disc harrow and packer	9 – 12	HTGY	*disturbed, consolidated, covered*
Conventional plow, leveling done with rotator	20 – 22	SZF	*plowed, leveled*
Plowed with reversible plow	32 – 35	VSZ	*disturbed, consolidated*
Plowed with reversible plow and leveled	32 – 35	VSZE	*plowed, leveled*
Plowed with reversible plow, eveled with flat disc	20 – 22	VSZSP	*plowed, leveled*
Loosening without leveling	35 – 40	L	*loosened, covered*
Loosening and leveling with flat disc	35 – 40	LE	*disturbed, consolidated, covered*

The experiment:

1	2	3	4	5	6	7	8	9	10	11	21	28	26	27	25	20	29	21	24	23	22
SP	K	HT	HTGY	SZF	VSZE	VSZ-SP	VSZ	L	LE	HN	HN	VSZ	VSZE	VSZ-SP	SZF	LE	L	SP	HTGY	HT	K

The experiment was done and compiled using the wide-spread practice of shallow (HT, HTGY) and deep tillage (SZF, VSZ, VSZE, VSZ-SP, L) treatments, variants subordinate to soil protection (SP, K, LE), as well as undisturbed stubble (HN) variants. The measurement time points are summarized in Table 3.

Table 3. The dates of measurement in the stubble tillage experiment (2008)

		Dates of measurement											
		07.13.	07.24.	07.26.	07.29.	08.12.	08.14.	08.30.	09.04.	09.12.	09.13.	09.27.	09.29.
1	Cover of stubble residues	x	x				x				x	x	
2	Soil moisture content	x			x	x			x				x
3	Soil resistance	x			x	x			x				x
4	Agronomic structure	x		x		x		x					x
5	Earthworm	x		x		x		x					x
6	Weed and volunteer	x	x				x			x		x	

2.2.2. Introducing the stubble seeding experiment

Stubble seeding experiment was performed in two years, 2008 and 2009. 5 treatments and 3 repetitions, and a random track layout were adjusted; 6 x 100 m area plots.

The stubble seeding experiment treatments:

1. On the day of harvest, stubble drilling (A)
2. The day of harvest, tilling, and sowing seeds in August, (B)
3. Two days after harvest, stubble drilling(C)
4. One week after harvest, stubble drilling (D)
5. On the day of harvest, tilling, then one week later sow the seeds (E)

The treatments used in this experiment model the wide-spread practice (B, E) and the more disputed (A, C, D) methods.

The order of the experiment:

1	2	3	4	5	23	22	25	21	24	35	34	33	32	31
A	B	C	D	E	C	B	E	A	D	E	D	C	B	A

The stubble was tilled with a conventional disc harrow at a depth of 6-7 cm, and was carried out according to the scheduled treatments. The 50-50% ratio mixtures of mustard and radish were 2.5 cm deep and a seed drill calibrated to 25 kg / ha was used for the sowing of the seeds. The measurement time points are shown in Tables 4 and 5.

Table 4. Dates of measurements in the stubble seeding experiment (2008)

		Dates of measurements								
		07.10.	**07.12.**	**07.29.**	**07.30.**	**08.12.**	**08.30.**	**09.04.**	**09.23.**	**10.09.**
1	**Cover of stubble residues**		x		x	x	x		x	
2	**Soil moisture**	x		x		x		x		x
3	**Soil resistance**	x		x		x		x		x
4	**Agronomic structure**	x		x		x		x		x
5	**Weed and volunteer, cover crop**		x		x	x	x		x	

Table 5. Dates of measurements in the stubble seeding experiment (2009)

		Dates of measurements								
		07.10.	**07.16.**	**07.30.**	**08.12.**	**08.18.**	**08.27.**	**09.03.**	**09.23.**	**10.18.**
1	**Cover of stubble residues**	x		x		x		x		x
2	**Soil moisture**		x	x	x		x		x	
3	**Soil resistance**		x	x	x		x		x	
4	**Agronomic structure**		x	x	x		x		x	
5	**Weed and volunteer, cover crop**	x		x		x		x		x

2.3. Methods of research

– To measure the coverage (%) of the stubble residues we used a 0.25 m^2 measuring frame and standard photo series.

–The physical condition of soil (0-50 cm) classification was performed in all treatments by measuring soil resistance with the Mobitech Bt. penetrometer from Szarvas (Daróczi és Lelkes 1999, Daróczi 2005). The device is suitable for determining on-site soil compactness up to a depth of 50 cm. The measurements were conducted at 50 cm depth, every 0.5 cm, and repeated 3 times.

–The soil moisture measurements (mass %) were performed with a PT-I moisture meter (Kapacitív Kkt, Budapest.), in three repetitions. The instrument can be used in a range between 2-40% mass.

– The agronomic soil structure analysis was completed by the separation of the clod (> 10 mm), the crumb (2.5-10 mm) and the dust fraction (<0.25 mm). The essence of the procedure is that from the sample areas 5-5 replicates are taken and averaged samples are dried out, and then sieved through seven different sieve sizes (20, 10, 5, 3, 1, 0.5, 0.25 mm). The weight of each fraction was measured, and their amounts expressed in percentage of the mass of the sample, which determined the soil's dust, crumb, and clod particles.

–During the earthworm count test (pcs / m^2 / 0-15 cm) quarter-square-meter plots were selected and the individual spade samples were collected and counted.

– The plant tests focused the examination on the stem quantity, the green mass, root length and root mass. The weighing was completed after the plants were dried.

– The soil - straw - weed and volunteer crop growth, as well as the soil - straw – ratio of crop drilled in stubble, (from the beginning to the completion of the experiment) was measured using a 0.25 m^2 frame.

– Among the statistical methods for analyzing the effect of the experiment the one factor variance analysis was used (Sváb 1981). The F-statistic (Fisher LSD test) was used for the detection of the significant differences with a 95 to 99% confidence level ($P < 0.05$ or $P < 0.01$). The association between variables was examined by regression analysis.

3. RESULTS

3.1. The results of the stubble tillage experiment

The importance of surface coverage is supported by a number of factors such as soil moisture retention, promotion of soil crumbling, moderate dust, low amounts of siltation and surface crust, plus the loosening of deeper layers, active earthworm activity and good weed and volunteer growth.

The optimum ratio of surface coverage differs per season, similarly to the proposed range, which is obviously wider than the optimum. Birkás (2009) suggests that between harvest and stubble stripping a minimum of 55-65% and 35-45% of coverage is desired after the shallow stubble stripping. The cover layer should be created for the occasion stubble, at least 35-65% coverage ratio in normal years, 55-60% in dry years and in wet years one should provide 30-50% coverage (Kalmár et al. 2011).

In July 2008, there was 22.2 mm less precipitation compared to the average of many years, while in August there was a consistently dry period, so developing a 45-55% coverage was a justified expectation contrary to the previous experiments. After the tilling of stubble, after only two treatments with the flat disc (SP) and the stubble cultivator (K), they provided the desired degree of coverage, while the result of the work with conventional heavy disc harrow (HT) and conventional heavy disc harrow with packer (HTGY) there were less plant residues left on the surface than the anticipated (Figure 2).

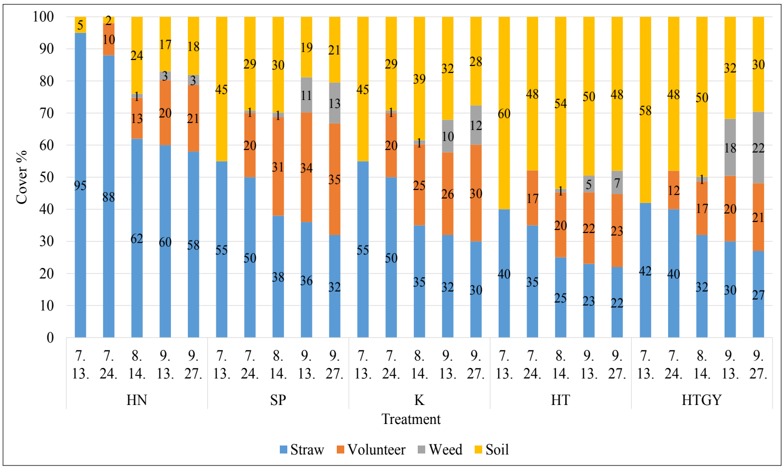

Figure 2. All cover in the shallow tillage treatments (Hatvan, 2008. 07. 13. – 09. 29.)

Treatments: HN: untilled, SP: flat disc, K: cultivator, HT: conventional heavy disc harrow,

HTGY: conventional disc harrow with packer

Straw cover $SD_{5\%}$ 10.85; $SD_{1\%}$ 14.49

Based on the single-factor variance analysis of straw cover P> 0.5% we found that the differences between the number of treatments offered a statistically reliable foundation. These were as follows (where for example the HN SP/K ... etc. denotation indicates the relationship between the HN and the SP, and K ... etc refers to the statistically proven differences between the treatment pairs):

HN-SP/K/HT/HTGY/SZF/VSZ/VSZE/VSZ-SP/L/LE,

SP-HT/SZF/VSZ/VSZE/VSZ-SP/L/LE,

K-HT/SZF/VSZ/VSZE/VSZ-SP/L/LE,

HT-SZF/VSZ/VSZ-SP/L,

HTGY-SZF/VSZ/VSZ-SP/L, and SZF-VSZE/L/LE, VSZ-L/LE, VSZE-L/LE, VSZ-SP-L/LE, L-LE. We found the same treatment pairs, SP-HT, K-HT, and K-LE with the exception of P>0.1% was all proven to be reliable.

Based on the single factor variance analysis of the composite cover (straw, volunteer crop, and weed), P>0.5% also the following treatment pairs can be considered as statistically reliable:

HN-K/HT/HTGY/SZF/VSZ/VSZE/VSZ-SP/LE,

SP-HT/SZF/VSZ/VSZE/VSZ-SP/LE,

K-HT/SZF/VSZ/VSZE/VSZ-SP/LE,

HT-VSZ/VSZE/VSZ-SP/L,

HTGY-SZF/VSZ/VSZE/VSZ-SP, as well as SZF-L, VSZ-L/LE, VSZE-L/LE, VSZ-SP-L/LE, L-LE. The P>0.1% following treatment pairs also achieved the reliable values:

HN-HT/HTGY/SZF/VSZ/VSZE/VSZ-SP/LE,

SP-HT/SZF/VSZ/VSZE/VSZ-SP/LE,

K-SZF/VSZ/VSZE/VSZ-SP/LE,

HT-VSZE/VSZ-SP,

HTGY-SZF/VSZ/VSZE, as well as SZF-L, VSZ-L, VSZE-L, VSZ-SP-L, and L-LE.

A covareg rate can be used for the characterization of the so-called surface coverage whose value is between 0.8 to 1.2 in the case of 45-55% coverage. As time progresses, the amount of crop residues left on the surface decreased at different rates depending on the treatments. Because of the decomposition the function of the surface protection of the stubble residues in the case of SP and K needed to be strengthened from the beginning of August.

In the meantime, weed and volunteer crop growth receive a similar role in surface protection as the stem residue. (Table 6).

Table 6. Changes in the straw:soil coverage ratio over 77 days (Hatvan, 2008)

Day	HN	SP	K	HT	HTGY	SZF	VSZ	VSZE	VSZSP	L	LE
07. 13.	19	1,22	1,22	0,66	0,72	0,12	0,01	0	0,01	2,3	0,49
07. 24.	7,3	1	1	0,54	0,67	0,11	0,03	0	0,01	1,86	0,43
08. 14.	1,63	0,61	0,54	0,33	0,47	0,05	0,01	0	0,01	1,33	0,33
09. 14.	1,5	0,56	0,47	0,3	0,43	0,03	0	0	0	1,22	0,3
09. 27.	1,38	0,47	0,43	0,28	0,37	0,01	0	0	0	0,72	0,27

Treatments: HN: untilled, SP: flat disc, K: cultivator, HT: conventional heavy disc harrow, HTGY: conventional disc harrow with packer, SZF: conventional plow with rotating element, VSZ: reversible plow, VSZE: reversible plow with leveler, VSZ-SP: reversible plow and flat disc, L: loosened, LE: loosened and leveled

In the experiment of the soil moisture, the upper 0-50 cm soil layer measured, since this layer can potentially soak through in the event of a summer rainfall of 40-50 mm, and further the moisture of lower layers, in favorable cases seep upwards into the measured layer. During the first measurement the average of shallow tillage surpassed the average of deep tillage by 14.8%. Due to less precipitation at the end of July, the soil's moisture values have decreased; however at the end of the experiment in all treatments more than 23% mass was measured (conservation tillage, soil cover). The maximum value of soil moisture indicators were SP, K and L (loosening) variants also had the highest values of covering (Figure 3)

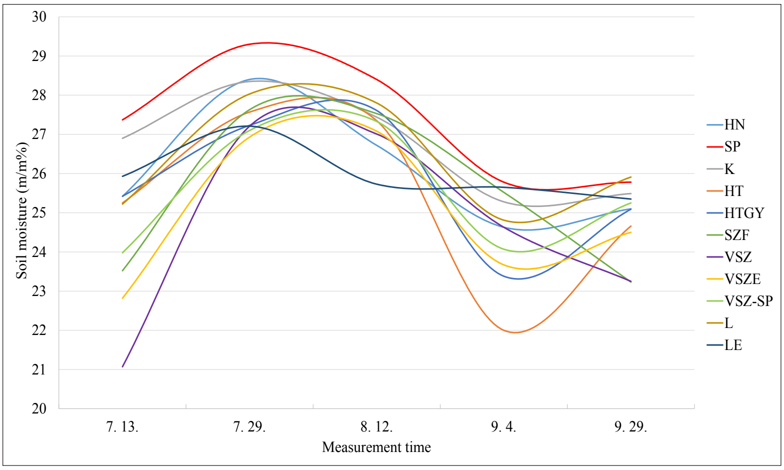

Figure 3. Soil moisture trend of the soil layer of 0-50 cm (Hatvan, 2008. 07. 13. – 09. 29.)

Treatments: HN: untilled, SP: flat disc, K: cultivator, HT: conventional heavy disc harrow, HTGY: conventional disc harrow with packer, SZF: conventional plow with rotating element, VSZ: reversible plow, VSZE: reversible plow with leveler, VSZ-SP: reversible plow and flat disc, L: loosened, LE: loosened and leveled

The 0-50 cm layer of soil moisture differences did not reach reliable statistical value. The strong relationship between the soil surface cover and soil moisture was examined with regression analysis, the weak relationship between the two variables was measured with a bilinear parabola ($R^2 = 0.592$).

The soil penetration resistance of the 0-50 cm layer was measured with a spring penetrometer. Based on the drawn pentagrams from the values of measurements taken every 5/10 cm, we can determine the degree of compactness, and the location of the dense layers. From the value 3 MPa we are talking about compact soil.

The surface layer of the soil which was shallow tilled was loosened until the depth of the disturbance, which means 10 cm for SP and K, and 20 cm in the case of HT and HTGY variants (Figure 4).

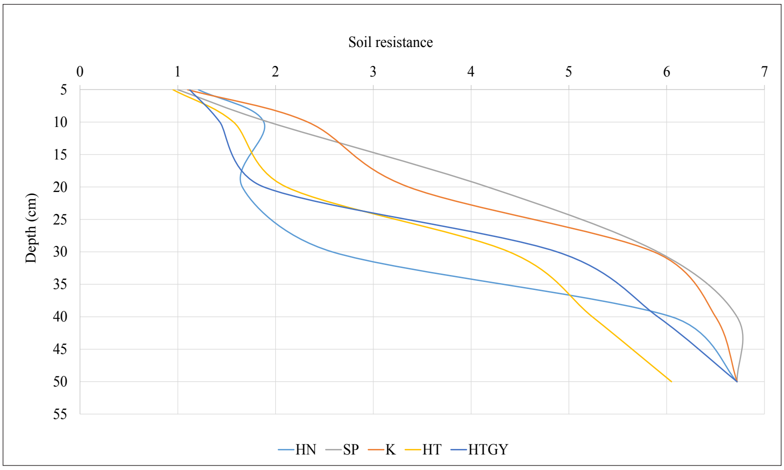

Figure 4. The soil resistance values on the first day of the shallow tillage treatments (Hatvan, 2008.07.13.)

Treatments: HN: untilled SP: flat disc, K: cultivator, HT: conventional disc harrow,

HTGY: conventional disc harrow with packer

The density of the untilled stubble (HN) due to the high density of coverage, in 79 days the value on the 0-10 cm surface layer decreased from 1.88 to 0.67 MPa, and the loosened area covered 30 cm deeper. At the end of the experiment, the depth of the loosened layer grew to 20 cm with the SP and HTGY while it increased by 10 cm in the case of treatment K, whereas the HT version remained the same. The soil resistance during the SP and HTGY treatments decreased more than 50% during the experiment (Figure 5).

We did not find the soil resistivity differences between the different treatments (0-50 cm), neither on the first nor the last day, statistically validated. We identified a weak association between the land cover and soil resistance $R^2 = 0.391$.

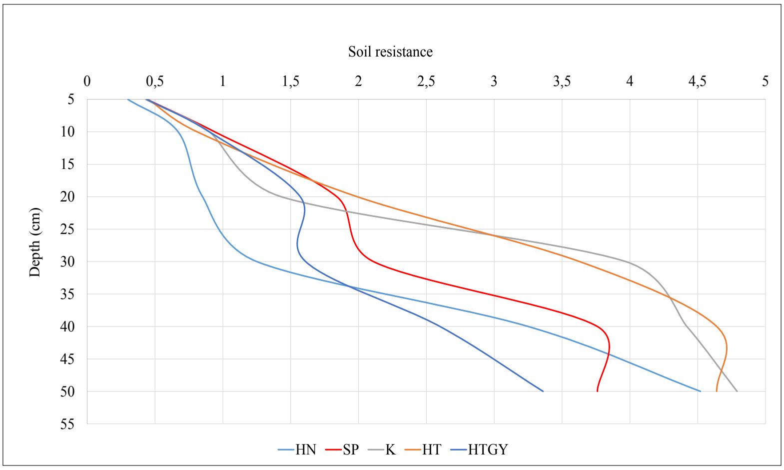

Figure 5. The soil resistance values on 79th day of the shallow tillage treatments (Hatvan, 2008. 09. 29.)

Treatments: HN: untilled SP: flat disc, K: cultivator, HT: conventional disc harrow,

HTGY: conventional disc harrow with packer

The soil constituents from 0.25 to 10 mm in size give the fraction of soil crumbs. The soil's crumbliness is promoted by appropriate dampness, sparing the soil's composition, and actively promoting soil ecology. Upon completion of the experiment, the average cultivation was 20:70:10, which was mainly due to the dust occurred during the plowing treatments. SP, K and HTGY treatments were qualified as favorable in crumb protection, since by the end of the experiment the crumb-ratio in all three cases was over 70%, moreover in the case of SP the value was over 80% which refers to favorable soil structure formation (Figure 6).

During the investigation of the crumb- and dust fraction, we determined that the differences between the treatment pairs did not reach a statistically credible limit.

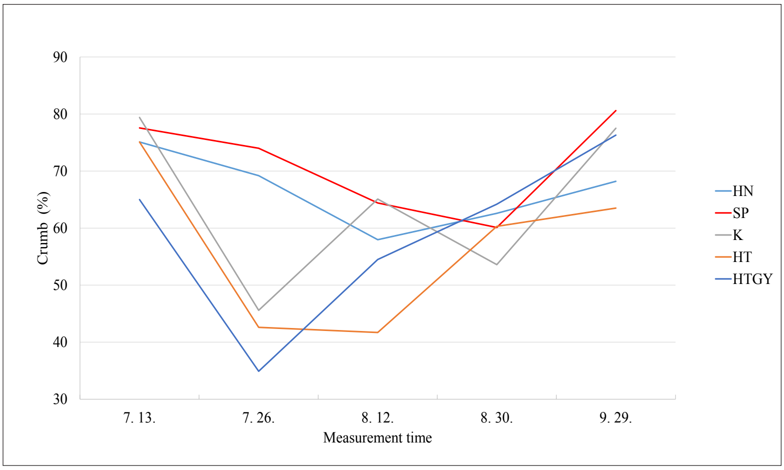

Figure 6. The crumbling trend in shallow tillage treathments (Hatvan, 2008. 07. 13. – 09. 29.)

Treatments: HN: untilled SP: flat disc, K: cultivator, HT: conventional disc harrow,

HTGY: conventional disc harrow with packer

Besides the negative process of soil crumbling, there is also soil clodding. During the tillage of dry soil, dust and clotting occurs, likewise, in wet soil clods form and when they dry out they become rock hard. The ratio of clod (> 10 mm) found after the several plowing techniques such as SZF and VSZ, as well as during leveled plowing (VSZ), loosening (L), and plowing with conventional disc harrow (HT), all showed increased levels until the end of August. By the end of the experiment, however, the values also decreased below 30% (Figure 7).

Regarding clod fractions on the level P> 5% the different values for HN-VSZ/L, SP-VSZ/L, a K-L, VSZ-VSZE/VSZ-SP/LE, VSZE-L, VSZE-SP-L, as well as L-LE, are statistically reliable. However, at the level P> 1% only the difference between versions SP-VSZ/L and L-LE can show us reliable deviation. The connection between soil moisture and soil crumbliness was weak (R^2=0.1616), whereas the connection between the land coverage and soil crumbliness revealed a moderately strong connection (R^2=0.7402).

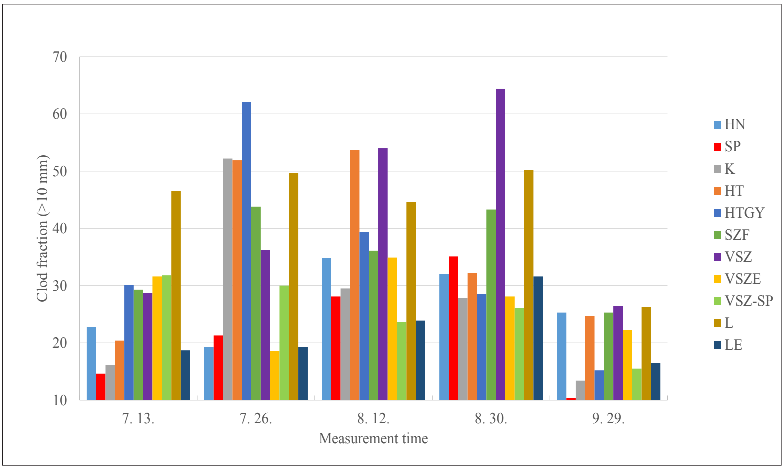

Figure 7. The trend of clod fraction in the case of several tilling methods (Hatvan, 2008. 07. 13. – 09. 29.)

Treatments: HN: untilled, SP: flat disc, K: cultivator, HT: conventional disc harrow, HTGY: conventional disc harrow with packer, SZF: conventional plow with rotating element, VSZ: reversible plow, VSZE: reversible plow with leveler, VSZ-SP: reversible plow and flat disc, L: loosening, LE: loosening and leveling

Clod fraction $SD_{5\%}$ *14.77;* $SD_{1\%}$ *19.74*

The earthworm activity is the indicator of the soil's biological life and physical condition. Probably due to the ongoing dampness and surface coverage of the soil - except for the decline in August - the earthworm count in the soil steadily increased.

The number of 3-4 earthworm per sample (approx. 30-40 /m^2/15 cm) indicates a very good living habitat. During the SP, K and HN treatments in late September 16 to 19 earthworms were found in the 0-15 cm soil layer per square meter, compared to the plowing, nearly double the number of earthworms were measured. (Figure 8).

The differences between the several treatments pairs, were not found to be statistically reliable. However, we have discovered a strong link between the soil covering and earthworm count, as well as soil moisture and earthworm count which is well reflected by the values R^2 = 0.8242, and 0.9066.

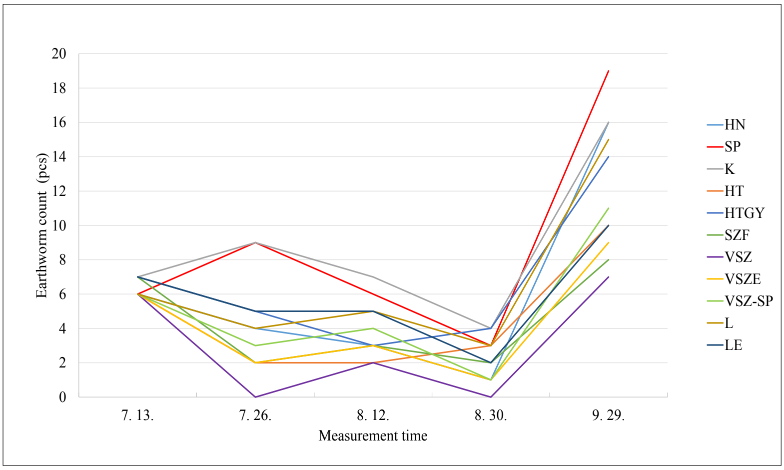

Figure 8. Developments of earthworm count during the different tillage methods (Hatvan, 2008. 07. 13. – 09. 29.)

Treatments: HN: untilled, SP: flat disc, K: cultivator, HT: conventional disc harrow, HTGY: conventional disc harrow with packer, SZF: conventional plow with rotating element, VSZ: reversible plow, VSZE: reversible plow with leveler, VSZ-SP: reversible plow and flat disc, L: loosening, LE: loosening and leveling

3.2. The results of the stubble drilling experiment

In the stubble stripping treatments (B, E) we observed a faster and more intensive decomposition of straw, weed and volunteer seeds emergence. Simultaneously, the emergence and development of cover crop in the plots B and E was more prominent (Figure 9).

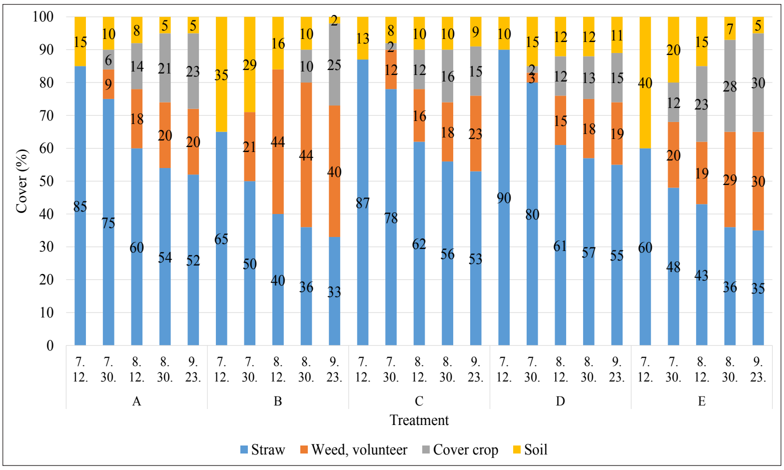

Figure 9. All cover during the stubble drilling experiment (Hatvan, 2008.07. 12. – 09. 23.)

Treatments: A: stubble drilling on the day of harvest, B: stubble stripping on the day of harvest, drilling in August,

C: stubble drilling two days after harvest, D: stubble drilling one week after harvest,

E: stubble stripping on the day of harvest, drilling one week later

Straw cover $SD_{5\%}$ *18.02*

During the dry season (2009) in the direct drilling treatments (A, C, D) 65 to 85%, during the stubble stripping treatments (B, E) 55 to 60% coverage was expected, accordingly the ratio values of coverage ranged from 1.8-5.6 and 1.2-1.5 (Table 7). In the B and E variants as early as July, whereas in the case of A, C and D from the beginning to the middle August it was necessary to reinforce the soil's protective function.

Table 7. Changes in straw:soil coverage ratio (Hatvan, stubble drilling experiment, 2008, 2009)

2008						2009					
Change during 74 days						Change during 101 days					
Day	**A**	**B**	**C**	**D**	**E**	**Day**	**A**	**B**	**C**	**D**	**E**
07.12.	5,66	1,85	6,69	9	1,5	**07.10.**	3	1,5	4	5,66	1,22
07.30.	3	1	3,54	4	0,92	**07.30.**	1,85	1	1,85	2,33	1
08.12.	1,5	0,66	1,63	1,56	0,75	**08.18.**	1,5	0,81	1,22	1,85	0,81
08.30.	1,17	0,56	1,27	1,32	0,56	**09.03.**	1,04	0,66	1	1,22	0,66
09.23.	1,08	0,49	1,12	1,22	0,53	**10.18.**	0,85	0,53	0,81	1	0,66

Treatments: A: stubble drilling on the day of harvest, B: stubble stripping on the day of harvest, drilling in August, C: stubble drilling two days after harvest, D: stubble drilling one week after harvest, E: stubble stripping on the day of harvest, drilling one week later

We have confirmed previous findings, according to which weeds, native desert plants and volunteers play a role similar to the surface protection as cover crop.

During the statistical evaluations, in 2008 we found reliable differences with regards to the straw coverage on the level of P> 5% during the A-B, A-E, B-C, B-D, C-E as well as the D-E treatment pairs. However, there was no justifiable differences between these versions on the level of P> 1%. We found no statistically significant differences between treatment pairs neither with green plants, nor with regards to any soil coverage. In 2009, the statistical analysis pointed out justifiable differences with regards to straw coverage on the level P> 5%, during the B-D and D-E treatment pairs. At the same time, there was no statistically verifiable differences between the various treatments pairs when we examined green plant and all coverage.

In the 2009 experimental period there was 186 mm less rain fall than in 2008. In the stubble stripping treatments (B, E) in both years higher soil moisture values were measured (Figure 10). There were no statistically reliable values relating to the differences in soil moisture between the several different treatments and the two separate years. However, between the soil coverage and soil moisture a strong association was observed in both years which can be represented by bilinear parabola where R^2=0.8785 (2008), R^2=0.885 (2009).

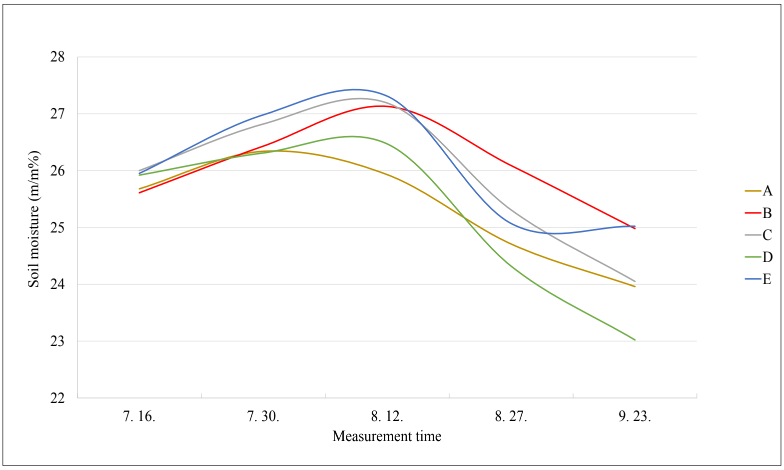

Figure 10. The trend of soil moisture in the 0–50 cm layer (Hatvan, 2009. 07. 16. – 09. 23.)

Treatments: A: stubble drilling on the day of harvest, B: stubble stripping on the day of harvest, drilling in August, C: stubble drilling two days after harvest, D: stubble drilling one week after harvest, E: stubble stripping on the day of harvest, drilling one week later

In both years the measurement of soil resistance carried out on the first day corresponded to the loosening values of the depth of the disturbed layer which were found in the individual treatments, which meant 3-5 cm in the direct drill variants (A, C, D) and 6-10 cm in the stubble stripping variants (B, E) (Figure 11). At the end of the experiment – in both experimental years – the loose layer extended to 20 cm (Figure 12). There were no statistically reliable values relating to the differences between the soil resistance between the several treatments and the two separate years. With the help of regressive analysis in 2008 there was a very strong connection observed between the soil coverage and the soil resistance (R^2=0.8969), and also between soil moisture and soil resistance (R^2= 0.9014). In the following year we discovered there was a weaker correlation between the soil cover and soil resistance compared to the previous year (R^2= 0.720) whereas we detected the strongest correlation between soil moisture and soil resistance (R^2 = 0.9081).

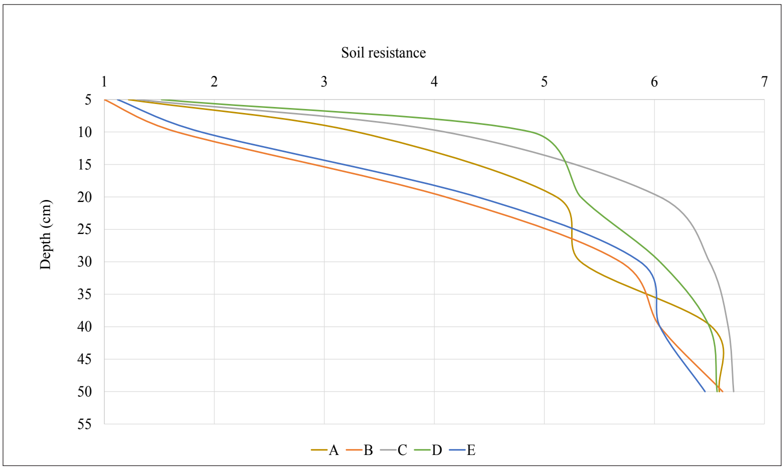

Figure 11. The soil resistance on the first day of the stubble drilling experiment (Hatvan, 2008. 07. 10.)

Treatments: A: stubble drilling on the day of harvest, B: stubble stripping on the day of harvest, drilling in August, C: stubble drilling two days after harvest, D: stubble drilling one week after harvest, E: stubble stripping on the day of harvest, drilling one week later

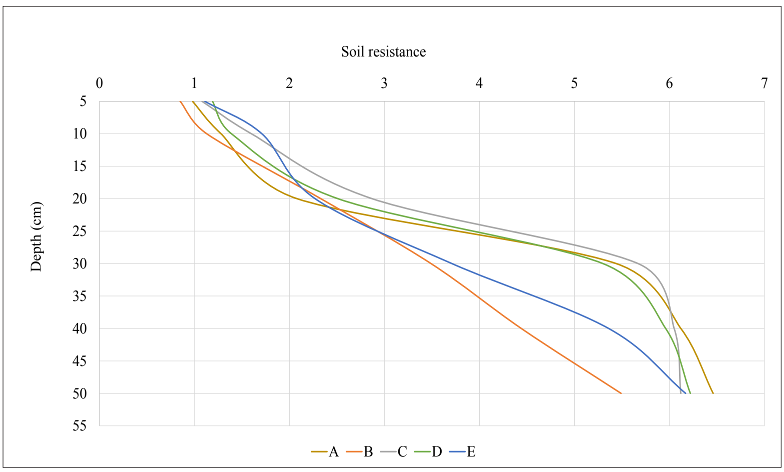

Figure 12. The soil resistance at the end of the stubble drilling experiment (Hatvan, 2008. 10. 09.)

Treatments: A: stubble drilling on the day of harvest, B: stubble stripping on the day of harvest, drilling in August, C: stubble drilling two days after harvest , D: stubble drilling one week after harvest, E: stubble stripping on the day of harvest, drilling one week later

The rate of crumb fraction in both years increased in the stubble stripping treatments (B, E) and reduced in the direct drilling (A, C, D) treatments. The highest value measured was in the treatment B in 2008 (clod: crumb: dust = 18: 79: 3). During the direct drill treatments (A, C, D), the presence of clods in the soil did not lessen by the end of the experiment, while the dust rate in the treatments B and E were more pronounced, the rates decreased by the end of the experiment (Figure 13).

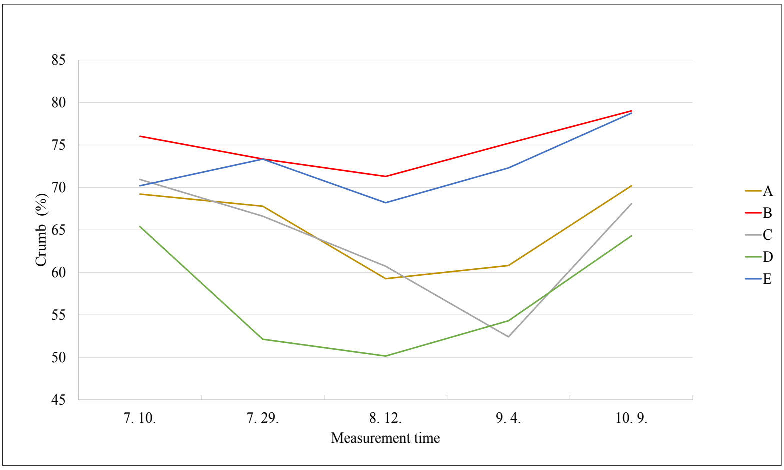

Figure 13. The trend of clod formation during the stubble drilling experiment (Hatvan, 2008. 07. 10. – 10. 09.)

Treatments: A: stubble drilling on the day of harvest, B: stubble stripping on the day of harvest, drilling in August,

C: stubble drilling two days after harvest, D: stubble drilling one week after harvest,

E: stubble stripping on the day of harvest, drilling one week later

Crumb fraction: $SD_{5\%}$ *7.33;* $SD_{1\%}$ *9.99*

In 2008, regarding crumb ratio, we observed statistically verifiable differences at level P> 5% between the treatment pairs A-B, A-D, B-C, B-D, C-E and D-E and at level P>1% during the B-C, B-D, and D-E treatment pairs. In 2008 we observed a very strong connection between soil moisture and crumb ratio (R^2 = 0.8656), and a moderately strong connection between the soil coverage and crumb ratio (R^2 = 0.7882). During the analysis of clod fractions, at the level P> 5% statistically verifiable differences were found during A-B, A-D, B-C, B-D, C-E and D-E treatment pairs, as well as at the level P>1% between the B-C, B-D and D-E pairs. However, with regards to dust fraction, the differences between the several treatment pairs are not statistically reliable. In 2009, in certain fractions, the differences between the treatment pairs do not give us statistically reliable values. We observed a stronger relationship between soil moisture and crumb formation (R^2 = 0.973), and soil coverage and crumb ratio (R^2 = 0,8092), compared to the previous year.

The green-plant product of the five treatments range from 19.89 to 25.52 tons per hectare, which is 40-50% of the potential productivity of mustard and radish (Figure 14). However, it is important to emphasize that the target of our experiment was to achieve perfect soil coverage, and not to achieve higher green mass. The green plant mass of the plot drilled in August (B) – because of the improving soil conditions - surpassed the previous month direct drilling treatments (A, C, D). The single factor variance analysis of plant maturity revealed statistically verifiable differences at level P> 5% during the A-C, A-D, C-E and D-E treatment pairs, and at level P> 1% between the C-E and D-E variants. The relationship between the cover crop and green mass can be described by a bilinear parabola. We found a strong connection between the two variables, where R^2 = 0.9519.

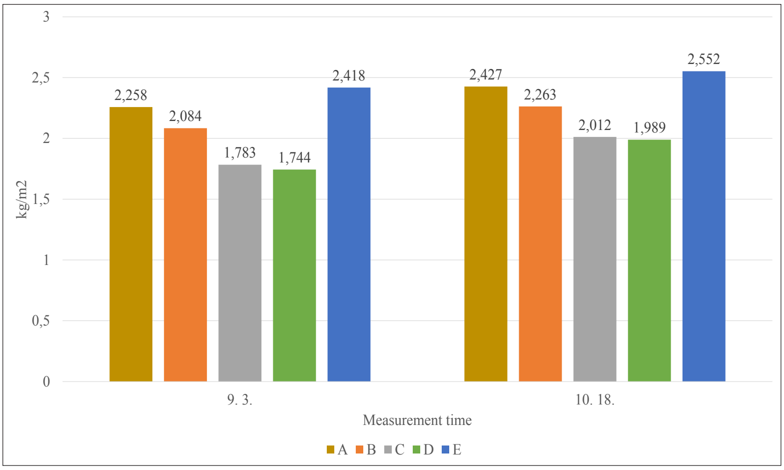

Figure 14. Green plant mass of the cover crop during the stubble drilling experiment (Hatvan, 2009. 09. 03. – 10. 18.)

Treatments: A: stubble drilling on the day of harvest, B: stubble stripping on the day of harvest, drilling in August,

C: stubble drilling two days after harvest, D: stubble drilling one week after harvest,

E: stubble stripping on the day of harvest, drilling one week later

$SD_{5\%}$ *0.35;* $SD_{1\%}$ *0.55*

During the study of soil penetration the soil of all treatments was loosened up to a depth of 20 cm (<3MPa) at the same time the root depth for each variant exceeded this level, moreover in the case of E it exceeded 30 cm. (Figure 15). This reflects the general view that some plant species have a soil loosening quality because of their strong root growth, and if the soil dosen' t have thick disc or plow pans, then this will prevail.

The single-factor variance analysis of the root length found statistically verifiable differences at level P> 5% during the A-C, A-D, B-E, C-E and D-E treatment pairs, and at level P> 1% between A-D, C-E and D-E versions. The relationship between root mass and root length can be described using a bilinear parabola. We found a strong relationship between the two variables, where $R^2 = 0.9719$.

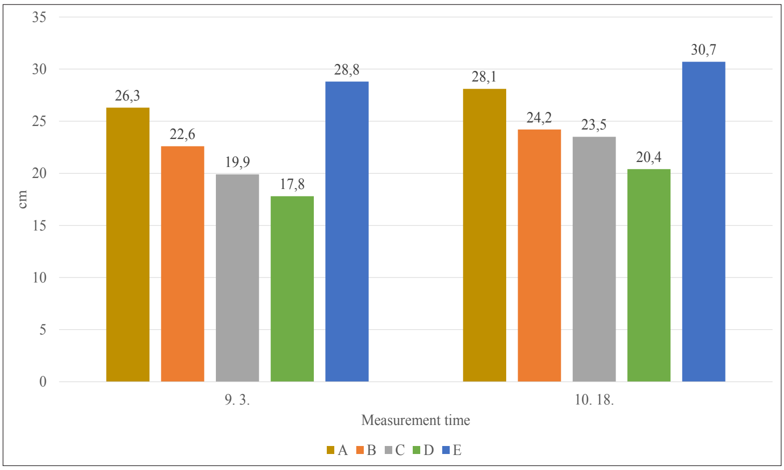

Figure 15. Root length of cover crop during the stubble drilling experiment (Hatvan, 2009. 09. 03. – 10. 18.)

Treatments: A: stubble drilling on the day of harvest, B: stubble stripping on the day of harvest, drilling in August,

C: stubble drilling two days after harvest, D: stubble drilling one week after harvest,

E: stubble stripping on the day of harvest, drilling one week later

3.3. New scientific results

The results of the new scientific experiments on the subject of „Stubble maintenance using tilling and biological methods" are as follows:

1. I worked out a so-called coverage ratio to characterize the soil coverage. I concluded that due to the reduction or lack of stubble residue, the value of soil coverage can show us be unfavorable by midsummer. To counteract this, we need to strengthen the surface protection effect of stubble residue by a simple adaptive manner.

2. I proved that in the case of weed and volunteer seed growth the regulated use of soil moisture can be used to reinforce the function of soil protection.

3. For the given crop production area, I defined in values how important role the mulch layer (left behind of modern tillage implements - flat disc, stubble cultivator) plays in retention of the soil moisture and thus the emerging of weeds and volunteers.

4. Using soil condition indicators - coverage ratio, crumb ratio, moisture, soil resistance, earthworm count – I was able to pinpoint the shortcomings of conventional stubble tillage in the process of soil regeneration.

5. I established the critical points of stubble drilling for soil conservation purposes during the dry and volatile summer season.

6. I proved that the timing of stubble drilling can logically be adapted in order to maintain surface protection. The shortage caused by the decline of straw cover can be replaced by live cover to maintain surface protection.

7. I demonstrated that the direct result of stubble drilling is modulated by the moisture retaining function of the straw cover.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. The lessons of the stubble stripping experiment

– At the start of the experiment we assumed that the expectations connected to the amount of cover material will vary depending on the given periods' rainfall and soil disturbance. Based on the rainfall in 2008, 45-55% coverage was to be considered acceptable after the stubble stripping period. Two of the shallow tillage techniques, conventional heavy disc harrow (HT), and the leveling version (HTGY) did not fulfill the required criteria after the stubble stripping. However, on the plots treated with soil mulch tools, that is the flat disc (SP) and the stubble cultivator (K) by mid-August at the time of the third measurements, the amount of soil cover material decreased below the critical value. The straw soil so-called coverage ratio value at this time reduced below the minimum level, which was 0.81. During the hot and dry summer months, especially from the end of July the straw cover must be supplemented, its protective function should be strengthened. To achieve this target weed and orphan seed, as well as plant cover crop can be used. Thanks to the coverage of green plants (weed and volunteer) the necessary values of surface protection were kept throughout the whole experiment. Out of the deep tilling techniques the plowed soil had a value of 45-52% of green coverage, which initially provided some protection from the dusty soil structure, and later on the muddy and incrusted soil. The leveling of the soil greatly improved the surface coverage, and surface protection. The conventional heavy disc harrow technique, including leveling, (HTGY) gave us a 23% higher value of straw coverage and a 43.3% higher value of green plant coverage compared to the conventional heavy disc harrow version without leveling. In practice, the favored procedure is to loosen the stubble soil (L) immediately after the harvest, which can be considered risk-free, if the unleveled surface is not rough or losing water. With the procedure of leveling, there was a greater ratio of weed and volunteer coverage on the plots treated with the LE technique, which replaced the rapidly dwindling straw coverage. Thus at the end of the experiment it was found that there is only 5% difference between all coverage, between the two versions of soil loosening treatments. Based on the single-factor variance analysis of straw and all soil coverage, statistically verifiable differences were observed between the treatment pairs.

– For the experiment, the optimum soil moisture value of tillage is at 22%. When setting up the experiment, the average moisture content in the 0-50 cm soil layer varied from 21.07 to 27.37%, showing different values for each treatment. The moisture percentage of the shallow tillage treatment surpassed the moisture percentage by 14.8% on plowed land. Despite the emerging dry period at the end of July, by the end of the experiment we measured soil moisture content at over 23% in the 0-50 cm soil layer, which is not only attributed to precipitation, but the moisture conservation tilling methods as well as the gradually changing quality, but ever-present mulch. The differences between the treatment pairs did not reach statistically reliable values. The most successful variants, SP, K and L had the largest surface cover rate at the end of the experiment.

– After setting up the experiment, the soil where shallow tillage treatments took place were loosened up to the depth of disturbance which was 10 cm in the case of SP and K, and 20 cm in the case of HT and HTGY treatments. On the plowed plots, we experienced loose soil at 25 as well as 32-34 cm in depth, while the effect of the loosening was not justifiable, since the soil was damper than the optimal at 30 cm. During the 77 day long experiment, in the top 10 cm soil layer of the untilled stubble (HN), the value of soil resistance reduced from 1.88 to 0.67 MPa, and the loose soil spread to 30 cm deep. The favorable moisture circulation is one of the positive results of mulch. The compactness of all treatments eased, in the case of SP it reduced to 51, while the version HTGY reduced to 55%. By the end of the experiment the loosened soil layer deepened 20 cm in the case of SP and HTGY treatments, and 10 cm in the case of plot version K. It has not changed for the HT version. The differences between the treatments did not reach statistically reliable values.

– The clod: crumb: dust ratio in the area of the experimental soil before tillage was 23:75:2 and by the end of the experiment it changed to 20:70:10 because of the dust occurrence during the plowing treatments. For soil crumb protection the mulching SP, K and HTGY treatments qualified as favorable, since in all three versions crumb ratio was above 70%, moreover it exceeded 80% in the case of SP. The crumb fraction measured on the undisturbed stubble decreased by 9.2% by the end of the experiment, which is believed to have occurred due to the reduced cover and soil moisture. Leveling increased crumb ratio by 15.9% and 27.6% with the two reversible plow versions including leveling (VSZE and VSZ-SP) compared to the unleveled plowing (VSZ). The better result of the VSZ-SP version focuses our attention towards a more effective, and better paced plow-leveling. Not with regards to the crumb and dust fraction, however with the analysis of the clod fraction we were able to find statistically reliable differences in value between the several treatment pairs.

– The experiments confirmed the known relationship which exists between intensively disturbed soil and the low earthworm population. At the end of September during the SP, K and HN treatments 16 to 19 individuals were counted in the top 0-15 cm soil layer per square meter, which was nearly twice the number of individuals compared to the conventional plowing. In the mid-deeply loosened and leveled LE version the earthworm count came very close to the earthworm-friendly SP and K versions, where loose, moist soil structure and a covered surface was the underlying factor.

– To summarize, by analyzing the characteristics of the condition of the soil, we can conclude that amongst the shallow tilling treatments the HN, SP, K and HTGY treatments, and amongst the deep tilling treatments the VSZ-SP, L, and LE treatments can be worth considering as summer tillage treatments. All examined parameters in the SP, K and HTGY treatments excelled. The choice between flat disc (SP) and the cultivator (K) can be influenced by the quality of stubble and crop residue. In case of more efficient straw chopping and/or less weedy soils the cultivators would be a better choice. They can be used on a broader range of soil moisture, compared to flat discs, therefore damp and dry soil can be tilled with less damage. The flat disc can rather be used for tilling dry and wet soil, however the danger of dust formation – as shown in our experiment – is plausible. Even though the conventional heavy disc harrow with the packer (HTGY) resulted in some shortcomings with regards to clod crushing and surface covering, it is still a tool that can be recommended for summer stubble management with a footnote, that we should always be attentive to the soil moisture. In the rainy season it can effectively eliminate the tire tracks left during harvest time, but in the 10-cm soil layer it creates a dense disc pan layer. The undesirable cloding of the soil during the HN and L method is a concern. In the case of the HN treatment, it seemed that under the plant cover the soil was unable to dampen itself as well as during the shallow tillage treatment where the soil was tender and powdery. The high clod fraction ratio of treatment L supported earlier findings which confirmed that the soil of the ripening drilled stubble can be tilled with less energy and better quality, therefore the direct loosening of the stubble can lead to clodding. At the same time the leveled and loosened LE treatment, regarding crumbliness, stands closer to the cultivator tilling technique, and is only second to the deep tilling treatment because of its medium earthworm activity. Amongst the plowing techniques, the flat disc and leveled treatment (VSZ-SP) showed positive values. Because of the deep soil disturbance, the earthworm activity was naturally lower, however the crumbliness and soil moisture was favorable which relates to the leveling of the surface and the green coverage. Despite all this, summer plowing is a risky intervention and is not considered as a climate stress mitigating procedure. The deep disturbance of the compact layers of soil during the period of vegetation, even in the event of immediate leveling, does not serve the renewal of the soil in the stubble phase. The soil cover which plays an important role in the surface protection and is an important step in the soil ripening phase, does not provide protection under the critical summer months.

The analysis of the effect on the characteristics of the soil condition during several treatments, are summarized in Table 8.

Table 8. The ranking of the several treatments in the stubble tillage experiment based on the characteristics of the soil condition (best 1, weakest 11)

Treatment	Soil condition characteristics					Ranking
	Cover after tilling	Soil moisture	Depth of loosened soil	Agronomic structure	Earthworm count	
HN	1	6	3	7	3	3
SP	3	2	1	1	1	1
K	3	3	2	2	2	2
HT	4	8	3	9	9	8
HTGY	5	7	1	5	5	4
SZF	NÉ	11	4	8	11	10
VSZ	NÉ	10	4	10	10	10
VSZE	NÉ	9	4	6	9	9
VSZ-SP	NÉ	5	4	4	6	6
L	2	1	NÉ	11	4	5
LE	6	4	NÉ	3	7	7

Treatments: HN: untilled, SP: flat disc, K: cultivator, HT: conventional disc harrow, HTGY: conventional disc harrow with packer, SZF: conventional plow with rotating element, VSZ: reversible plow, VSZE: reversible plow with leveler, VSZ-SP: reversible plow and flat disc, L: loosening, LE: loosening and leveling

**NÉ: not explainable*

4.2. Lessons from the stubble drilling experiment

– The discussion of the stubble drilling experiment was sorted into two groups; stubble stripping (B, E), and direct drilling (A, C, D) variants. Based on the precipitation of 2008, after setting up the experiment, it was agreed that for direct drilling parcels 60-70%, and for stubble stripping treatments 45-55% would be the acceptable value for coverage. In the experimental period of the next year, 186 mm of less rain fell, therefore it was agreed that for the stubble stripping treatments 55-60%, and for the direct drilling treatments 65-85% would be the acceptable harvest values. We determined that from the end of July – beginning of August the protective function of the surface residue needs to be supplemented depending on the type of treatment. The greater ratio of incorporation during the stubble stripping treatments, as well as the more intensive straw decomposition due to better soil conditions reduced the amount of stubble residue on the surface, likewise to the direct drilling methods, which were well compensated by the vivid weed and volunteer seed growth as well as the development of cover crop. Regarding the straw coverage in both years there were statistically verifiable differences detected between the several treatments pairs.

- There were no statistically verifiable differences found between the several treatment pairs regarding the value of soil moisture in the 0-50 cm layer of soil, although the moisture diagrams were different between the two study years. The advantage of the stubble stripping treatments was manifested through a higher moisture content percentage.

– The analysis of the soil resistance in both years – regardless of the treatments - revealed a deepening of a loosened layer of soil, which is due to surface saving disturbance and coverage. The stubble stripping and the direct drilling treatments are both shallow tilling procedures, during the set up of the experiment the plots showed 3-5 cm (direct drilling treatment) and 6-10 cm (stubble stripping treatments) deep loosened soil. The depth of the loosened soil layers in both years, for each treatment, spread to 20 cm deep at the time of the last measurement. The differences between the resistance of the soil did not reach statistically reliable values in neither treatment pair nor either year.

– The examination of the agronomic structure showed a lot of similarities throughout the two experimental years. The ratio of crumb fraction increased in both years during the stubble stripping treatments (B, E), and showed a decrease on the direct drilled land plots (A, C, D). This is due to the combined effect of two factors. The flat disc which performed the stubble stripping levels and closes off the disturbed surface with better efficiency compared to the packer wheels of the direct seeder machine. At the same time the stubble stripping treatment generated a shallow, tender, insulated soil layer, under which process of the soil's dampening occurred more intensively compared to the direct drilled plots where the surface was covered with a large amount of straw. Thus the cloddiness of the plots where the direct drilling treatment was used did not decrease. In addition, in the drier year in 2009, the cloddiness became a major process. The weaker agronomic structure manifested in weaker weed an volunteer coverage.

– The study of the cover crop has called attention to the fact that sowing in mid-August (B treatment) achieved a higher soil coverage level – thanks to the improving soil conditions- compared to the direct drilled plots (A, C, D) which were set up one month earlier. By the end of the experiment in all treatments, the measured root depth exceeded the 20 cm deep loosened layer of soil. This supports the view that certain plant species have a soil loosening effect thanks to their strong roots, which comes into effect if the soil dosen't have thick disc or plow pans. In the case of the plants sowed for soil protective purposes, the level of surface coverage is more important than the green plant product, therefore the 19.89 – 25.52 t/ha yield is an acceptable value.

– Overall, we can conclude that all treatments of the stubble drilling experiment which was set up two years in a row, resulted in shallow disturbed soil. Because of this, soil moisture with regards to soil resistance did not result in statistically verifiable differences between each treatment. The minimum green plant vegetation (weed and volunteer, cover crop) supplemented with surface coverage, was 82 % (D treatment in 2009), therefore the soil protection expectations in all treatments were realized. The agronomic structure and soil moisture worked out in a more favorable way in the case of the stubble stripping treatments, which had an effect on the growth and progress of weed and volunteer seed as well as cover crop growth. Therefore the stubble drilling performed on the day of harvest, then the drilling performed one month later (E), and performed in August (B), turned out to be the more perspective procedure. The direct drilling procedure can be considered in years with more precipitation, when the greater soil disturbance would contribute to cloddiness. Direct drilling can give us good results in dry years as well, namely if the tilled soil is rested for a certain amount of time under a cover of straw (C and D treatments). The sandy soil exposed to deflation, as well as erosion-affected forest and shallow topsoil, direct drilling can come into focus with eroded soil, because after the harvest the reduction of disturbed soil can reduce soil loss.

The several treatments studied in the experiment based on the characteristics of the soil condition are summarized in the Table 9.

Table 9. The ranking of the several treatments in the stubble drilling experiment based on the characteristics of the soil condition

Treatment	Soil condition characteristics										Ranking
	Change in the coverage		Soil moisture		Depth of the loosened soil		Agronomic structure		Cover plant number	Root length of the cover crop	
	2008	2009	2008	2009	2008	2009	2008	2009	2009	2009	
A	3	3	3	4	1	1	3	5	2	2	3
B	2	2	1	2	2	2	1	1	3	3	2
C	4	4	4	3	1	1	4	3	4	4	4
D	5	5	5	5	1	1	5	4	5	5	5
E	1	1	2	1	2	2	2	2	1	1	1

Treatments: A: stubble drilling on the day of harvest, B:stubble stripping on the day of harvest stubble cultivation, drilling in August, C: stubble drilling two days after harvest, D: Stubble drilling one week after harvest, E: Stubble stripping on the day of harvest, stubble drilling one week later

SCIENTIFIC PUBLICATIONS WRITTEN ON THE SUBJECT

Scientific Publications

Foreign Language scientific publications:

1. *Kalmár T., Bottlik L., Kisic I., Gyuricza Cs., Birkás M*. (2013): Soil protecting effect of the surface cover in extreme summer periods. Plant, Soil and Environment, 59: (9) 404-409. (IF: 1,113)

2. *Birkás, M., Kisic, I., Bottlik L., Jolánkai, M., Mesic, M., Kalmár T.* (2009): Subsoil compaction as a climate damage indicator. Agriculturae Conspectus Scientificus, 74: (2) 1-7.

3. *Birkás M., Kalmár T, Bottlik L., Takács T.* (2007): Importance of soil quality in environment protection. Agriculturae Conspectus Scientificus, 71: (1) 21-26.

Hungarian scientific publications:

4. *Birkás M., Kalmár T., Kisic I., Jug D., Smutny V., Szemők A.* (2012): A 2010. évi csapadék jelenségek hatása a talajok fizikai állapotára. Növénytermelés, 61: (1) 7-36

5. *Kalmár T., Birkás M., Stingi A., Bencsik K.* 2007. Tarlóművelési módszerek hatékonysága szélsőséges idényekben. Növénytermelés, 56: (5-6) 263-279

Other scientific works

Foreign Language conference publications:

6. *Kalmár T., Pósa B., Sallai A., Csorba Sz., Birkás M.* (2013): Soil quality problems induced by extreme climate conditions. Növénytermelés, 62: (Suppl.) pp. 209-212.

7. *Kalmár T., Csorba Sz., Szemők A., Birkás M.* (2011): The adoption of the rain-stress mitigating methods in a damaged arable soil. Növénytermelés, 60: (Suppl.) pp. 321-324

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9. *Birkás M., Stingli A., Szemők A., Kalmár T., Bottlik L.* (2008): Soil condition and plant interrelations in dry years. Cereal Research Comm. 36: (Suppl.) pp. 15-18.

10. *Birkás M., Kalmár, T., Fenyvesi L., Földesi P.* (2007): Realities and beliefs in sustainable soil tillage. Cereal Research Comm. (35): (Suppl. 2) pp. 257-260.

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