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Evaluation of Various Soil Tillage Methods in Terms of Percent Crop Residue Cover and Erosion Control

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ABSTRACT: The aim of this study was to estimate the percent crop residue cover remaining on the soil surface after field operations with various soil tillage methods on wheat, barley, oats and rye fields and evaluate these methods in terms of soil erosion control. Tillage methods were mainly formed as fall tillage, fallow and spring tillage. Six tillage implements including mouldboard plough, disc plough, rotary tiller, one-way disc plough, chisel plough with sweeps and paraplough were selected for fall tillage and three tillage implements including heavy disc harrow, light disc harrow and harrow with spike tooth were selected for spring tillage. The percent crop residue cover before tillage were determined by using a regression equation which gives the relationship between the amount of crop residue (kg ha^{-1}) and the percent crop residue cover. The percent crop residue cover after tillage operation was predicted by using calculation method. Research results showed that percent crop residue cover remaining on the soil surface after tillage operation is ≤ 21.99% for Method 11-16, ≤ 42.51% for Method 21-26, between 14.64% to 59.07% for Method 31-36, between 18.59% to 63.02% for Method 41-46, between 40.90% to 85.33% for Method 51-56, between 42.59% to 87.03% for Method 61-66 and between 45.71% to 90.14% for Method 71-76. Method 11-16 used on barley field, method 11-13 used on wheat field and method 11-12 used on rye field were evaluated as the most unsuccessful methods, whereas Method 76 used on oats field was evaluated as the most successful method in terms of soil erosion control.

Keywords *– Soil tillage methods, percent crop residue cover, calculation method, water and wind erosion.*

Farklı Toprak İşleme Yöntemlerinin Bitki Yüzey Artığı Kaplama Yüzdesi ve Erozyon Kontrolü Yönünden Değerlendirilmesi

ÖZET: Bu araştırmada; buğday, arpa, yulaf ve çavdarın bitki yüzey artıklarıyla kaplı toprak koşullarında, çeşitli toprak işleme yöntemleriyle çalışmadan sonra toprak yüzeyinde kalan bitki yüzey artığı kaplama yüzdesinin tahmin edilmesi ve yöntemlerin erozyon kontrolü yönünden karşılaştırılması amaçlanmıştır. Seçilen toprak işleme yöntemleri esas olarak sonbahar toprak işlemesi, nadas ve ilkbahar toprak işlemesinden oluşmaktadır. Sonbahar toprak işlemesinde kulaklı pulluk, diskli pulluk, rototiller, diskli anız bozma pulluğu, uzun kanatlı kazayağı uç demirli çizel ve parabolik pulluk olmak üzere 6 farklı; ilkbahar toprak işlemesinde ise ağır diskli tırmık, hafif diskli tırmık ve düz dişli tırmık olmak üzere 3 farklı toprak işleme alet ve makinasının kullanılması öngörülmüştür. Toprak işlemeden önceki bitki yüzey artığı kaplama yüzdesinin tahmininde bitki yüzey artığı miktarı (kg ha^{-1}) ile bitki yüzey artığı kaplama yüzdesi arasındaki ilişkiyi veren bir regresyon eşitliğinden, toprak işlemeden sonraki bitki yüzey artığı kaplama yüzdesinin tahmin edilmesinde ise hesaplama yönteminden yararlanılmıştır. Araştırma sonucunda, toprak işlemeden sonraki bitki yüzey artığı kaplama yüzdelerinin Yöntem 11-16' da ≤ % 21.99 olduğu, Yöntem 21-26' da ≤ % 42.51 olduğu, Yöntem 31-36' da % 14.64-59.07, Yöntem 41-46' da % 18.59-63.02, Yöntem 51-56' da ≤ % 40.90-85.33, Yöntem 61-66' da % 42.59-87.03 ve Yöntem 71-76' da ise % 45.71-90.14 arasında değiştiği bulunmuştur. Arpanın yüzey artıklarıyla kaplı tarla koşulunda Yöntem 11-16, buğdayın yüzey artıklarıyla kaplı tarla koşulunda Yöntem 11-13 ve çavdarın yüzey artıklarıyla kaplı tarla koşulunda ise Yöntem 11-12 erozyonun önlenmesi yönünden en başarısız yöntemler olarak değerlendirilmiştir. Toprak

erozyonunun önlenmesi yönünden en başarılı sonuç ise yulafın bitki yüzey artıklarıyla kaplı tarla koşulunda Yöntem 76 ile çalışılması durumunda elde edilmiştir.

Anahtar Kelimeler – *Toprak işleme yöntemleri, bitki yüzey artığı kaplama yüzdesi, hesaplama yöntemi, su ve rüzgar erozyonu.*

1. Introduction

Crop residue is one of the most important conservation tillage factors for reduce runoff and soil loss (Shelton et al., 1995; Al-Kaisi and Hanna, 2009). The soil loss decreases as the percent crop residue cover increases (Dickey et al., 1986).

Crop residues consist of stubble, stalk, straw, glume, leaves, capsule etc. which are remaining after processes such as soil tillage, planting, harvesting and threshing.There are several benefits of crop residues such as preventation of water and wind erosion, increasing soil organic matter content, reduction of soil moisture loss, improving soil structure, prevention of the soil crust and improving soil microorganism populations (Al-Kaisi and Hanna, 2009; Dursun, 2015; Dursun, 2017).

There are some factors that affect crop residue cover. These factors can be listed as type of residue, chopping versus leaving residue unchopped, carryover of residue, the fragility of the residue, degree of grazing after harvest, type of field operations, soil moisture and weather conditions and timing of field operations (Al-Kaisi and Hanna, 2009).

Percent crop residue cover remaining on the field surface after all tillage and planting operations is ≤ 15% in conventional tillage, 15-30% in reduced tillage and ≥ 30% in conservation tillage. The soil loss in conventional tillage is more than the others (Dickey et al., 1986; Shelton et al., 1995; Zheng et al., 2014).

In order to prevent soil erosion, it is recommended that generally the soil surface should be covered by crop residues between 20-65% after all tillage and planting operations (Shelton et al., 1995). In order to prevent the water erosion, the percent crop residue cover should be between 12-20% in flat fields and ≥ 50-60% in over-sloped fields (Al-Kaisi and Hanna, 2009).

The aim of this study was to estimate the percent crop residue cover remaining on the soil surface after field operations with various soil tillage methods on wheat, barley, oats and rye fields and evaluate these methods in terms of soil erosion control.

2. Materials and Methods

In this study, 4 different soil conditions covered by wheat, barley, oats and rye crop residue were selected. Tillage methods were mainly formed as ‘‘fall tillage + fallow + spring tillage’’. In all methods, it is planned that planting should be done with double disc opener drill after spring tillage. There are 42 methods consisting of seven applied in the fall and six in the spring (Table 1).

***Table 1.** Selected methods and equipments used (Dursun, 2017[*])*

Equipments Used in Fall Tillage		Equipments Used in Spring Tillage[**]
Method 1 Mouldboard plough (MP) Method 2 Disc plough (DP) Method 3 Rotary tiller (R) Method 4 One-way disc plough (OWDP) Method 5 Chisel plough with sweeps (CPS) Method 6 Paraplough (PP) Method 7 No-till in fall (NFT)	**Fallow (F)**	Heavy disc harrow + Light disc harrow + Harrow with spike tooth (HDH + LDH + HST) (Method X1)[***]
		Heavy disc harrow + Light disc harrow (HDH + LDH) (Method X2)
		Heavy disc harrow + Harrow with spike tooth (HDH + HST) (Method X3)
		Heavy disc harrow (HDH) (Method X4)
		Light disc harrow + Harrow with spike tooth (LDH + HST) (Method X5)
		Light disc harrow (LDH) (Method X6)

[*] Except Method 6.
[**] In all methods it is accepted that planting was done with double disc opener drill after spring tillage.
[***] The «X» letters in spring tillage are the main method numbers. For example; Method 11, Method 23, Method 75.

In order to estimate the percent crop residue cover (PCRC) remaining on the soil surface after soil tillage and planting, the amount of crop residue (ACR) remaining on the soil surface after soil tillage and planting was determined by using the calculation method (Shelton et al, 1995; Dursun, 2002a; Dursun, 2002b). The amount of crop residue after all tillage and planting operations is calculated by using equation (1) (Shelton et al., 1995; Dursun, 2017):

$$ACR = ACRB \times RCRCA \quad (1)$$

where ACRB is the amount of crop residue before soil tillage in kg ha^{-1}, RCRCA is the ratio of crop residue cover after all tillage and planting operations in decimal. The amount of crop residue before soil tillage was selected depending on crop yield from the related literatures. Crop yields and the amounts of crop residue before soil tillage (ACRB) were taken as 2647 and 4320 kg ha^{-1} for wheat, 3030 and 3120 kg ha^{-1} for barley, 2682 and 7560 kg ha^{-1} for oat, 3135 and 5400 kg ha^{-1} for rye, respectively (Anonymous, 2015; Dursun, 2017).

The ratio of crop residue cover after all tillage and planting operations (RCRA) was calculated by using equation (2):

$$RCRCA = FT \times F \times ST \times P \quad (2)$$

where FT is the ratio of crop residue cover after fall tillage in decimal, F is the ratio of crop residue cover after fallowing in decimal, ST is the ratio of crop residue cover after spring tillage in decimal and P is the ratio of crop residue cover after planting in decimal. The ratio of crop residue cover after fall tillage, the ratio of crop residue cover after fallowing, the ratio of crop residue cover after spring tillage and the ratio of crop residue cover after planting was selected from the related literatures (Table 2). The ratios of crop residue cover after (RCRCA) working with selected tillage methods are given in Table 3.

The percent crop residue cover after soil tillage and planting was determined by placing ACR in the regression equation (3) ($R^2 = 0.9947$) developed by McCool et al., (1995). Percent crop residue cover remaining on the soil surface after soil tillage and planting was estimated as:

$$PCRC = 29.598 \times \ln(ACR) - 158.99 \quad (3)$$

Table 2. *The ratios of crop residue cover with selected equipments after operations and fallow (Anonymous, 1992; Al-Kaisi and Hanna, 2009; Dursun, 2017)*

Operation	Equipment/Fallow	The Ratio of Crop Residue Cover (Decimal)
Fall Tillage (FT)	Mouldboard plough (≥ 20 cm working depth) (MP)	0.10
	Disc plough (DP)	0.20
	Rotary tiller (15 cm working depth in primary soil tillage) (R)	0.35
	One-way disc plough (Disc diameter 450-760 mm) (OWDP)	0.40
	Chisel plough with sweeps (CPS)	0.85
	Paraplough (PP)	0.90
Fallow	Fallow (F)	0.90
Spring Tillage and Planting (ST and P)	Heavy disc harrow (HDH)	0.60
	Light disc harrow (LDH)	0.70
	Harrow with spike tooth (HST)	0.90
	Double disc opener drill (D)	0.95

Table 3. *The ratios of crop residue cover (RCRCA) after tillage and planting operations (Dursun, 2017[*])*

Operations in Spring[**]	Operations in Fall						
	Method 1 (MP)	**Method 2 (DP)**	**Method 3 (R)**	**Method 4 (OWDP)**	**Method 5 (CPS)**	**Method 6 (PP)**	**Method 7 (NFT)**
Method X1 (HDH + LDH + HST + D)	0.03232	0.06464	0.11312	0.12928	0.27471	0.29087	0.32319
Method X2 (HDH + LDH + D)	0.03591	0.07182	0.12568	0.14364	0.30523	0.32319	0.35910
Method X3 (HDH + HST + D)	0.04617	0.09234	0.16165	0.18468	0.39244	0.41553	0.46170
Method X4 (HDH + D)	0.05130	0.10260	0.17955	0.20520	0.43605	0.46170	0.51300
Method X5 (LDH + HST + D)	0.05386	0.10773	0.18853	0.21546	0.45785	0.48478	0.53865
Method X6 (LDH + D)	0.05985	0.11970	0.20947	0.23940	0.50872	0.53865	0.59850

[*] Except Method 6.
[**] The X letters in the operations in spring are the actual method number. For example; Method 11, Method 23, Method 75

In the study, it was considered that if the percentage crop residue cover > 20% after soil tillage and planting, it is sufficient to prevent soil erosion. It was also taken into consideration that percent crop residue cover should be ≥ 50-60% for preventation of water erosion in over-sloped fields (Shelton et al., 1995; Al-Kaisi and Hanna, 2009).

3. Results and Discussion

The percentages of crop residue cover remaining on the soil surface after working with the selected methods (%) are given in Table 4.

The percent crop residue cover after soil tillage and planting is ≤ 18.87% for all combinations of Method 1 (except Method 16) in which tillage is done with a mouldboard plough in fall for the fields covered with all the selected crops. Method 1 is not suitable for prevention of erosion because of the percentages of crop residue cover are < 20%. The main reason for this situation is that soil tillage is done by mouldboard plough in fall. Particularly, when the soil tillage was done with mouldboard ploughs which have a high burying ability, the protective cover of the soil surface was decreased and and soil losses increased (Dickey et al., 1981; Meijer et al., 2013; Dursun, 2015; Dursun, 2017). The percent crop residue cover is 21.99% after working with Method 16 (MP + F + LDH + D) in the soil condition covered with oats. Method 16 can be accepted sufficient for prevention of erosion.

Table 4. *The percentages of crop residue cover remaining on the soil surface after working with the selected methods (%)*

Methods		Type of Residue on the Soil Surface Before Tillage			
		Barley	**Wheat**	**Rye**	**Oat**
Method 1 (MP)	**Method 11 (HDH + LDH + HST + D)**	-	-*	-	*3.75*
	Method 12 (HDH + LDH + D)	-	-	-	*6.87*
	Method 13 (HDH + HST + D)	-	-	*4.35*	*14.31*
	Method 14 (HDH + D)	-	*0.87***	*7.47*	*17.43*
	Method 15 (LDH + HST + D)	-	*2.31*	*8.91*	*18.87*
	Method 16 (LDH + D)	-	*5.43*	*12.03*	21.99
Method 2 (DP)	**Method 21 (HDH + LDH + HST + D)**	-	*7.71*	*14.31*	24.27
	Method 22 (HDH + LDH + D)	*1.19*	*10.83*	*17.43*	27.39
	Method 23 (HDH + HST + D)	*8.63*	*18.26*	24.87	34.83
	Method 24 (HDH + D)	*11.75*	21.38	27.99	37.95
	Method 25 (LDH + HST + D)	*13.19*	22.83	29.43	39.39
	Method 26 (LDH + D)	*16.31*	25.94	32.55	42.51
Method 3 (R)	**Method 31 (HDH + LDH + HST + D)**	*14.64*	24.27	30.87	40.83
	Method 32 (HDH + LDH + D)	*17.76*	27.39	33.99	43.95
	Method 33 (HDH + HST + D)	25.21	34.84	41.44	51.40
	Method 34 (HDH + D)	28.31	37.95	44.55	54.51
	Method 35 (LDH + HST + D)	29.76	39.39	45.99	55.95
	Method 36 (LDH + D)	32.88	42.51	49.11	59.07
Method 4 (OWDP)	**Method 41 (HDH + LDH + HST + D)**	*18.59*	28.22	34.83	44.79
	Method 42 (HDH + LDH + D)	21.71	31.34	37.95	47.90
	Method 43 (HDH + HST + D)	29.15	38.78	45.38	**55.34**
	Method 44 (HDH + D)	32.27	41.89	48.50	**58.46**
	Method 45 (LDH + HST + D)	33.71	43.34	49.95	**59.91**
	Method 46 (LDH + D)	36.83	46.46	**53.06**	**63.02**
Method 5 (CPS)	**Method 51 (HDH + LDH + HST + D)**	40.90	**50.53**	**57.14**	**67.09**
	Method 52 (HDH + LDH + D)	44.02	**53.65**	**60.26**	**70.21**
	Method 53 (HDH + HST + D)	**51.46****	**61.09**	**67.69**	**77.65**
	Method 54 (HDH + D)	**54.58**	**64.21**	**70.81**	**80.77**
	Method 55 (LDH + HST + D)	**56.02**	**65.65**	**72.26**	**82.22**
	Method 56 (LDH + D)	**59.14**	**68.77**	**75.38**	**85.33**
Method 6 (PP)	**Method 61 (HDH + LDH + HST + D)**	42.59	**52.22**	**58.83**	**68.79**
	Method 62 (HDH + LDH + D)	45.71	**55.34**	**61.95**	**71.91**
	Method 63 (HDH + HST + D)	**53.15**	**62.78**	**69.39**	**79.34**
	Method 64 (HDH + D)	**56.27**	**65.90**	**72.50**	**82.46**
	Method 65 (LDH + HST + D)	**57.71**	**67.34**	**73.95**	**83.91**
	Method 66 (LDH + D)	**60.83**	**70.46**	**77.07**	**87.03**
Method 7 (NFT)	**Method 71 (HDH + LDH + HST + D)**	45.71	**55.34**	**61.95**	**71.91**
	Method 72 (HDH + LDH + D)	48.83	**58.46**	**65.07**	**75.02**
	Method 73 (HDH + HST + D)	**56.27**	**65.90**	**72.50**	**82.46**
	Method 74 (HDH + D)	**59.39**	**69.02**	**75.62**	**85.58**
	Method 75 (LDH + HST + D)	**60.83**	**70.46**	**77.07**	**87.03**
	Method 76 (LDH + D)	**63.95**	**73.58**	**80.19**	**90.14**

* The percentages of crop residue cover are ≤ 0.22% in (-) marked boxes.
** The values of < 20% showed in italic numbers are not enough for preventation of the erosion.
*** The bold values that are ≥ 50-60% was accepted as sufficient to prevent erosion in over-sloped fields.

The percentages of crop residue cover are ≤ 16.31% after working with all combinations of Method 2 in the soil condition covered with barley. The percentages of crop residue cover are ≤ 18.26% after working with Method 21 (DP + F + HDH + LDH + HST + D), Method 22 (DP + F + HDH + LDH + D) and Method 23 (DP + F + HDH + HST + D) in the soil condition covered with wheat. The percentages of crop residue cover changed between 21.38-25.94% after working with Method 24 (DP + F + HDH + D),

Method 25 (DP + F + LDH + HST + D) and Method 26 (DP + F + LDH + D) in the soil condition covered with wheat. The percentages of crop residue cover are ≤ 17.43% for Method 21 and Method 22 in the soil condition covered with rye and these methods are not sufficient for prevention of the erosion. However, the percentages of crop residue cover changed between 24.27- 42.51% after working with all combinations of Method 2 in the soil condition covered with oat and this method is evaluated as sufficient in terms of prevention of the erosion.

In general, the percentages of crop residue cover are sufficient for prevention of the erosion after working with all combinations (except Method 31 and Method 32) of Method 3 in which the tillage is done by rotary tiller in fall. The percentages of crop residue cover after working with Method 31 (R + F + HDH + LDH + HST + D) and Method 32 (R + F + HDH + LDH + D) are not sufficient because these values are < 20% in soil condition covered with barley.

The percentages of crop residue cover after working with all combinations of Method 4, in which the primary soil tillage is made by one-way disc plough, are sufficient to prevent erosion except by working with Method 41 (OWDP + F + HDH + LDH + HST + D) in the soil condition covered with barley residues. The percentages of crop residue cover after working with all combinations of Method 4 (except 41) changed between 21.71- 63.02%.

The percentages of crop residue cover are generally sufficient for the prevention of the erosion for Method 5, in which tillage is done with a chisel plough with sweeps, and for Method 6, in which tillage is done with a paraplough in fall.

The highest values of percent crop residue cover (45.71- 90.14%) were obtained after soil tillage and planting working with Method 7, in which the primary soil tillage was not done. The percentages of crop residue cover after working with Method 7 is quite sufficient for the prevention of the erosion.

The percentages of crop residue cover after working with the following methods are ≥ 50%. For this reason, all these methods are successful in terms of water erosion control in over sloped fields. These methods are;

- Method 33 (R + F + HDH + HST + D), Method 34 (R + F + HDH + D), Method 35 (R + F + LDH + HST + D) and Method 36 (R + F + LDH + D) in a field covered by oat residues;
- Method 43 (OWDP + F + HDH + HST + D), Method 44 (OWDP + F + HDH + D), Method 45 (OWDP + F + LDH + HST + D) and Method 46 (OWDP + F + LDH + D) in a field covered by oat residues and Method 46 in a field rye residues;
- All combinations of Method 5 except Method 51 (CPS + F + HDH + LDH + HST + D) and 52 (CPS + F + HDH + LDH + D) in a field covered by barley residues;
- All combinations of Method 6 except Method 61 (PP + F + HDH + LDH + HST + D) and 62 (PP + F + HDH + LDH + D) in a field covered by barley residues;
- All combinations of Method 7 except Method 71 (NFT + F + HDH + LDH + HST + D) and 72 (NFT + F + HDH + LDH + D) in a field covered by barley surface residues.

The highest percent crop residue cover was obtained in the field condition covered with oat, while the lowest percent crop residue cover was found in the field condition covered with barley. Oat is the highest amount of crop residue and barley is the lowest amount of crop residue before soil tillage. The percent crop residue cover after soil tillage and planting is changed depending on the amount of crop residue before soil tillage.

The amount of crop residue increases as the crop yield increases (Reddy et al., 2003; Al-Kaisi and Hanna, 2009; Anonymous, 2015; Dursun, 2017). According to this, the crops with higher yields are more effective in preventing erosion (Dickey et al., 1981; Dickey and Havlin, 1985; Meijer et al., 2013). The highest percent crop residue cover (90.14%) after tillage and planting was obtained with Method 76 (NFT + F + LDH + D) in the soil condition covered with residues of oat residues.

4. Conclusion

As a result, the most successful method is Method 76 (NFT + F + LDH + D) in which tillage is done in the field covered with oat residue and the percent crop residue cover is 90.14%. The most unsuccessful method is Method 11 (MP + F + HDH + LDH + HST + D) in terms of preventing of soil erosion because of the percent crop residue cover is $\leq 3.75\%$. In Method 11 the percentages of crop residue cover are the lowest for all selected surface residues. Particularly, the percentages of crop residue cover were found lowest when soil tillage was done with mouldboard plough. Because, it has high burying ability. Thus, the protective cover of the soil surface is decreased and and soil losses is increased.

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