Soil protecting effect of the surface cover in extreme summer periods

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ABSTRACT

It was to investigate the effects of mulch cover and stubble tillage on soil water content and to assess grounds of recommendations in stubble management in an extreme dry period. Tests were carried out in undisturbed (U) soil, after shallow (S) and deep (D) tillage, soil with (UCO, SCO, DCO) and without surface cover (UCL, SCL, DCL) and after conventional stubble treatment (STR). Effective moisture conservation (8–11%) was observed in undisturbed soil under 55% and 65% cover ratios. The water content in the top 0.65 m soil layer increased significantly (*LSD*, $P < 0.05$) between the different stubble variants, the following order was established on day 85: DCL < STR < SCL < UCL < DCO < SCO < UCO. The conventional stubble management cannot be applied in soils after shallow (STR) or deep tillage (DCL) in a dry season, when the loss of water is even statistically proven. Leaving the soil without a cover (UCL) or having it with insufficient cover (< 15%) entails risks in soils. Increasing the soil cover ratio (from 5% to 75%) had a 1.3–2.3 times stronger impact on crumb forming than did the moisture recorded in the various seasons.

Keywords: summer tillage; stubble residues; moisture conservation; climate

Soil protection has been a key subject of research and publications for decades now, and the results achieved so far are taken into account in the development of farming practices (Némethy et al. 2006, Spoljar et al. 2011). The practical solutions applied in protecting soils are just as varied as are the types of damage affecting soils across the world (Sarkar and Singh 2007, Shen et al. 2012). Thanks to its diverse and, for the most part, positive impacts, surface cover belongs to the category of special means of soil conservation. The first results came from the work of North-American researchers (Magleby et al. 1985). Covering the soil was found to be an effective approach to control dust storms on the Great Plains in the 1930s (Allen and Fenster 1986). Some decades later, the soil conservation tillage was really accepted (Schertz 1988). Assessments of the soil protecting effects of plant residues have been and are being conducted in areas exposed to erosion, in parallel with no-till experiments, quite understandably, as the rates of surface cover are up to 30–100% in no-till systems (Mikanová et al. 2012, Soane et al. 2012). Crop residues as a possible material for soil conservation came under the limelight again, at a time when they started to be used as a source of 'bio-energy' (Lal 2009). Materials for soil protection are required at different times and in different quantities in the different regions (Cannell 1985, Gruber et al. 2012). Keeping crop residues on the surface or near the surface entails crop protection-related issues (Váňová et al. 2011). Climate-induced damage however, is observed frequently outside the growing season in some regions.

The first experience with surface cover was reported in Hungary in 1909 and two of classic

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authors, Manninger and Kemenesy were encouraged first to use a mulch in summer tillage in the 1930's (Birkás 2012). The training of mulch-tillage in Hungary was laid down 32 years ago (Birkás 2012), and the ratio of mulch-tilled fields has increased to 70–75% by today.

Although different mulch tillage systems have been widely investigated on different arable sites, relatively few trials were conducted on soil preservation outside the growing season. Since the period after summer harvest is growing increasingly critical from the aspect of the soil, this is one of the focal issues of our investigations. Each of the factors that are being studied – surface cover, moisture content, penetration resistance and crumb forming – affects each of the other factors under review. This is why we found it important to study surface cover ratios and to set up an order in terms of effectiveness.

MATERIAL AND METHODS

Site description and experimental design. Since 2004, the stubble-climate experiment has been repeatedly conducted in the harvested wheat fields of the Experimental and Training Farm of the Szent István University, located in the region of the town, Hatvan (47º41'N, 19º36'E, 136 m a.s.l.) on Chernic Calcic Chernozem soil (WRB 2006) with a clay loam texture. In this region, the long-term annual mean temperature is 10.0°C and the precipitation is 580 mm. The given years' precipitation figures are as follows: average (2009), dry (2011 – 283 mm, 2012 – 286 mm) and rainy (2010 – 371 mm).

The experiments involved two main types, namely undisturbed soils (1, U) with clean (UCL) and covered (UCO) – from 5% to 75% – surface variants (e.g. UCO10, UCO25 etc.), and tilled (2) soils. Variants of the tilled soils were: shallow disturbance (0.06–0.08 m) with clean surface (SCL), shallow disturbance (0.06–0.08 m) and covered, consolidated surface (SCO), shallow disturbance (80–100 mm) with clean, and cloddy surface (STR), deep disturbance with clean and cloddy surface (DCL) and deep disturbance with covered surface (DCO). Ratio of the SCO and DCO variants was 45%. The UCO and SCO variants fall under modern stubble managing methods and variant STR represents the traditional mode. Tools of the shallow disturbance were flat plate disk and mulch-cultivator. Deep tillage (DCL) was executed by a reversible plough (0.30–0.32 m), a subsoiler (0.40–0.45 m) and a roll (DCO). Stubble tillage performed within 1–3 days after harvest. The size of each plot was 60 × 10 m and arranged in strips at random, with four replications. Places for measurements were pointed in each strip with an area of 8 m × 4 m and these micro plots were kept free from weeds.

Soil surface cover. Checking and correcting of the chopped straw cover to the planned ratios a quadrate device with area of 0.50 m × 0.50 m was used. Moreover, the meterstick method (Hartwig and Laflen 1978) was also applied in the assessing process. Poor ratio of the cover (0–20%) represents the conventional idea and further variants (≥ 25 and ≤ 75), according to our schedule, may fill the climate mitigation requirements.

Soil moisture. Measurements were taken with the PT-I type gauge (Kapacitiv Kft, Budapest, Hungary). The LCD display of the instrument shows the moisture content in terms of %, g/g. Soil water content was also measured gravimetrically at 0–0.65 m and 0–1.00 m from every 0.05 m layer in six repetitions, and calculated from the difference between the weights of the samples before and after drying at 105°C for 24 h. The water content of soil immediately after harvest was examined, and that was repeated in the required intervals. The short term (11^{th} day after harvest) and the long-term (45^{th}, 65^{th} and 85^{th} day after harvest) efficiency of the surface cover are discussed.

Penetration resistance was recorded using a handheld Szarvas-type penetrometer (Szarvas, Hungary) having 10.0 mm diameter cone and a 60° apex, at soil depths of 0.55 m at each 0.05 m increment, in at least six repetitions. The tip of the probe should penetrate the soil at a standard speed of 20 mm/s. The force meter's scale is calibrated for 150 lbf, at 2 lbf intervals. Multiplying the readings by 0.04448 yields the soil's resistance value in MPa. Sampling times followed the measurements of the water content.

Samples for assessing aggregate size distribution were taken just after harvest and later in 10-day interval in each variant in six repetitions, were air-dried and then they were gently sieved (60 shakes/min). The grades measured were < 0.25, 0.25–2.5, 2.5–10, and > 10 mm. Ratios of these particles are adequate in ranking of the tillage variants in summer (Huisz et al. 2009). The mass distribution between the grades was also established. The relations between the assessed factors were evaluated by a multiple regression analysis.

Statistical analyses. The data were statistically analysed to determine the significance of the treatments on the measured parameters. Statistical analyses were performed using IBM SPSS Statistic 20 (Gödöllő, Hungary). ANOVA was performed at a 0.05 level of significance to determine whether the treatments were different. Multiple comparisons were made between the significant effects using the least significant difference (*LSD*) test at α = 0.05. Analysing the parallel effect of the water content and the cover % on soil crumbling a regression analysis with two independent variables (Sváb 1981) was used. Correlations between the individual data were controlled using Microsoft Excel (Gödöllő, Hungary).

RESULTS AND DISCUSSION

Surface cover and soil moisture conservation. A total of 78 mm rain fell in the first half of 2012 in the experimental field, 210 mm less than the long term average for the same period. The amount of water that remained in the top 0.65 m soil after harvest was 0.248 g/g (239 mm), while in the 0.65–1.00 m layer it was 0.267 g/g (150 mm). No rain fell until the 66^{th} day and thereafter a mere 59 mm rain fell until the 85^{th} day, therefore particular attention was paid to conserve the water in the soil. A number of techniques without soil disturbance were applied, with cover ratios in the 0–65% range (Figure 1). Soil cover is found important in retaining the moisture moving up from the deeper layers of soil towards the surface. Less moisture was found at clean surface and in the soil under a 10% cover after the passage of 45 days. The moisture content of the soil under a 25–35% surface cover equalled the level measured right after harvest. More effective moisture conservation (8–11%) was found under 55–65% surface cover ratios. Increasing ratios of the surface cover significantly ($LSD_{0.05}$ 0.00378, $P < 0.05$) improved the soil moisture content at the depth of 0–0.65 m. Szász (1997) reported that the evaporation rate through a bare surface at a 15°C average daily temperature is 3.4 mm/day. The rate of soil moisture loss can, however be controlled (Birkás 2011). Mitigation of the soil moisture loss during the growing season was confirmed by authors (e.g. Sarkar et al. 2007, Shen et al. 2012). Since the advantages of undisturbed soils were proven from the aspects by direct drilling (Soane et al. 2012, Roper et al. 2013), the recommendations can be applied to the period outside the growing season as well. The stubble techniques applied during the dry season of 2012 were even more important than in an average year. The average soil moisture levels measured on the 11^{th}, 45^{th}, 65^{th} and 85^{th} day after the beginning of the experiment are presented in Table 1. Significant differences were found in the soil moisture levels in the top 0.65 m soil layer in each of the periods (*LSD*, $P < 0.05$). The highest moisture levels were measured in the undisturbed and covered soil (UCO). The second highest levels were found at shallow tillage with surface cover (SCO). According to Schertz (1988) soil conserving tillage is characterised by at least 30% cover ratio after sowing, therefore at least 45% ratio of cover – by evenly chopped straw – may be justly expected to be present on stubbles in a dry year. The last position in our rank was taken by deeply tilled soil with a bare surface (DCL) where the soil moisture content declined steadily until day 65 and it increased slightly even after the modest rains recorded during the period. This finding is, at the same time, an objective criticism of the summer ploughing. The STR variant representing conventional stubble treatment came in fifth in the ranking order. Surface free of residues was an objective of stubble management for decades and it believed to be good even if the soil contained a large proportion of clods. This however, does not meet the new requirement of reducing the loss of moisture (Kalmár et al. 2007, Várallyay 2011). Considering the moisture loss, the SCL variant shows a slightly favourable moisture balance than does the STR but the bare surface turned into a disadvantage during the given dry period.

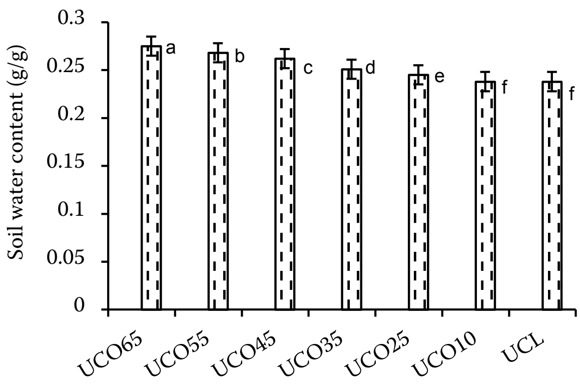


Figure 1. Average values of water content in undisturbed stubble soil (0–65 cm) at seven surface cover treatments, on the 45^{th} day after harvest. Vertical bars are standard errors. Columns designed by the same letter do not differ significantly ($P = 0.05$). UCO – undisturbed and covered with the ratio of 65, 55, 45, 35, 25, 10; UCL – undisturbed, clean

Table 1. The values of the significant differences and the moisture content differences of soil (0–65 cm) between 1st and further days at different stubble management in an extreme dry season

Treatment	11st day		45th day		65th day		85th day	
	mean	difference between 1st–11th day	mean	difference between 1st–45th day	mean	difference between 1st–65th day	mean	difference between 1st–85th day
UCL	0.244a	–0.004	0.238a	–0.010	0.238a	–0.010	0.248a	0
UCO	0.269b	+0.021	0.251b	+0.014	0.267b	+0.019	0.270b	+0.022
SCL	0.238c	–0.010	0.233c	–0.015	0.243c	–0.005	0.245ac	–0.003
SCO	0.268d	+0.020	0.240ad	–0.008	0.265bd	+0.017	0.258d	+0.01
STR	0.231e	–0.017	0.213e	–0.035	0.218e	–0.030	0.229e	–0.019
DCL	0.220f	–0.028	0.200e	–0.048	0.213f	–0.035	0.225ef	–0.023
DCO	0.229g	–0.019	0.233cf	–0.015	0.258g	+0.010	0.250ag	+0.002
$LSD_{0.05}$	0.0042		0.01213		0.0189		0.042	

Different letters document statistical differences between moisture contents of soil (g/g). UCL – undisturbed and clean surface; UCO – undisturbed and covered surface*; SCL – shallow tillage and clean surface; SCO – shallow tillage and covered surface*; STR – shallow tillage traditional; DCL – deep tillage and clean surface; DCO – deep tillage and covered surface*; *Cover %: 45

Penetration resistance. In the conventional stubble systems the quality of the treatment is measured in terms of the soil workability. Instead of this subjective approach we found the soil's penetration resistance to be suitable for evaluation. 2012 was taken in our study as the dry, while 2009 was the average season. The mean values of penetration resistance of an undisturbed soil in the top 0.65 m layer are presented in Figure 2. Differences were found between the values measured in various seasons and between the effects of the various surface covers. Significant differences were found between the latter ($LSD_{0.05}$ 0.1363, $P < 0.05$), confirming the importance of soil moisture content again. The penetration resistance measured in average seasons is lower, and the differences between the treatments are also smaller. The resistance values are higher by 38.9%, in dry seasons when markedly lower values – 3.15–2.86 MPa – can be found in soil under at least 45% cover rates, i.e. at higher soil moisture content. Gao et al. (2012) drew similar conclusions. Dexter et al. (2007) outlined the influence of the soil compaction status, but the given soils were free from compact layers.

Soil surface cover and crumb formation. We assumed that crumb forming may be a combined result of surface cover and the soil moisture content. The tests were carried out during dry, average and wet seasons and the evaluation was completed in the 65th day after harvest. This is the usual length of the stubble field stage. For evaluation a multiple linear regression analysis with two independent variables (soil water content and ratio of the surface cover) was used (Figure 3). Soil water content and surface cover ratio had significant effects both on the crumb ratio ($P < 0.01$, Table 2). In the dry season a higher ratio (≥ 69%) of crumbs was found under a minimum of a 55% surface cover and at 0.21–0.228 g/g soil moisture content. A poor ratio

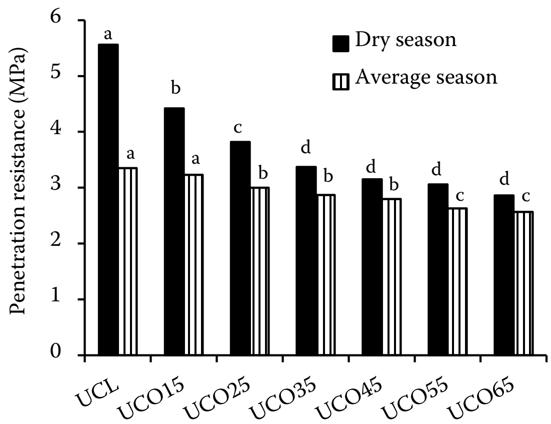
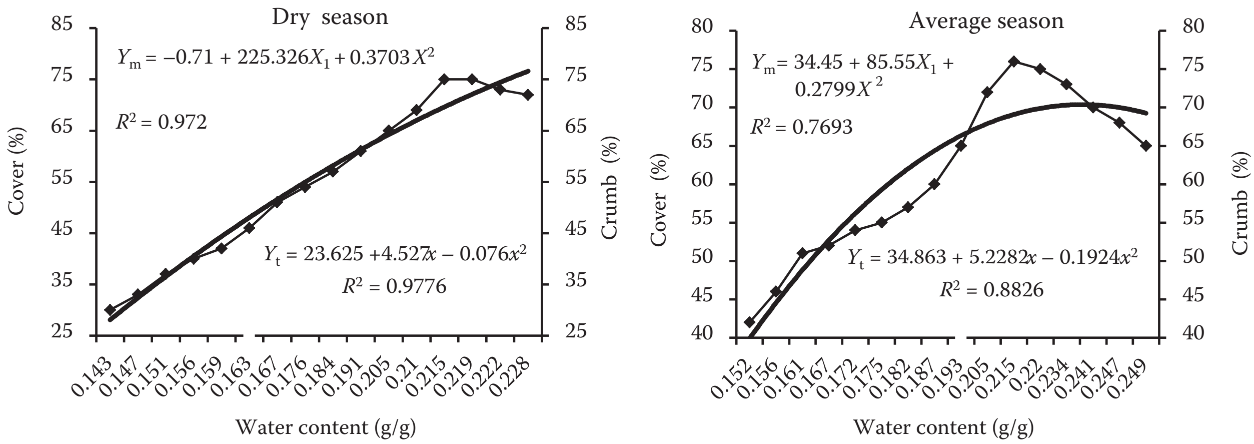


Figure 2. Average values of penetration resistance in stubble soil (0–55 cm) at seven surface cover treatments, on the 65th day after harvest. Columns designed by the same letter do not differ significantly ($P = 0.05$). $LSD_{0.05}$: 0.1363 (average season), 0.2271 (dry season). UCO – undisturbed and covered with the ratio of 65, 55, 45, 35, 25, 15; UCL – undisturbed, clean



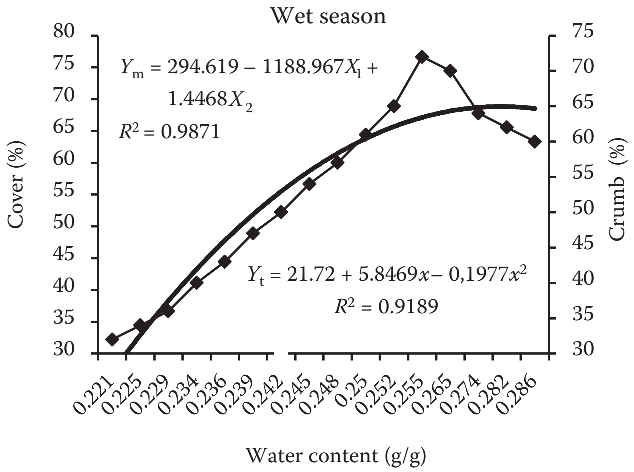


Figure 3. Combined effects of soil water content (to a depth of 0–25 cm) and surface cover ratio on the soil crumbliness in three different seasons. Y_m – formula of regression analysis with two independent variables, originates from measured data; Y_t – formula of theoretical function, continuous line: measured data, dashed line: theoretical data

(≥ 25%) of the cover really limited formation of the crumb. The correlation between the data was close ($P < 0.01$), our formula gave a 97.2% explanation in dry, 76.9% in average and 98.7% in wet season for the combined effect of soil moisture and surface coverage. At the same time the relative impact of cover ratio on crumb formation was found higher than soil moisture content that is 1.33 times in dry, 2.33 times in average and 1.5 times in the wet season. The optimum crumb structure is produced under a 50–55% cover in an average season, while in a wet season it is found under a 55–60% cover. The shape of both theoretical curves differed from the curves are originated from the measured data particularly in average and in wet seasons (Figure 3). As Huisz et al. (2009) notes the natural processes of soil can critically be followed by mathematical function. The soil moisture level is permanently favourable in an average season and the high crumb formation may ensue at relative lower (0.215 g/g) content. Crumbs are fairly exposed to the rain stress in the wet season and in addition, those may destruct at higher (≥ 2.74 g/g) water content. Sallaway et al. (1990) found that the soil needs protection in the case of both weather extremes. In a dry year increased cover helps prevent desiccation while

Table 2. ANOVA analysis of soil surface cover, water content of soil and crumb formation

		Sum of squares	*df*	Mean square	*F*	Significance
Water (g/g)	between groups	0.114	2	0.057	74.009	0.000
	within groups	0.109	141	0.001		
	total	0.223	143			
Crumb (%)	between groups	1818.097	2	909.049	4.954	0.008
	within groups	25872.729	141	183.495		
	total	27690.826	143			

in a rainy season, as Morris et al. (2010) noted, it protects the aggregates.

Finally, in the examined soil, the expected stubble state occurred under a 55–75% surface cover and at 0.21–0.23 g/g soil moisture content.

In the light of the findings the conventional approach of 'tillage until the field is black' and that of deep tillage in the summer do not seem to be justified at all, as resulting in the loss of soil moisture, and it is exposed soils to climate stress. At the same time, the findings confirmed the need for soil surface protection outside the growing season.

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