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Short Term Effects of Livestock Manures on Soil Structure Stability, Runoff and Soil Erosion in Semi-arid Soils under Simulated Rainfall

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Abstract: The long term effects of applying livestock manures as soil amendment are well known. However, these manures usually contain high soluble salts content, which could increase the soil salinity and sodicity within a short time after their application. The aim of this study was to investigate the short term effects of animal manure application on soil structure stability, infiltration rate (IR), and runoff and soil erosion formation under rainfall conditions. Two soils, a non-calcareous, sandy soil with 0.2% organic matter, and a calcareous, clayey soil with 4.7% organic matter were sampled from a semiarid region. The soils were mixed with raw cattle manure or with compost, and soils with no addition were considered as a control. The two soils with the three treatments were incubated for 21 days, and then subjected to 80 mm of simulated rainstorm. In contradiction to previous works, it was found that the manure reduced soil structure stability, reduced infiltration, increased surface runoff and led to soil loss. The negative impact of the raw manure on soil structure was stronger than that of the mature compost. The findings of this study indicate the high sensitivity of arable soils to erosion processes during the first few weeks following the addition of manure to the soil, and therefore could contribute to the decision-making process of the timing of manure application, namely to make sure that the manure is applied well before the rainy season, in order to avoid the aforementioned soil erosion.

Keywords: soil conservation; organic soil amendments; soil erosion

1. Introduction

Soil structure refers to the geometry and architecture of the soil particles and pores, and is a major factor that effects soil functionality. The soil pore network system is typically characterized by the pores' total volume, size distribution, tortuosity and connectivity, and it has an important role in respect to water and nutrient transport in the soil [1]. In arable lands, favorable soil structure conditions lead to improved soil hydraulic properties, better soil aeration, improved root growth and better connection between roots and soil aggregates [2–5]. Consequently, water and nutrient uptake by the plants, and root respiration are more efficient, thus crop yield increases. Nevertheless, soil structure in agricultural lands is prone to changes, due to external destruction forces, such as compaction and grinding processes resulted by travel of heavy machinery over the fields [6] and intensive soil tillage [7]. In addition, internal forces may also affect soil structure stability, mainly in soils with high exchange sodium potential (ESP), which is the level of adsorbed Na^+ in the exchangeable complex of the clays in the soil [8]. In these soils, wetting, drying and leaching processes lead to soil swelling, clay particle dispersion and aggregate slaking [9]. These external and internal structure deformation processes lead to soil crusting, increase of soil bulk density, reduction of hydraulic conductivity, and elevation of surface runoff and soil erosion [10].

Soils in arid and semiarid regions are characterized by low organic matter content [11], a high percentage of expandable clay minerals, such as montmorillonite [9,12,13], and relatively high ESP [9,14]. Soils with such properties are sensitive to breakdown and erosion processes as under rainfall events or sprinkler irrigation; a compacted and impermeable crust (~2 mm thick) is formed at the soil surface [5,10,15]. This crust decreases the soil infiltration rate (IR), and consequently increases the surface runoff and soil erosion [10,15,16]. The crust formation is a result of three complementary mechanisms: (i) a physical breakdown of the aggregates at the soil surface by the raindrop impact energy [10]; (ii) fast wetting of the aggregates, which leads to aggregates slaking [10]; and (iii) a physio-chemical dispersion of the clay particles [17].

The salinity and sodicity of the soils, expressed by electrical conductivity (EC) in the soil solution, and ESP, respectively, are the two main parameters controlling the physio-chemical process in the soil [14,18,19]. Increasing the soil ESP, and decreasing the EC, in the soil solution, enhance the electrical repulsion forces between the clay particles, which in return weaken the soil structure stability [18]. The exchange of Na^+ ions in the exchangeable complex of the clays in the soil, by polyvalent cations such as Ca^{2+}, Al^{3+} and Fe^{3+}, leads to the reduction of the soil ESP, thus improving soil structure stability [5]. Promoting of the exchange process can be achieved by the addition of Ca^{2+} ions to the soil through soil amendments rich in Ca^{2+}, such as gypsum and lime [20,21]. Rain and irrigation water dissolve the Ca^{2+} rich minerals and increase calcium concentration in the soil pore water, which elevates the rate of Ca^{2+}/Na^+ exchange processes. Similar processes also occur naturally in calcareous soils [8]. The higher the cation exchange capacity (CEC) of the soil, which is a measure of how many cations can be retained on soil particle surfaces, the more exchanges between Na^+ and Ca^{2+} can occur, thus, soil structure stability is elevated for soils with high CEC [5,22].

Soil erosion by water is a product of two main processes: (i) soil detachment of soil particles from the soil surface by raindrop impact and runoff shear; and (ii) soil transport of the detached particles by raindrop splash or surface runoff [23]. Hence, the structure stability of the soils affects the rate of soil erosion. In general, for a certain erosivity rate of the rainfall, the lower the aggregate stability at the soil surface, the higher the susceptibility of the soil erosion processes [5,10,15,16,23]. This was recently demonstrated by Tanner et al. [24], who found a positive correlation between soil erodibility and ESP values for various loess soils from a semiarid region. Important to emphasize that at low ESP conditions, where soils are not subjected to swelling, dispersion and slaking, high clay content in the soil tends to improve soil stability and reduce erosion, as the clay acts as a cementing material that holds particles together in the aggregates [15,25].

A common practice to improve agricultural soil fertility and soil structure stability in croplands is the application of organic residues, such as animal and green manures, and organic wastes, to the fields [5,12,26]. This practice has well-known archeological evidence that goes back more than 2500 years [27]. A major worldwide source of organic residues is animal wastes from the livestock industry, which can be applied as raw or composted manures [28,29]. Livestock waste is produced in large quantities, and can threatened environmental hygiene if it is not disposed of appropriately [30,31]. For example, every year, ~35 million tons of dry livestock waste is produced in the United States alone, and in Europe more than 1500 million tons of fresh livestock waste is generated annually [31,32]. About 56 billion livestock are cultivated worldwide annually for human consumption. This number is continually growing, mainly in the developed world, and by 2050, it is expected to have doubled [32]. Therefore, the reuse of livestock organic wastes is very important, as it provides a sustainable way to cope with the growing quantities of animal waste.

Addition of organic materials to the soil could be beneficial in respect to soil health as it elevates soil water holding capacity, supplies nutrients, provides a habitat and energy to soil biota, and improves soil structure [33,34]. The application of organic residues to the field stimulates formation and stabilization of granular and crumb type aggregates, as the decomposition of the organic residues supports the generation of gels and other viscous microbial products, together with bacterial communities and fungi that encourage crumb formation [26] and increase soil elasticity and compressibility [35]. Organic complexes such as polysaccharides interact chemically with silicate clay particles, iron and aluminum oxides, and the organic compounds formed orient the clay particles in a uniform plane and then form bridges between specific soil particles, thereby binding them together in water-stable aggregates [26,36].

The works cited above, and many others [37–39], studied the long term effects of organic residue application in agricultural fields. As expected, most of these works have shown a positive contribution of the organic residues' application to soil structure. In order for these organic residues to be active in the soil and function as soil amendments, biological and chemical processes should decompose the applied organic residues and assimilate them into the soil aggregates. The duration of these processes is in the order of several months, before the organic residues become beneficial in respect to soil structure [40–43]. On the other hand, livestock manures usually contain high contents of soluble salts, including Na^+ salts [44–47]. Therefore, application of these manures in cultivated fields could increase the salinity and the sodicity of the soils in the first weeks or months after application. During this time, prior to the assimilation of the organic matter (OM) into the soil, the manure application could harm the crops and the seeds germination by salinity increase, and the soil structure by sodicity increase. Nevertheless, we could not find works in the literature that examined the short-term effect of added OM from the livestock industry on soil stability and erodability. Therefore, the aim of the present study is to shed more light on the short term impact of animal manure application on the structure stability, IR, runoff and soil erosion processes in two different soils from a semiarid region, under rainfall conditions.

2. Materials and Methods

Soils and manures: Two different soils, sandy soil (Hamra) from the coastal plain of Israel, and clayey soil (Rendzina) from the North of Israel, were sampled from the top layer (0–20 cm) of uncultivated, open fields. By the "World Reference Base" (WRB) classification, Hamra and Rendzina are classified as "Vertic Luvisol" and "Rendzic Leptosols", respectively. The samples were air dried; each sample was mixed for homogeneity after the removal of gravels and big prats of plants, crushed and sieved to <4 mm aggregates. A portion from each soil sample was further crushed and sieved to <2 mm for soil property analyses in three replications for each sample. The soil analyses included standard methods for: (i) soil particle sizes distribution by the hydrometer method [48]; (ii) organic matter content using the Walkley–Black method [49]; (iii) $CaCO_3$ content by calcimeter [50]; (iv) and cation exchange capacity (CEC) and ESP using ammonium acetate at pH 7 [51]. Soil water extract from each soil sample, and three replications for each, were conducted by mixing soil and deionized water at a ratio of 1/4.5 (*w*/*w*) soil/water, respectively, in 250-mL Teflon centrifuge tubes, shaking mechanically for 1 h at 160 rpm, and centrifuged (Avanti J-E, Beckman Coulter, Brea, CA) for 10 min at 7000 rpm. In the extracted solutions, the following parameters were determined: (i) pH; (ii) EC; and (iii) concentrations of Na^+, Ca^{2+}, and Mg^{2+}. The pH was determined by a pH meter (pH 700 pH/mV/C/F Bench Meter, Eutech Instruments Pte Ltd, Singapore City, Singapore), EC by EC meter (86505-pH/ORP/Cond./ TDS/Salinity, AZ Instruments, Taichung, Taiwan), Na^+ and K^+ concentration by a Flame photometer (Model 420 Clinical Flame Photometer, Sherwood Scientific Ltd, Cambridge, UK), and Ca^{2+} and Mg^{2+} concentrations by atomic adsorption spectroscopy (Absorption Spectrometer Analyst 400, PerkinElmer Inc, Waltham, MA, USA), after adding 10% concentration of $LaCl_3$ to each extract sample. The sodium adsorption ratio (SAR) values of the soil water extracts were calculated by:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (1)$$

where the concentrations of the cations are expressed in meq/L.

Two types of cattle manure were used: (i) Industrial composted manure (named "compost"), which was taken from a composting facility "Compost Haamakim" located in the North of Israel; and (ii) raw manure (named "yard manure"), which was collected from a resting area yard, where the cows lie down, after its daily tillage. The yard manure was taken from cow dairy farm in Kibbutz Ramot Menashe located near "Compost Haamakim". The chemical proprieties of the two studied manures were analyzed by a certified laboratory of the Israeli Agricultural Ministry, and included: (i) dry matter content; (ii) organic matter content; (iii) C/N ratio; and (iv) N, P, K percentages. The water extracted from the manure was diluted at a ratio of 1:10 (manure: deionized water) in order to measure: (i) pH; (ii) EC; (iii) and Cl^- and Na^+ concentrations.

Rainfall simulator study: The experiments were carried out in a Morin-type rainfall simulator [52], which enables simulating rainstorms with different rainfall intensities on soils with varied slope gradients. In each soil type, Hamra and Rendzina, three treatments, with four replications for each, were studied: (i) soil with no manure addition (control); (ii) mixture of soil with compost (compost treatment); and (iii) mixture of soil with yard manure (yard manure treatment). For all the treatments, air-dried soil with <4 mm aggregates size was used, when in the two latter treatments, the soil was mixed thoroughly with compost or yard manure at 0.013/1 (*w*/*w*) ratio of dry manure/soil, respectively. This ratio of manure/soil is equivalent to the commercial ratio used in agricultural fields in Israel, at the order of 10 m^3 per hectare. The treated soil samples were packed and levelled into perforated metal trays in dimensions of 0.3×0.5 m^2 and 0.02 m depth, with average bulk density of 1.38 ± 0.13 g cm^{-3}. The packed soils in the trays were first wetted to approximately field capacity with deionized water by a mist (almost zero kinetic energy), and then stored at 30 °C for 21 days for incubation. During the incubation, the soils were rewetted to field capacity every 2–3 days. After the incubation period, the trays were placed in the rainfall simulator at a slope of 9% gradient, and were exposed to an 80 mm simulated rainstorm of deionized water with high kinetic energy. Rainstorms of comparable duration and intensity are commonly used in similar studies, as they allow the reaching of final and stable IR values [16,38,52–54]. The physical parameters of the rainstorm were: (i) rain intensity of 55 mm h^{-1}; (ii) raindrop mean diameter of 1.9 mm; (iii) drop velocity of 6.02 m s^{-1}; and (iv) kinetic energy of 18.1 J mm^{-1} m^{-2} [52]. During the rainstorm, the water percolating through the soil was collected frequently and its volume was measured, and the IR values were calculated with respect to the cumulative rainfall. The runoff and leachate were collected in four fractions during every 17.5 mm of rainfall, and their volumes were measured. Twenty-four hours after the end of each rainstorm, a portion from each leached sample was filtered (0.45 µm) and measured for EC and pH values, and Ca^{2+}, Mg^{2+}, and Na^+ concentrations, as detailed above. Soil loss (erosion) was determined by evaporating the runoff water and weighing the mass of dry sediments within.

Statistical analysis: Statistical analysis was conducted using mean separation and analysis of variance (ANOVA) by JMP Pro12 software. Differences among means were tested using analysis of variance followed by Tukey's honest significant difference test [55], and at a significance level of $\alpha = 0.05$.

3. Results and Discussion

Soil and manure properties: As detailed above, the examined soils were: (i) sandy soil, named Hamra; and (ii) a clayey soil named Rendzina. Measured properties of the soils, including texture, ESP, CEC, OM, $CaCO_3$, and EC, pH, and SAR of extracted water from the soils are detailed in Table 1. It is evident that the two soils are markedly different in their texture, OM and $CaCO_3$ contents, and CEC. The high CEC of the Rendzina is a result of the high clay content of that soil. These differences suggest that the Hamra would be more susceptible to soil erosion at rain events, as high clay content at low ESP conditions, high OM and high CEC are favorable in respect to soil structure stability and reduction of soil erosion. Moreover, the high percentage of $CaCO_3$ also contributes to soil structure stability as it increases Ca^{2+} concentration in the soil pore water, thus accelerating Ca^{2+}/Na^+ exchanges in the exchangeable complex of the clays, which further decreases soil ESP and improves soil structure stability [15,20].

Table 1. Soil properties. Numbers in brackets are standard deviation values (n = 3).

Soil Type	Texture			Organic Matter (OM)	$CaCO_3$	Exchange Sodium Potential (ESP)	Cation Exchange Capacity (CEC)	Soil Water Extract (1:4.5)		
	Clay	Silt	Sand					Electrical Conductivity (EC)	pH	Sodium Adsorption Ratio (SAR)
	[%]			[%]			[meq/100 g]	[ds m^{-1}]		[–]
Sandy soil (Hamra)	6.7	0	93.3	0.2 (0.0)	0.6 (0.0)	0.6 (0.3)	4.2 (0.1)	0.1(0.0)	6.7 (0.0)	0.3 (0.0)
clayey soil (Rendzina)	51.3	24.3	24.4	4.7 (0.1)	41 (0.4)	0.5 (0.1)	51.2 (1.0)	0.2 (0.0)	6.9 (0.0)	0.5 (0.0)

Chemical analyses of compost and yard manure indicate high similarities between the two composts, with a notable difference in dry matter content, as the compost was ~50% drier than the yard manure (Table 2). This is expected, as the yard manure was collected directly from the cowshed and it did not go through any processes of composting or drying.

Table 2. Manure properties.

Manure Type	General Content						Manure Water Extract (1:10)				
	Dry Matter	OM	C/N	N	P	K	pH	EC	Cl^-	Na^+	SAR
	[%]		[–]	[%]			[–]	[dS m^{-1}]	[meq L^{-1}]		[–]
compost	74.6	62.1	14.7	2.5	1.1	2	7.2	11.3	48.5	47.5	19.6
Resting area (yard manure)	52.9	68	15.4	2.6	1.3	2	7.2	10.9	50.5	45	22.9

Rain simulator—Infiltration: As detailed in the introduction, OM soil amendments are known to improve infiltration and wetting processes of the root zone. Nevertheless, herein it was observed that the addition of the two manures did not improve infiltration compared to the control, and even reduced it. In the Rendzina soil, both manures led to a small decrease of IR compared to the control, but the differences were not significant (Figure 1A). In the Hamra soil, the same trend was observed, with significant differences between treated soils and control (Figure 1B). No significant differences were observed between the two manure types. In all examined soils and manures, the highest infiltration rate was measured at the beginning of the experiment and it was reduced with the proceeding of the simulated rain event, due to soil structure destruction, which resulted in the creation of a soil crust at the soil surface and the clogging of pores within the soil due to clay dispersion and swelling.

Since infiltration is measured by collecting and measuring of the draining water at the bottom of the two cm thick soil profile, it takes some time from the onset of the rain event, until the soil is fully saturated and steady drainage is measured. During this time, as long as surface run-off is minor (Figure 2), it is reasonable to estimate that IR is equal to rain intensity. For Rendzina and Hamra soils, full saturation (and the beginning IR measuring) was achieved after a cumulative rainfall of 38 and 20 mm, respectively—see Figure 1. For the Rendzina (treated and non-treated), initial IR was in the order of 45 mm h^{-1} and for the non-treated Hamra, initial IR was in the order of 55 mm h^{-1}. These differences between the two soils indicate the initial higher hydraulic conductivity of the Hamra compared to the Rendzina, which coincides with the textural differences between the two soils (Table 1). The fact that control and treated soils started to drain at the same time indicate that the manures did not increase the water holding capacity of the soils and that the reduction in IR of the treated soils, throughout the rain event, is a result of reduced hydraulic conductivity.

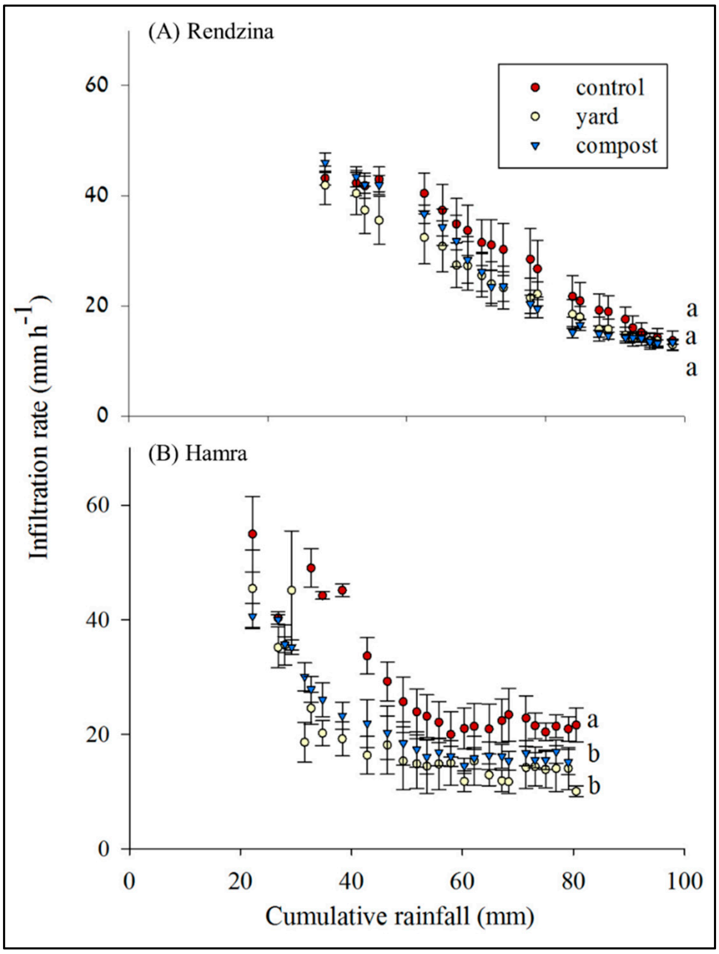

Figure 1. Infiltration rates for Rendzina (**A**) and Hamra (**B**) soils, with no addition of organic matter (control), and addition of yard manure (yard) and compost. Different letters "a" and "b" indicate significant differences between treatments.

Rain simulator—Surface runoff: Surface runoff was consistent with IR measurements (Figure 1). It is seen, for both soils, that the addition of the manures resulted in increased surface runoff (Figure 2), even though differences were not significant. In agreement with IR measurements, the largest differences between control and treated soils were observed for the Hamra, where the yard manure and compost increased surface runoff by 100% and 30–50%, respectively (Figure 2B). In the Rendzina soil, differences between yard manure and compost manures were minor, and in general, the addition of the manures led to increased surface runoff by 20–30%.

As mentioned above for the reduced IR, increased surface run-off indicates the crusting and degradation of soil structure, which result in the reduction of the soil hydraulic conductivity; thus, IR is lowered and surface run-off increases.

Rain simulator—Soil loss: Soil loss rates in the Hamra soil, even without the organic amendments, were higher than those in the Rendzina soil by an order of magnitude (Figure 3). For both soils, the compost and the yard manure did not improve soil stability and did not reduce soil erosion. While the compost treatment had soil loss values similar to the control, the addition of the yard manure resulted in reduction of soil stability and increased erosion (Figure 3). The largest differences between the yard manure and control and compost treatments were observed for the Hamra, with soil erosion increased by three folds (Figure 3B). This is consistent with surface runoff values that were highest for the Hamra soil, with the yard manure (Figure 2B) and IR measurements that were significantly reduced in the Hamra soil (Figure 1B). The differences between the two soils and two manures and the reasons for increased soil erosion of the yard manure and Hamra soil are discussed below.

Hamra and Rendzina disparities: As detailed above, the rain simulation experiments showed that the Hamra is more susceptible to soil destruction processes and erosion, compared to the Rendzina. The simulated rain events resulted in the greater reduction of IR and increased surface runoff and erosion for the Hamra, compared to the Rendzina (Figures 1–3). Even in the control soils, with no addition of manures, soil loss of the Hamra was more than four folds greater than the Rendzina. This difference in soil loss between the Hamra and Rendzina, for control conditions, is attributed to: (i) low clay content of the Hamra (6.7%) compared to the Rendzina (51.3%); (ii) higher $CaCO_3$ concentration of the Rendzina (41%) compared to the Hamra (0.6%); and (iii) higher OM of the Rendzina (4.7%) compared to the Hamra (0.2%) (Table 1).

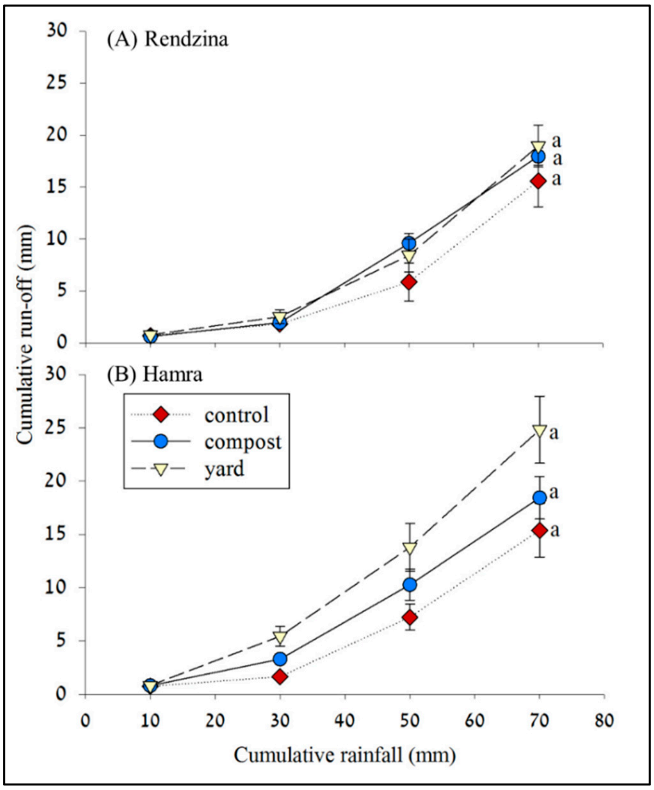

Figure 2. Cumulative runoff for Rendzina (**A**) and Hamra (**B**) soils with no addition of organic matter (control), and addition of yard manure (yard) and compost. The "a" letters indicate statistical significance.

Both the Hamra and Rendzina soils, with no addition of OM, had relatively low ESP (0.6 and 0.5, respectively), and in these values, as detailed in the introduction section, high clay content is an advantage in respect to soil structure stability and erosion, as it cements the soil. Moreover, the high $CaCO_3$ concentration of Rendzina further improves its resilience against swelling, dispersion and slaking processes, as it contributes Ca^{2+} ions to the soil solution, thus increasing pore water electrolytes concentration and decreasing soil ESP by the Ca^{2+}/Na^{+} exchange processes. This positive effect of cation exchange is even more pronounced in the Rendzina soil, due to its high CEC, which is more than 10 fold higher than the Hamra (Table 1).

The impact of the compost was negative on both soils with respect to soil erosion, but the differences compared to the control were insignificant. However, following yard manure application, a notable reduction of IR, and an increase of surface runoff and soil loss, were observed for both soils, with a much greater influence in the Hamra soil, with increased soil erosion compared to the control, by three and two folds for the Hamra and Rendzina, respectively (Figure 3). In respect to infiltration, in the Rendzina soil, the yard manure resulted in a minor and insignificant reduction of IR, while in the Hamra soil, the IR was reduced by almost 50% compared to control (Figure 1). Surface runoff was also greatly affected by the yard manure in the Hamra soil, where it was elevated by ~30% compared to the control; whereas in the Rendzina surface, runoff rates were similar for the control, compost and yard manure conditions (Figure 2).

Yard manure and compost disparities: As mentioned, both the yard manure and the compost negatively affected soil structure stability, which led to reduced IR and increased surface runoff and erosion. This was most prominent in the Hamra soil with the addition of the yard manure and least significant in the Rendzina soil with the compost. The higher sensitivity of the Hamra to soil structure deterioration is detailed above and in this section the differences between the two manures will be discussed, in the light of EC and SAR analyses of drained water at the bottom of the soil trays (Figure 4).

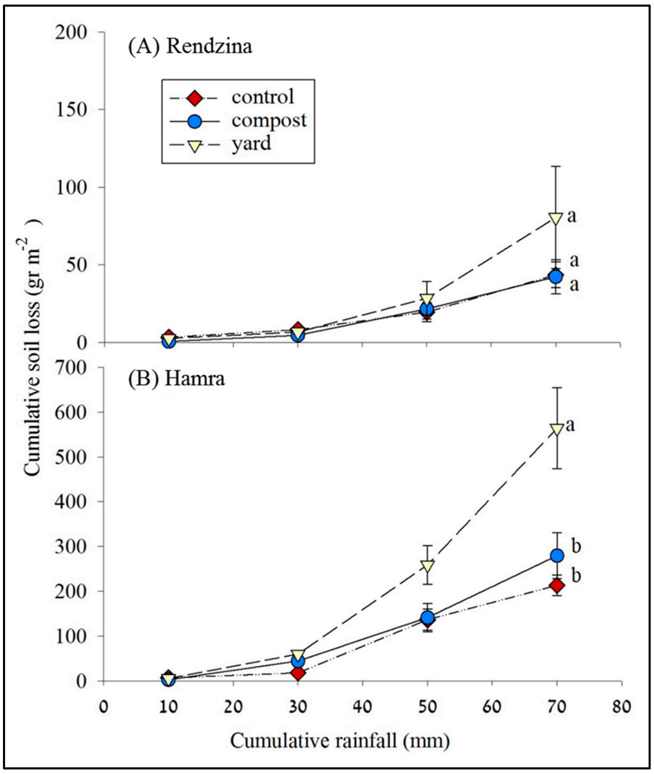

Figure 3. Cumulative soil loss for Rendzina (**A**) and Hamra (**B**) soils, with no addition of organic matter (control), and addition of yard manure (yard) and compost. Different letters 'a' and 'b' indicate significant differences between treatments.

At the beginning of the simulated rain events, after a cumulative rainfall of 30 mm, EC values of drained water from the control soils were in the order of 1.2 and 0.7 dS m^{-1} for the Rendzina and Hamra, respectively (Figure 4A–B). These relatively high values of salinity are a result of dissolution processes of minerals within the soil by the rain water. With proceeding of the rain events, EC values of the leachate water were reduced for both soils to values in the order of 0.1–0.2 dS m^{-1}, due to removal of the soluble minerals out of the soils, with the leaching water. Towards the end of the rain event, the EC of leachate water from the control Rendzina soil was approximately two folds higher than the Hamra. This could be a result of the high $CaCO_3$ content of the Rendzina which is a low soluble mineral that slowly and continually is dissolved by the infiltrating rain water, contributing ions to the system. SAR values were relatively low for the control soils, both Hamra and Rendzina, in the order of 0.4-0.5, indicating the low ESP of the soils in their natural form.

In the samples with the manures, initial EC measurements were in the order of 2.5 dS m^{-1} for both soils and both manures. This was more than two-fold salinity than in the control soils, indicating the high contribution of ions to the soil system by the two manures. With the proceedings of the simulated rain events, EC readings of all setups were reduced, but in most cases were more than double compared to the control conditions and in almost all cases, EC of the yard manure was higher than the compost. This is a result of the low degree of composting of the yard manure compared to the compost, as the maturity of the compost reduces the degree and rate of solutes release to the environment [56].

Increased SAR values were calculated for both soils, with both manures (Figure 4C–D). This means that both manures contributed high levels of Na^+ to the soil pore water. Under the assumption that leachate water represents pore water chemistry and that soil ESP is correlated to pore water SAR, due to exchange reactions between soil solution and the exchangeable phase of the soil [8], it is evident that the yard manure and compost led to sodification of the soils. Soil sodification due to anthropogenic processes, such as irrigation and the addition of soil amendments, is termed secondary sodification.

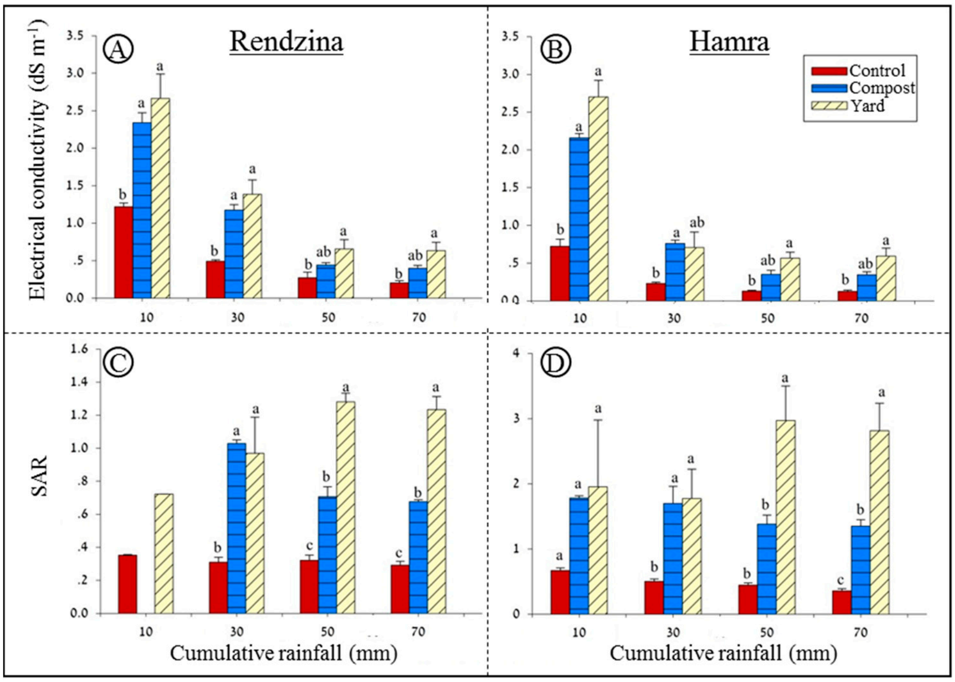

Figure 4. EC (**A**,**B**) and SAR (**C**,**D**) values for leachate water at the bottom of the Rendzina (**A**,**C**) and Hamra (**B**,**D**) soils. Notice that SAR scales are different between the two soils. The fact that data was missing for compost in (**C**) is the result of a technical failure during the experimental procedure. Different letters "a" and "b" indicate significant differences between treatments.

For cumulative rainfall of 50 mm and above, where SAR and EC readings are stable, in the Rendzina soil, the addition of compost and yard manure resulted in elevation of SAR by two and three folds, respectively, compared to the control. Absolute values were in the order of 0.7 and 1.3 for the compost and yard manure, respectively. However, in the Hamra soil, the increase in SAR was much greater, due to the addition of the two manures, with absolute values of 1.5 and 3 for compost and yard manure respectively (Figure 4C,D). These values are 3 and 6 times higher respectively, compared to the control.

The higher SAR values of the yard manure compared to the compost can also be explained by the fact that the compost is more mature, thus contributes less solutes to the pore water than the yard manure does. The amplified effect of soil sodification in the Hamra soil compared to the Rendzina is attributed to the difference in chemical properties between the two soils, as detailed above; mainly the high $CaCO_3$ content of the Rendzina (Table 1), which acts as a buffering mechanism that constantly releases Ca^{2+} ions, moderating the pore water SAR values and soil ESP. On top of that, the high CEC of the Rendzina elevates Ca^{2+} absorption by the exchangeable complex of the clays, which further reduces soil ESP and improves its stability and resistance for soil structure deterioration processes.

4. Summary and Conclusions

The chemical differences between the yard manure and compost, and Hamra and Rendzina soils which were discussed above, support the observed phenomenological differences in respect to infiltration, surface runoff and erosion processes measured in the rain simulations. These observations are inconsistent with past observations, which have shown an improvement in infiltration processes and reduction in surface runoff rates and soil loss for soils with organic soil amendments from the livestock industry [37–39]. These differences are explained by the fact that previous studies examined soils which were treated with manures over time scales of months and years, whereas in this work, the manures were applied into the soil only 21 days prior to the simulated rain events.

It is suggested here, that during the first few weeks following the addition of the manures to the soil, the negative processes of solute contribution by the manures to the soil and the associated processes of soil sodification overcome the impacts of the OM that should improve soil structure stability. As detailed in the introduction, the major impact of the organic soil amendments to soil structure stability is the assimilation of the OM into the soil which includes the generation of gels and other viscous microbial products, together with bacterial and fungal communities that stabilize the soil aggregates and encourage crumb formation. Since these processes are not instantaneous and require several weeks to months to develop in the soil [40–43], the positive impact of the manures on soil structure are manifested only a few weeks to months after the manures are applied. However, the dissolution and solute release of the manures to the soil time scales are very short, in the order of minutes and hours, during a single rain event. Consequently, in this period of the few weeks following manure addition, the soil is relatively sensitive to erosion and soil loss processes during rain events.

This understanding of the sensitivity of the soil to erosion processes immediately after the addition of the manures may play an important role for farmers and decision makers in the agricultural industry, as it is essential to apply the manures enough time in advance before the rainy season, to allow the manures to be decomposed and assimilated into the soil, prior to the onset of the strong rain events which may lead to severe soil erosion processes. While the intensity and duration of the simulated storm, in this study, compared to that experienced in natural semi-arid environments, it was shown experimentally, that reduction of IR, increased surface runoff and elevated soil erosion were observed after cumulative rainfall at the order of 20-40 mm. These rainfall values of high intensity over a short time period are common for arid and semi-arid environments [57–59], therefore the experimental findings of this study are considered to be applicable for field conditions.

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