



The Use of Straw Mulches to Mitigate Soil Erosion under Different Antecedent Soil Moistures

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Abstract: Straw mulch cover is one of the most important soil erosion control measures applied to reduce runoff and soil loss in cultivated areas. However, in developing countries such as Iran, without a clear tradition or knowledge about soil erosion control measures, the use of straw mulch is rare, and its impact in the most extended crops is not well understood. We investigated the separate and combined effects of colza (Brassica napus L.) and corn (Zea mays L.), to mitigate the activation of soil loss and runoff in sandy-loam soils, under different antecedent soil moisture conditions, in a rainfed plot in Northern Iran. Under laboratory conditions, we used a rainfall simulator device. The experiments were performed by using a rainfall intensity of 50 mm h^{-1} , with a duration of 10 min and an inclination of 30%, with three replications. These conditions were used to evaluate the soils under extreme meteorological and topographical conditions. Two types of straw mulch, colza and corn, separated and combined with three different cover levels (25, 50 and 75%) and four distinct antecedent soil moisture conditions (0, 15, 20 and 30%), were used. The results showed that the applied straw mulches had significant effects on the reduction of soil loss and sediment concentration, by almost 99%. The maximum reduction of soil loss and sediment concentration was observed for the treatments with 0% moisture and 75% of corn, colza + corn and colza, with a reduction of 93.8, 92.2 and 84.9% for soil loss, respectively, and 91.1, 85.7 and, 60.7% for sediment concentration, respectively. The maximum reduction of runoff was also obtained with 0% soil moisture and a cover of 75%, reducing 62.5, 48.5 and 34.8% for colza, colza + corn and corn, respectively. The corn straw mulch showed the highest effectivity on reducing soil loss and sediment concentration toward colza treatment. But the colza straw mulch showed the best results on reducing runoff toward corn treatment. We conclude that the application of straw mulch is affordable and useful in reducing soil loss and runoff, instead of bare soils.

Keywords: combined straw mulches; laboratory conditions; soil conservation; rainfall simulator

1. Introduction

Nowadays, soil erosion by water is considered one of the major threats to soil resources worldwide [1,2]. Soil erosion in agricultural areas is a complex and, on several occasions, gradual process



that causes a loss of fertility, productivity and quality of the final product [3,4]. To better understand hydrological responses at the pedon and watershed scales, soil erosion mechanisms must be specifically assessed considering a large number of influencing factors on controlling runoff generation and soil erosion, such as antecedent soil moisture, drainage, infiltration, roughness, rainfall characteristics (amount and intensity), soil type, topography and human modifications [5–10]. The measurement of soil and water losses is one of the most important steps to develop successful soil-conservation practices and efficient land-management practices after drastic land-use changes [11,12]. Several methods are being used to assess soil erosion and develop control measures in agricultural fields. The small and portable rainfall simulators are considered to be useful instruments for the measurement of the initial process and activation, which can help to prevent and foresee soil and water responses at the pedon scale to be extrapolated for larger areas [13–16].

Iran, located in the arid and semi-arid regions of the world, manifests highly sensitive formations toward water erosion [17]. Recent investigations focused on soil erosion forms such as gullies, rills, aeolian processes, soil depletion or landslides [18–21]. Annual soil loss due to water erosion processes is estimated at 16 t per hectare year⁻¹ [22]. Several human activities and environmental changes are affecting Iranian soils, such as intensive tillage, grazing or abandonment, and leaving the soils bare and not protected against rainfall and wind impacts [23–26]. On the other hand, fortunately, there are various groups applying soil conservation measures, but some methods in bare soils or degraded hillslopes need a long time to be established to show effective results [27]. Different mulch types (including straw mulch, compost, wood chips, vermicompost, biochar, polyacrylamide, polyvenilacetate and plastic film) are applied to reduce or stop runoff and soil loss [28–31]. Among these materials, straw mulch has shown similar effects than vegetation cover to mitigate soil erosion [32].

Soil conservation practices involving plant-residue cover (straw mulch) have proven that using straw mulch is one of the best management practices (BMPs) for maintenance of soil quality [33]. There are numerous studies about the impacts of straw mulch on soil characteristics (soil aggregate stability, soil structure and surface sealing), hydrological responses (soil moisture, infiltration and runoff changes) and soil loss and sediment concentration (e.g., see References [34–41]). Recent studies showed that straw mulch could decrease the raindrop impacts and reduce soil loss by absorbing kinetic energy during the splash effect [42]. Several researchers stated that the straw mulch could also conserve soil moisture along the surface [43], favor the organic-matter generation [44] and, subsequently, reduce the amount of runoff [45] and soil loss [46]. Despite this, it is well-demonstrated that changing runoff and soil loss dynamics largely depends on previous soil conditions and topographical characteristics (e.g., see References [47–53]). Related to soil moisture content, several researchers stated that the increase in this parameter can enhance the runoff generation and soil loss by 60% [54]. These results were also reported by Gholami et al. [55], with the application biochar on changing runoff and soil loss in North Iran. In other parts of the world, it was also evident. For instance, Mannering and Meye [56] and Adams [35] showed that the straw mulch could reduce soil loss at the plot scale. Another example is the research conducted by DeHaan [57], who simulated the role of different mulch application rates in reducing water erosion and runoff rates. The runoff rates were 13 times lower on land mulched than on bare soils, after harvesting. To reduce the effects of fire, Poulenard et al. [58] studied soil loss by using rainfall simulation experiments for the páramos in Colombia, considering the effects of tillage and burning at the plot scale. They stated that the sediment loss was very low when mulches were used in the first year after the fire. The use of corn residual was also tested in Tinaja, by Ruy et al. [59], who concluded that, considering treatments of bare soils, no-tilled and no planted with 1.5 t ha^{-1} of residue mulch, direct drilling of corn with 1.5 and 4.5 t ha⁻¹ of residue mulch. This straw mulch could decrease runoff and soil loss drastically. Adekalu et al. [36] stated that Pennisetum purpureum mulching decreased soil loss, while increased if there was an increase in slope. Groen and Woods [60] showed that straw-mulch usage at a rate of 2.24 t ha⁻¹ in plots of 0.5 m² was able to decrease soil loss in post-wildfire and Northwestern Montana. Jiang et al. [61] reported that the wheat straw reduced soil erosion by 95%, compared to bare soils. Gholami et al. [62] studied the effect of straw mulch on

splash erosion, runoff and soil loss. The results showed that the straw mulch had a significant effect (95%) in changing runoff and soil loss.

The literature verified the significant factors affecting the activation of soil loss under different soil erosion control measures, under laboratory conditions. For instance, Wang et al. [63] investigated the effects of wheat straw mulch on changing soil loss in laboratory plots under simulated rainfall. These results revealed that the straw mulch had an effective role in reducing soil loss and could be used to develop erosion control measures in the Loess Plateau region. Niziolomski et al. [64] investigated the interactive effect of mulch and shallow soil disturbance on reducing runoff and soil loss in a commercial asparagus field near Ross-on-Wye (England, UK). However, the results indicated that the efficacy of the tested treatments was not adequate for the reduction of soil loss.

However, not only natural materials are used to reduce soil and water losses but also artificial materials, such as geotextiles and polymers [65–67]. Babcock and McLaughlin [68] published representative studies related to the effect of straw mulch, hydro-mulch and polyacrylamide (PAM) on control soil loss, under rainfall simulation conditions. The best results were obtained by using hydro-mulch plus PAM. However, the results also showed that adding PAM to a less expensive straw mulch produced similar or better results than the hydro-mulch application without PAM. Chen et al. [69] investigated the effects of plastic film combined with straw mulch on the soil moisture, temperature, grain yield and water-use efficiency (WUE) of winter wheat in the drylands of the Loess Plateau of China. The results indicated that the plastic film, combined with straw mulch, variably increased the grain yield (mean 35%) and WUE (mean 25%), with a slight increase of evapotranspiration (mean 8%), as compared to conventional practices. Tang et al. [70] surveyed the effects of rice straw mulch and soybean planting around maize blocks on yields on runoff amount. Treatments of the control without fertilization and agronomic measures (CK), chemical fertilizer application without agronomic measures (CF), chemical fertilizer combined with rice-straw mulching (CF + R), chemical fertilizer combined with planting soybean around the cultivated block (CF + S), chemical fertilizer combined with rice-straw mulching and planting soybeans around the cultivated block (CF + R + S) were considered. Their results showed that, compared to CF, the yield of maize treated with CF + R and CF + R + S could increase by 16.0 and 23.2% (p < 0.05). The total runoff volume during the growth period of maize significantly decreases by 18.5 and 22.0%. Although artificial mulches can greatly improve the soil conditions, their prices and availability, especially in developing countries, make them difficult to be widely applied for farmers.

Most previous researchers studied the effect of straw mulch on various aspects; nonetheless, few studies are available about separate and combined effects of different mulches, considering different antecedent soil conditions on soil loss and water losses [62]. Therefore, the main goal of this research was to study the separate and combined effects of two different types of straw mulch that are rarely studied, namely colza and corn, on the activation of soil erosion processes, while considering different antecedent soil moistures under extreme rainfall conditions and on steep slopes. The experiments were conducted in an eroded sandy-loam soil, sampled in the region of Dasht-e-Naz, Sari City, in Northern Iran. The experiments were performed by using a rainfall simulator under laboratory conditions, with a rainfall intensity of 50 mm h^{-1} and 30% of inclination.

2. Materials and Methods

2.1. Soil Preparation and Erosion Plots

Soil samples were collected from the top layer (0–20 cm) of a typical cultivated field in the Dasht-e-Naz, Sari City (36°66' latitude and 53°19' longitude), and transported to the simulation laboratory of Sari Agricultural Sciences and Natural Resources University (SANRU). The soil was dried in open areas, to reach optimum moisture content and maintain the relative stability of soil aggregates [71] (Figure 1a). Then, the soil was sieved at 4 mm [72], to increase the homogeneity of the soil samples [73]. The soil moisture was measured with a soil moisture-meter (GMK-770s, G-WON

HIGHTECH CO-LTD. Seoul, Korea). Soil analysis included soil texture determined by Bouyoucos Hydrometer method [74] and soil pH determined in a 1:2.5 soil:water ratio. Soil organic carbon was determined by Walkley-and-Black method [75]. Soil texture, organic matter, organic carbon, pH and electrical conductivity were sandy-loam, 1.68%, 0.98%, 7.37% and 0.88 dS/cm, respectively. The plots used are characterized by some specific dimensions of $1 \times 0.5 \times 0.2$ m and steep slopes of 30%. A layer with a 10 cm thick plot was filled with pumice grains, to simulate natural drainage condition [76] (Figure 1b). Then, the upper layer of the plot was filled with soil. Then, it was compacted, using a PVC roller, to make its specific bulk density similar to natural conditions [77].





Figure 1. A view of dried soil in an open area (a) and the plots filled with pumice grains (b).

2.2. Straw Mulch and Soil Moisture

The colza (*Brassica napus* L.) and corn (*Zea mays* L.) straw mulches were collected from rainfed agricultural lands in the Dasht-e-Naz region, Sari. The experiments were conducted by using straw mulch with different cover levels, i.e., 25, 50 and 75%. The soils were first air-dried to the lowest possible moisture level (0%), then placed on plots and brought to 15, 20 and 30% ASM by spraying water [62]. The experiments were conducted with a separation of straw mulches (colza and corn) and combined ones (colza + corn) under each soil moisture condition (Figure 2). Table 1 presents the separate and combined treatments per experiment.



Colza

Corn

Figure 2. Cont.



Combined (colza + corn)

Figure 2. A view of applied straw mulches of colza (a), corn (b) and combined colza and corn (c).

	a a	1 07 50/	R	(L)	SC (g	g L−1)	SL (g)		
ireatment	Cover%	ASM% -	С	М	С	М	С	М	
		0	3.450	3.131	56	35	193	111	
	05	15	4.028	3.520	51	48	202	171	
	25	20	4.710	3.990	56	47	266	188	
		30	5.501	4.858	94	46	522	224	
		Mean	4.422	3.874	64.25	44	295.75	173.5	
		0	3.450	1.863	56	29	193	55	
colza	50	15	4.028	2.038	51	41	202	83	
COIZa	50	20	4.710	3.913	56	21	266	85	
		30	5.501	4.543	94	23.05	522	104	
		Mean	4.422	3.089	64.25	28.51	295.75	81.75	
		0	3.450	1.293	56	22	193	29.06	
	75	15	4.028	1.821	51	30	202	58	
	75	20	4.710	3.725	56	18	266	68	
		30	5.501	4.203	94	19	522	83	
		Mean	4.422	2.760	64.25	22.25	295.75	59.51	
		>0	>3.450	3.213	56	18	>193	>60	
	25	15	4.028	3.963	51	22	202	89	
	23	20	4.710	4.640	56	33	266	155	
		30	5.501	5.346	94	45	522	241	
		Mean	4.422	4.290	64.25	29.5	295.75	136.25	
		0	3.450	2.901	56	13	193	40	
Corn	50	15	4.028	3.656	51	17	202	64	
	00	20	4.710	4.451	56	14	266	64	
		30	5.501	4.726	94	17	522	79	
		Mean	4.422	3.933	64.25	15.25	295.75	61.75	
	75	0	3.450	2.251	56	5	193	12	
		15	4.028	3.330	51	9	202	30	
		20	4.710	4.313	56	8	266	36	
		30	5.501	4.583	94	11	522	52	
		Mean	4.422	3.619	64.25	8.25	295.75	32.5	
	25	0	3.450	3.143	56	33	193	103	
colza+ corn		15	4.028	3.501	51	38	202	134	
		20	4.710	3.650	56	52	266	185	
		30	5.501	3.905	94	57	522	225	
		Mean	4.422	3.561	64.25	45.25	295.75	478.25	
	50	0	3.450	2.430	56	24	193	59	
		15	4.028	3.283	51	27	202	90	
		20	4.710	3.456	56	35	266	121	
		30 Mean	5.501 4 422	3.656 3.206	94 64 25	42 32	522 295 75	155 106 25	
		0	2 /50	1 776	51.20	0	102	150.20	
		15	4.028	2 883	51	13	202	10	
	75	20	4.020	2.000	54	15	202	40 59	
		20	5 501	3.466	94	23	200 522	82	
		50	3.301	3.400	71	23	322 005 75	51 00	

Table 1. Soil erosion results under different soil moisture conditions and straw mulch covers. C, control;M, mulched; ASM%, antecedent soil moisture; R, runoff; SC, sediment concentration; SL, soil loss.

2.3. Rainfall Simulator and Rainfall Intensity

The rainfall simulator is situated on an A-frame metal structure, in a laboratory. The rainfall simulator has different parts, such as the water supply system, tow nozzles, water collection system and one control board. The telescopic legs allow for the selected height of the nozzles to be changed between 2 and 2.7 m. The frame rainfall has two movable nozzles: Veejet 80100 [78,79], with a diameter of 4 mm [77]. The water pressure is set up with a pressure gauge from 0 to 160 KPa that is installed in the transfer hose and nozzles. Moreover, a control board was designed with a program setting of ten different precipitation events. This control board can be used to set the velocity fluctuation of the nozzles with a precipitation duration from 1 min to 1 h and an oscillation angle by the nozzles from 0° to 60° (Figure 3). The rainfall simulator height, pressure, distance and angle of the nozzles are 2 m, 60 KPa, 70 cm and 45 degrees, respectively, and the rainfall simulator can generate drops with a diameter classes, from a height of 0.5 m above the soil surface [74]. For this experiment, the rainfall intensity selected was 50 mm h⁻¹, with a duration of 10 min, to simulate a heavy rainfall event [80]. The rainfall intensity was applied according to the curves of the Intensity–Duration–Frequency of Sari Synoptic Station, which has a return period of 20 years.



Figure 3. A view of the rainfall simulator at the laboratory of Sari University of Agricultural Sciences and Natural Resources.

2.4. Measurement of Runoff and Soil Loss

The runoff volume was collected at the outlet of each plot, at intervals of 2 min, for a total duration of 10 min, with three replications. Then, the volume of runoff was measured by standard gauged cylinders. It is important to mention that each run was conducted by using a new soil surface and straw mulches [36]. Then, the amounts of soil loss were estimated by using the decantation procedure and oven-dried at 105 °C for 24 h, e.g., [73,81,82]. The sediment mean concentration was obtained by dividing the total soil loss by the runoff volume at each sample [83] (Figure 4).



Figure 4. Laboratory measurements of runoff volume and soil loss.

2.5. Statistical Analysis

The statistical analysis under separate and combined straw mulches at various soil moisture conditions was carried out, using the SPSS v. 22 (software IBM, New York, NY, USA). First, the normality test was performed, using the Kolmogorov–Smirnov test, at a level of 0.05 [83–87]. Then, an ANOVA test was used based on linear regressions and general linear models (GLM), to quantify the interaction between the dependent variables and the independent ones. Finally, the determination of homogeneous subgroups was included, to detect which variables can affect the final soil erosion results, using the Duncan test [62].

3. Results

3.1. Soil Loss, Sediment Concentration and Runoff

The results showed that the colza, corn and colza + corn with the cover rate of 75% were the most effective at decreasing soil loss and sediment concentration (Table 1 and Figures 5–7). The results revealed that the colza, corn and colza + corn showed a significant effect, at a level of 99%, in reducing soil loss and sediment concentrations (Table 2). In general, under higher antecedent soil moisture content, 75% cover of each straw mulch treatment obtained the best results reducing soil loss, sediment concentration and runoff. According to the result of Table 1, under antecedent soil moisture conditions from 0 to 30%, in the control plot soil loss, sediment concentration and runoff increased from 193 to 522 g, from 56 to 94 g L⁻¹ and from 3.5, to 5.5 L, respectively. The results of mean runoff, sediment concentrations and soil loss showed that the colza straw mulch, using a cover from 25 to 75%, reduced runoff from 3.9 to 2.8 L, sediment concentration from 44 to 22.3 g L⁻¹, and soil loss from 173.5 to 59.5 g. Using corn straw mulch with a cover from 25 to 75%, runoff decreased from 4.3 to 3.6 L, sediment concentration from 29.5 to 8.25 g L⁻¹ and soil loss from 136.5 to 32.5 g. Finally, the combination of colza + corn straw mulches from 25 to 75% cover reduced the runoff from 3.6 to 2.8 L, sediment concentration from 478.3 to 51.2 g.

Table 2. General linear model test after applying the one way and two-way ANOVAs per soil moisture condition and straw mulch application, considering soil loss and sediment concentration.

Source		Dependent Variable	df	Mean Square	Value F	Significant Level
	colza	Sediment concentration (g L ⁻¹)	3	301.035	8	0.000 **
		Soil loss (g)	3	40,821	97	0.000 **
Soil moisture	corn	Sediment concentration (g L^{-1})	3	860	30	0.000 **
		Soil loss (g)	3	51,212	119.09	0.000 **
	colza + corn	Sediment concentration (g L^{-1})	3	1429.09	48	0.000 **
		Soil loss (g)	3	54,772	124	0.000 **

Source		Dependent Variable	df	Mean Square	Value F	Significant Level
	colza	Sediment concentration (g L^{-1})	3	4215	121	0.000 **
	colla	Soil loss (g)	3	138,305.08	329	0.000 **
Straw mulches	Corn	Sediment concentration (g L^{-1})	3	7476	262	0.000 **
		Soil loss (g)	3	166,603	387	0.000 **
	colza + corn	Sediment concentration (g L^{-1})	3	5069	171	0.000 **
		Soil loss (g)	3	134,075	305	0.000 **
	colza	Sediment concentration (g L ⁻¹)	9	453	31	0.000 **
		Soil loss (g)	9	13,362	13.04	0.000 **
Moisture \times Straw mulch	corn	Sediment concentration (g L^{-1})	9	270	9	0.000 **
		Soil loss (g)	9	13,733	31	0.000 **
	colza + corn	Sediment concentration (g L^{-1})	9	172	5	0.000 **
		Soil loss (g)	9	11,013	25	0.000 **

Table 2. Cont.

df: Degree of freedom, **: Significant in 99%.



Figure 5. Comparison of soil loss and sediment concentration at different levels of colza straw mulch (above) and soil moisture conditions (below), based on the Duncan test.



Figure 6. Comparison of soil loss and sediment concentration at different levels of corn straw mulch (above) and soil moisture conditions (below), based on the Duncan test.



Figure 7. Cont.



Figure 7. Comparison of soil loss and sediment concentration at different levels of colza + corn straw mulches (above) and soil moisture conditions (below), based on the Duncan test.

3.2. Soil Erosion Rates, Considering Different Soil Moisture Conditions and Straw Mulches

Table 3 shows that, by increasing the level of colza straw mulch from 25 to 75%, the amount of soil loss increased 36.1, 69.6 and 78.7%; sediment concentration reached 27.6, 51.5 and 62.4%; and runoff obtained 12.2, 32.4 and 40.5%, respectively. Using corn straw mulch, from 25 to 75% of cover, these rates relatively decreased 55.1, 77.1 and 88.9% in soil loss; 54.5, 75.1 and 86.9% in sediment concentration; and 3.2, 11.1 and 19.3% in the runoff. The combination of colza + corn showed that various soil moisture contents decreased 41.9, 62.4 and 83.7% in soil loss; 28.3, 49.3% and 76.8% in sediment concentration; and 18.4, 27.1 and 36.5% in the runoff. According to these results, corn straw mulch showed more advantages to reduce soil loss and sediment concentration, compared to colza straw mulch, and also than the combination of colza + corn straw mulches.

Table 3. Percentage of changes in soil erosion results after the application of colza, corn and colza + corn straw mulches, under different soil moisture level conditions. ASM, antecedent soil moisture; R, runoff; SC, sediment concentration; SL, soil loss.

Treatment	ASM (%)	R			SC			SL		
		25%	50%	75%	25%	50%	75%	25%	50%	75%
	0	9.24	46	62.52	37.5	48.21	60.71	42.48	71.50	84.94
	15	12.61	49.40	54.79	5.88	19.60	41.17	15.34	58.91	71.28
colza	20	15.28	16.92	20.91	16.07	62.5	67.85	29.32	68.04	74.43
	30	11.68	17.41	23.59	51.06	75.47	79.78	57.08	80.07	84.09
	Mean	12.20	32.43	40.45	27.62	51.45	62.38	36.06	69.63	78.69
	0	6.86	15.91	34.75	67.85	76.78	91.07	68.91	79.27	93.78
	15	1.61	9.23	17.32	56.86	66.66	82.35	55.94	68.31	85.14
corn	20	1.48	5.49	8.42	41.07	75	85.71	41.72	75.93	86.46
	30	2.81	14.08	16.68	52.12	81.91	88.29	53.83	84.86	90.03
	Mean	3.19	11.17	19.29	54.47	75.09	86.85	55.10	77.09	88.85
colza + corn	0	8.89	29.56	48.52	41.07	57.14	85.71	46.63	69.43	92.22
	15	13.08	18.49	28.42	25.49	47.05	74.50	33.66	55.44	80.19
	20	22.50	26.62	31.99	7.14	37.5	71.42	30.45	54.51	78.19
	30	29.01	33.53	36.99	39.36	55.31	75.53	56.89	70.30	84.29
	Mean	18.37	27.05	36.48	28.26	49.25	76.79	41.91	62.42	83.72

On the other hand, the results showed that the soil loss and sediment concentration increased when soil moisture increased, being less the positive effect of straw mulches (Table 1, Figures 5 and 7). The measurements showed that soil moisture 30% was able to decrease the maximum amount of soil loss, registering from 0 to 30%, with rates of 193, 202, 266 and 522 g, respectively, and sediment

concentrations of 56, 51, 56 and 94 g L^{-1} , respectively. The results revealed that the various soil moistures showed a significant effect on changing soil loss and sediment concentration, at a level of 99% (Table 2).

Finally, in Figures 5–7, we demonstrate how soil moisture values of 0, 15, 20 and 30% affect the application of colza, corn and colza + corn straw mulches to reduce soil erosion. The results confirmed that, for the highest level of soil moisture (30%), where soil erosion is more intense, the application of the 75% mulch is effective.

4. Discussion

4.1. Straw Mulches Effect on Changes in Soil Loss and Sediment Concentration

The results showed that both straw mulches (colza and corn) or the combined ones (colza + corn) could reduce soil loss and sediment concentration, as compared to the control treatment, as other studies also confirmed with other types [36,87–91]. The results of different straw mulch applications with levels of 75% showed that the runoff could not transport soil particles to the outlet [45]. Moreover, applied straw mulches prevented the direct effect of raindrops on the soil surface, which was observed during the experiments, as other authors found [45]. This effect indicates that this amendment could increase the roughness and cover of the soil surface, as well as reduce the kinetic energy of rainfalls and the destruction of soil aggregates [92–94]. Our results showed that the straw mulches had a clear significant effect on reducing soil loss and sediment concentration at a level of 99%. In some cases, the separated particles of soils were surface-deposited behind and below the straw mulches; thus, the amount of sediment concentration was highly reduced toward the outlet of the control plots [29–95]. The results of changes in per cent values showed that the maximum reduction of soil loss and sediment concentration was obtained applying 75% of cover with a soil moisture conditions of 0%. This confirms that the unique use of one mulch type can be enough to mitigate the activation of soil erosion processes with dry soils. The results also stated that increasing the level of straw mulches had a higher effect on decreasing soil loss and sediment concentration, which was necessary when the antecedent soil moisture increased. These results agreed with previous studies, including Sadeghi et al. [96], Kavian et al. [29] and Gholami et al. [62]. The homogenization results showed that straw mulch with rates of 75% (four subgroups) had the most important impact on reducing soil loss and sediment concentration at separate and combined straw mulches (Figures 5 and 7). Naturally, it directly affects the costs and the amount of work invested in plots with this soil erosion control measures. Therefore, policies and subsidies should be designed and planned to help the farmers and owners to apply this sustainable control measure. This also agrees with recent publications where farmers were surveyed and are willing to apply the straw mulches if they are subsidized [96–99].

4.2. Antecedent Soil Moisture Effect on Changes in Soil Loss and Sediment Concentration

The results of Table 1 showed that the increase in soil moisture could affect soil loss and sediment concentration [5]. Increasing soil moisture caused the reduction of infiltration rates, possibly due to the resistance between soil aggregates and soil stability and the saturation of the soil [85]. Moreover, by increasing soil moisture, the stability of soil aggregate could decrease and, therefore, the amount of soil loss and sediment concentration would 0increase [100]. When the soil was air-dried (0% soil moisture), the major part of rainfall was getting wet rapidly, but it conserved the infiltration rate, and, therefore, runoff activation was slower. However, when the soil moisture was higher, runoff activation was faster, which also affected soil loss transported into the outlet [51]. The results showed that the soil moisture had a significant effect on changing soil loss and sediment concentration at a level of 99%. The results stated that the soil moisture with the level of 30% had a major effect on increasing soil loss in the treatments of soil moisture from 0 to 30%, with rates of 193, 202, 266 and 522 g, respectively, and sediment concentration of 56, 51, 56 and 94 g L⁻¹, respectively. However, at each of the moisture

levels, after application of each straw mulch (colza and corn) or combined ones (colza + corn), the decrease in soil loss and sediment concentration, compared to the control treatment, was drastic.

The results stated that the corn straw at all the applied rates was more effective at decreasing soil loss and sediment concentration, considering different increases in soil moistures. The homogenization results showed that, among different soil moisture contents, 30% had effective impacts on reducing soil loss and sediment concentration at both separate and combined straw mulch application, coinciding with other authors [101,102].

The ANOVA results revealed that the effect of various soil moistures with the four levels of soil moisture of air-dried of 15, 20 and 30% was significant on changing soil loss and sediment concentration ($R^2 = 0.99$). Some researchers also stated the same results, including Orsham et al. [103], Ziadat and Taimeh [50] and Khaledi Darvishan et al. [51]. Considering this, in the future, the logical next step should be focused on performing rainfall simulation experiments or soil erosion monitoring with plots under real conditions applying these mulches to verify if these results are or not correct to be implemented in agricultural and soil management plans.

5. Conclusions

According to the results, corn straw mulch, at different rates of the application, was able to get the best results to decrease soil loss and sediment concentration. The results also confirmed that soil moisture had a significant effect on increasing soil loss and sediment concentration at a level of 99%, and the use of straw mulch helped in reducing it. The measurements concluded that soil moisture with a level of 30% had the highest negative effect by increasing soil loss. Therefore, to select the best conservation measure, in this case, corn straw mulch, it is worthy to highlight that the level of antecedent soil moisture can highly affect its ability to minimize the impacts of soil erosion. In the future, the positive effects of these mulches must also be tested under real conditions and non-controlled agricultural environments. A big number of experiments must also be conducted in order to detect the variability under different topographical conditions, e.g., higher or lower slopes, or soil types with diverse soil textures and organic matter contents. However, these results give new positive insights into the use of cheap materials in developing countries.

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