PLANT NUTRIENT LOSSES BY WATER EROSION ON THE SOILS OF BEQA'A, LEBANON

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NUTRIENT LOSSES BY EROSION

AHMAD

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A study was conducted on the micro plots 2 X .5 meters in size at the Agricultural Research and Education Center of the American University of Beirut, Lebanon. In this experiment, the effects of three treatments (fallow, straw mulch, and barley) on three soils (Chestnut, Rendzina, and Terra Rossa) at 8 and 16% slope were studied.

Significant differences were observed among the soils. Losses of soil and plant nutrients on these soils decreased in the following order: Rendzina < Chestnut < Terra Rossa. Rendzina differed significantly from Chestnut and Terra Rossa while the latter two did not differ significantly from each other.

Among the treatments, barley reduced the losses significantly as compared to straw mulch and fallow, especially with regard to available nutrients. Straw mulch did not show marked difference over fallow.

The difference between the 8 and 16% slopes were significant for macro-nutrients in available forms, but it did not apply for micro-nutrients.

Enrichment Ratios varied with each element, showing the selectiveness of the erosion process. The losses of available nutrients were higher than the total elements, and the available forms were strongly affected by cropping treatments, whereas non-available forms were little affected.

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I. INTRODUCTION

Rainfall erosion is a serious problem of farming over a large part of the world. It is particularly acute on gently to steeply sloping land of both humid and semi-arid areas (Smith and Wischmeier, 1962, pp 109-148). Available measurements indicate that at least 3,000,000,000 tons of solid material is eroded from the fields and pastures of the United States of America every year. The soil lost in this way contains 92,172,300 tons of the five principal elements of plant food, i.e. phosphorus (P), potassium (K), nitrogen (N), calcium (Ca), and magnesium (Mg), as described by Bennet, (1939, pp 11-12).

Four factors and their interactions have long been considered the basic determiner of the rate of rainfall erosion. These are ;- climate (particularly rainfall energy), soil; topography; and plant cover (Smith and Wischmeier, 1962, pp 109-148).

The removal of elements by erosion is non-selective in the sense that nutrients in all forms may be removed by the erosion process. The process tends to be differential, however, in that the organic matter (O.M.) and finer particles of soil relatively high in plant nutrients are more readily lost by erosion than are the coarser soil fractions.

Considerable work has been carried out to determine the quantities of soil and water lost from different soils and under different cultivation practices. Little study has been made, on the other hand, of the chemical nature of the soil material that has been eroded away, and especially of the amounts of specific nutrients, such as organic matter, N, P, and K, that are lost as a result of erosion.

To assess the extent and nature of the chemical losses, an experiment was initiated at the Agricultural Research and Education Center of American University of Beirut on three soils of Beqa'a using artificial sprinkling and micro-plots.

II. REVIEW OF LITERATURE

Although the importance of the erosion problem is well recognized, comparatively little data are available regarding plant nutrient losses by water erosion.

Soil Losses

The first field plots in the United States specifically designed to measure quantitatively the loss of soil, water, and nutrients from surface runoff were established in Missouri in 1917 by Duley and Miller as reviewed by Barrows and Kilmer, (1963, pp 303-315). The 1/80 acre plots, located on Shelby loam having a 3.68% slope, were subjected to various management practices. Plots in sod lost 42 lb of soil per acre per year; fallow plots lost 5195 lb of soil. Moldenhaur and Wischmeier (1960) reported the loss from a coarse loess soil in Western Iowa on 12% slope. In a two years rotation of corn-oats with sweet clover catch crop averaged about 25 tons of soil loss per acre per year. Contouring reduced the annual loss to ten tons per acre. Knoblauch et al. (1942) observed 13,000 lb of soil per acre per year from 3.5% slope and these losses were reduced to 6,000 lb by employing rye as a cover crop. Neal (1944) recorded 6,270 lb of soil loss per acre on Collington sandy loam. Stoltenberg and White (1953) reported average annual soil loss 7,500 lb per acre for corn under the existing conditions on five percent slope.

More recently Wischmeier (1960) has analyzed some 8,000 plot years of data to evaluate the influence of various factors on each crop period. Ready reference tables have been prepared that help to provide valuable guides for conservation farm planning adopted to local rainfall pattern, e.g., in case of continuous corn rotation, under no treatment, period one (seedling stage) gave 92% soil loss as compared to losses from continuous fallow. The loss was reduced to 50% at period three (growing crop). With fertilized N.P.K. treatment the losses were 85 and 30% under period one and period three, respectively. Similar tables have been prepared by Van Doren and Bartelli (1956) by developing a method of forecasting soil loss from various soils in Illinois under different management practices. Moldenhauer _et al_. (1967) studied the influence of crop management on runoff erosion and soil properties of Marshal silty clay loam soil. They observed that soil losses rate were high, especially when corn followed several years of corn, and were inversely related to organic matter content and aggregate stability of soil. Soil losses from corn following meadow was, however, substantially less than from the N-treated continuous corn. Epstein and Grant (1967) obtained a linear relationship between clay content and soil loss while studying the relationship between the soil loss and physical properties of six soils. Crust formation was given an important factor in effecting the soil loss.

Organic Matter Losses

The importance of soil organic matter is well known. The losses reported for organic matter are critical. It is among the first constituent to be lost through erosion, and also among the hardest to replace. Not only is the soil being depleted of one of its most valuable components, but significant quantities of nutrients, such as N and P, are removed with the organic matter. Bedell _et al_. (1946) reported a total loss of 555 lb of organic matter per acre. The eroded material contained about twice as much organic matter as the original surface soil from which it came. On the other hand, Neal (1944) found that eroded material contained 4.7 times as much organic matter as soil proper. Hayes _et al_. (1948) reported 951 lb per acre of organic matter lost annually from moderately eroded Fayette silt loam and 668 lb per acre from a severely eroded phase. Knoblauch _et al_. (1942) indicated a loss of 337 lb per acre of organic matter from a 3.5% sloping Collington silt loam protected with a manured cover crop of rye, whereas the fallow check plot lost 1149 lb per acre. Slater and Carleton (1938) found a correlation between the decrease in organic matter contents of a series of plots and the amount of erosion that occurred. For a fallow plot on which the greatest erosion occurred, it was estimated that erosion had increased the depletion of organic matter to 18 times that normally lost by oxidation. Massey _et al_. (1953) while working on two Wisconsin soils, found that Fayette silt loam and Almena silt loam lost 1.15 and 1.24 times the organic matter of the soil proper. On the contrary, Free (1956) reported only 30% increase in organic matter contents of eroded material from Honeoye sandy loam over that in the soil remaining in the plots.

Nitrogen Losses

Losses of N by erosion are probably more serious than losses of any other elemental nutrient. This results from the fact that most of the N lost is combined with the soil organic matter which is so susceptible to erosion. Neal (1944) obtained an enrichment ratio (E.R.)[1] of 5.0 for N on Collington silt loam while Massey and Jackson (1952) reported an enrichment ratio of 2.7 for total N from two Wisconsin soils. Hayes et al. (1948) found 42 lb per acre of N lost annually from Fayette silt loam planted to oats. Rogers (1941) reported 32 lb of N losses on Dunmore silt loam when planted to either wheat or corn. Knoblauch _et al_. (1942) reported 67 lb of N loss on Collington sandy loam, but when use was made of a cover crop of rye the loss was reduced to 19 lb. Stoltenberg and White (1953) found that N contents of the eroded material were almost double the amount present in the surface soil. Free (1956) reported no difference in the ammonium nitrogen content of the eroded material, but the eroded material contained 48% less nitrate than did the plot soil. Duley (1926) had found that most of the soluble N removed is in the organic form, but the annual removal of N in this form was insignificant. Even lesser amounts of ammonia, nitrate, and nitrite were lost. Harrows and Kilmer (1963, pp 303-315), reviewed the work of Bryant and Slater, who found that about ten pounds of dissolved N per acre was removed annually from a fallow Dunkirk silty loam with a five percent slope, but that a fallow Ontario loam having an eight percent slope lost less than a pound of dissolved N during the same

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1. Ratio of the concentration of an element in the runoff to that in the original soil.

period. Attempts have been made to calculate the total amount of N lost from various soils and to replace this by additions of fertilizers. Wooley (1943) published tables showing N losses from the soils of Missouri under different management schemes. These losses varied from none on a well-sodded meadow to 18% for continuous row crop on a 1200-foot, 12% slope. By using this table, and another showing N removal by various crops, a balance sheet program was prepared by which soil N could be maintained.

Phosphorus Losses

It has been considered that P is one of the least mobile plant nutrient under ordinary field conditions. The downward movement of this element is exceedingly slow (Scarseth and Chandler, 1938). About 50% of the total P may be held on clay surfaces in the plow layer of light textured soils. Thus, P is very susceptible to losses through erosion of clay and organic matter. Ensminger and Cope (1947) who collected samples at the beginning of the experiment and after a 15 years period found that P which could not be accounted for by analysis of the surface 16" of soil and by crops removal was assumed to be lost by erosion. The unlimed plots lost an average of 70% of the added P by erosion. There was no difference between plots receiving sodium nitrate and those receiving ammonium sulphate. On limed plots, sodium nitrate plots lost an average of 32% of the added P, while the ammonium sulphate plots lost an average of 75%. Ensminger (1952) studied the P status of soils which had received phosphate application over a period of years to determine the loss of P by erosion. P that could not be accounted for by analysis of the surface 16" of soil and by crops removal was again assumed to be lost by erosion where corn and cotton was used as the rotation, an average of 63% of P applied during a 16-year period to Hartsell fine sandy loam soil was lost by erosion as compared to 40% for a corn, cotton and winter legume rotation. Scarseth and Chandler (1938) made a study of the residual phosphate in a nearly level, light textured soil in Alabama that had been used for a 26-year period in an experiment involving a three-year rotations of cotton, corn and oats with various legumes. They concluded that 32% of phosphate was used by the plants, eight percent was still present as a residue, and 60% had been carried away with clay fraction lost by erosion. Volk (1945) could not account for 26% of the native and applied phosphorus over a 14-year period on Hartsell very fine sandy loam soil. He considered that this unaccounted P was removed by erosion.

Roger (1941) found an enrichment ratio of 1.3 for total P on 20 to 25% slope while Neal (1944) reported an enrichment ratio of 3.1 on soil having 3.5% slope. Massey and Jackson (1952) reported that eroded material contained 3.4 times as much available P as the soil proper on the Wisconsin soils.

Potassium Losses

Hayes *et al.* (1948) while working on Fayette silt loam planted to either oats or corn, found 854 lb of total K loss per acre from oat plots, but only 26 lb from plots cropped to corn. The loss of available K was 26 and 0.5 lb per acre, respectively.

Knoblauch et al. (1942) recorded 426 lb of total K loss annually from Collington sandy loam soil. The losses were reduced to 98 lb under cover crop of rye. Bryant and Slater (1948) obtained soluble K losses of less than 1 lb per acre annually from Dunkirk soils while Bedell et al. (1946) recorded annual losses of 0.8 to 6.6 lb of available K per acre. The enrichment ratios for available K were much higher than the enrichment ratios for total K as reported by different workers. Neal (1944) obtained an enrichment ratio of 1.4 for total K. The removal of total K by erosion, where no conservation practices were employed, exceeded the removal of K by tomatoes and was four times as much as the removal by sweat corn. Rogers (1941) obtained an enrichment ratio of 1.07 and 4.7 for total available K while Massey et al. (1953) recorded an enrichment ratio of 3.8 and 6.7 for total and available K, respectively. In contrast to the many low values recorded, Stoltenberg and White (1953) got very high enrichment ratios of 7.3 and 12.6 for total and available K, respectively.

Magnesium Losses

The limited data relating to the loss of magnesium through erosion suggest that negligible amounts of this element are removed in the soluble form. Kilmer et al. (1944) from lysimeter study observed a loss of 10 to 31 lb per acre from cropped and fallow, respectively. Robers (1941) reported that eroded material contained 1.39 times magnesium as much as the soil proper. Bryant and Slater (1948) recorded a loss of 1.33 lb from fallow Ontario loam and 3.6 lb per acre from Dunkirk silty clay loam cropped to corn, respectively.

Micro-Nutrient Losses

No published data are available regarding the micro-nutrient losses. Barrows and Kilmer (1963, pp 303-315) have reviewed the more pertinent data related to the water erosion losses for the last 40 years and came to the following conclusions. Significant losses of organic matter with the concomitant removal of N and P do occur and rather large amounts of K are removed, but only a small percentage of this is in an exchange form. Magnesium losses are of little importance.

III. MATERIALS AND METHODS

The experiment is part of a programme of runoff and erosion studies , initiated at the Agricultural Research and Education Center (AREC) of the American University of Beirut, Lebanon.

Nine artificial microplots 2 X .5 meters in size, were laid out in troughs. Sets of three were filled to a depth of 20 cm with three different soils from the Beqa'a: Three with soil taken from the AREC field (Chestnut) about plough layer deep. Three were filled with soil (Rendzina) brought from the anti-Lebanon foot-hills area and the remaining three were filled with soil (Red Earth, Terra Rossa) brought from one kilometer from Khader village. To each soil, N was applied at the rate of 20 kg per dunum in the form of ammonium nitrate and P also at 20 kg per dunum in the form of triple super phosphate. The troughs were filled to a depth of 20 cm, emptied, mixed, and then refilled to get a homogeneous soil. Samples were taken from four places in each of the troughs, composited and an eliquot of these was taken for chemical determinations of the original soil. Various treatments were given to the soils in the troughs as follows:-

1. One plot of each soil was kept fallow.
2. One plot of each soil was covered with a thin layer of wheat straw.
3. One plot of each soil was sown to barley.

All the plots were set initially at a slope of eight percent for a first series of determinations and subsequently at 16% for obtaining eroded material for chemical analysis. A swing type artificial sprinkler was used periodically between rains for eroding the soils at the above mentioned slopes, supplementing natural rainfall. The eroded material produced was collected in sedimentation tanks having 1000 litres capacity each. In order to obtain all the nutrients in a soil sludge, Seperan 2610 flocculant was added to the runoff water as described by Jackson (1964). From each tank, about two gallons of sludge was taken from the bottom, decanted, centrifuged and then freeze dried. These were weighed and stored in labelled cans to await various chemical determinations. At the conclusion of the experiment further soil samples of the original soils were taken and analyzed for comparison whether changes had taken place in the soil.

Since the eroded material frequently differs in composition from the original soil, as reported by most of the earlier workers, the loss of nutrients are expressed in terms of an enrichment ratio (E.R.).

Analytical Procedures

Organic Matter

The chromic acid method based on spontaneous heating by dilution of sulphuric acid (Walkley-Black) was adopted as described by Jackson (1958, pp 219-220).

Total N

The regular macro-Kjeldahl method was followed by digesting the sample in sulphuric acid and then titrating it with hydrochloric acid (Jackson, pp 187-190).

Total K

The Jackson method (1958, pp 283-284) for the determining total K was used by digesting o.1 g of soil with 0.5 ml of perchloric acid and 4 ml of 48% hydrofloric acid at 200- to 225^{o}-C in a platinum crucible. After heating the contents to dryness, the residue were dissolved with 6 N hydrochloric acid and was diluted with distilled water. The resultant solution was then transferred to a 100 ml volumetric flask and the K was determined by means of a Perkin-Elmer 303 atomic absorption spectrophotometer.

Exchangeable K and Ammonium Acetate (NH_4OAc) Extractable Mg

Exchangeable K and ammonium acetate (NH_4OAc) extractable Mg were determined by extracting with 1 N ammonium acetate as suggested by Richard (1954, pp. 100-101).

Total Phosphorus

The colour was developed in ammonium molybadate-stannous chloride in hydrochloric acid system (Jackson, 1958, pp 145) on the perchloric hydrofloric acid system digest. The absorption was measured by a Fisher spectrophotometer.

Available P

Available P was extracted by 0.5 M $NaHCO_3$, pH 8.5 and the colour was developed in modified ammonium molybadate stannous chloride as reported by Jackson (1958, pp 144).

Total Cupper (Cu), Iron (Fe), Zinc (Zn), and Manganese (Mn)

Total Cu, Fe, Zn, and Mn were determined on the perchloric-hydrofloric acid digest by means of a Perkin-Elmer 303 atomic absorption spectrophotometer.

IV. RESULTS AND DISCUSSION

In this experiment the effects of treatments (fallow, mulch, and barley crop), and slopes (8 and 16%) upon the losses by erosion, of major plant nutrients (organic matter, N, total phosphorus, available phosphorus, total potassium, exchangeable potassium, and NH_4OAc extractable magnesium) and minor plant nutrients (Fe, Cu, Zn, and Mn) from three soils (Chestnut, Rendzina, and Terra Rossa) were determined. The data pertaining to each of the above mentioned factors are presented in Tables 1 to 4. Most of the data reported by previous workers regarding plant nutrient losses are without any statistical analysis for critical evaluation, since plot replications are largely impractical in this field of study. The data presented in this section have, however, been statistically analyzed at five percent and one percent levels of significance on the basis of F values. Variation among the significantly different factors has been appraised by Least Significance Difference (L.S.D.) These results have been summarized in Table 4 and detailed analysis has been shown in Appendix A.

Soil Losses

The soil loss data are presented in Tables 1 and 4. It can be seen that soil losses vary significantly among the three soils. Rendzina lost 455.0 kg per hectare with fallow treatment as compared to Chestnut and Terra Rossa which lost 375.5 and 350 kg per hectare, at eight percent slope, respectively. Straw mulch reduced the loss to 429.1 kg per hectare, 348 kg per hectare and 322.6 kg per hectare from Rendzina, Chestnut, and Terra Rossa, respectively, and cropping to barley in turn reduced the loss considerably as compared to both fallow and mulch treatments.

Table 1. Soil loss by erosion from 8 and 16% slopes, in kg per hectare, from three soils of the Beqa'a.

Soils	Treatments	Soil loss, kg/hectare	
		8%	16%
Chestnut	Fallow	375.5	586.3
	Straw Mulch	348.0	560.2
	Barley crop	301.2	470.5
Rendzina	Fallow	455.0	702.8
	Mulch	429.1	675.1
	Barley	385.6	594.0
Terra Rossa	Fallow	350.7	572.5
	Mulch	322.6	538.9
	Barley	300.8	440.0

Analysis of variance shows that there are highly significant differences among the soils, treatments, and slopes. Losses on Rendzina are higher than those of Chestnut and Terra Rossa, and are highly significant at the one percent level. On the other hand, the losses are nonsignificant between the chestnut and Terra Rossa. Similarly, barley treatments gave significantly lower losses than fallow and straw mulch whereas, there was little difference in soil loss between the fallow and straw mulch. The loss of soil at 16% slope is greater than at eight percent slope, which is highly significant at one percent level.

Organic Matter Losses

From the results in Tables 2, 3, and 4, it is clear that soils vary considerably among one another with regard to organic matter losses. An enrichment ratio of 3.63 was obtained on Rendzina soil, while 1.29 and 1.50 enrichment ratios were obtained from Chestnut and Terra Rossa, respectively, on eight percent slope. The enrichment ratios were reduced on each of these soils by straw mulch and barley treatments. Rendzina is highly significantly different from Chestnut and Terra Rossa while the differences between the latter two soils is nonsignificant.

There is no significant difference among the treatments on any one soil, and this is in line with the findings of Knoblauch *et al.* (1942) where they showed that the normal process of erosion removed relatively as much organic matter from the check as from manure and cover crop treatments. Losses from 16% slopes varied from 5.3

Table 2. Chemical analysis of original as well as at eight percent eroded soils for plant nutrients with their enrichment ratios.

Soils	Treatments	O.M.		Total N		Total P		Available P		Total K		Exchangeable K		NH_4OAc extractable Mg	
		%	E.R.	%	E.R.	%	E.R.	ppm	E.R.	meq/ 100 g	E.R.	meq/ 100 g	E.R.	meq/ 100 g	E.R.
Chestnut	Original soils	1.34		.097		.134		10		35.90		2.37		2.57	
	Fallow	1.74	1.29	.19	1.94	.190	1.42	31	3.1	34.20	.95	2.88	1.24	3.09	1.20
	Mulch	1.62	1.20	.18	1.85	.190	1.42	25	2.5	31.68	.88	2.62	1.12	2.99	1.16
	Barley	1.31	0.97	.15	1.54	.185	1.38	19	1.9	27.22	.75	2.24	0.96	2.85	1.11
Rendzina	Original	0.27		.029		.180		34		5.89		0.25		1.19	
	Fallow	0.98	3.63	.12	4.14	.220	1.22	54	1.59	16.40	2.78	1.25	5.0	1.38	1.16
	Mulch	0.91	3.37	.09	3.10	.215	1.19	53	1.55	13.80	2.34	1.15	4.61	1.36	1.14
	Barley	0.82	3.03	.08	2.76	.207	1.11	32	0.94	10.25	1.74	0.70	2.82	1.24	1.04
Terra-Rossa	Original	1.0		.077		.072		8.5		30.75		1.02		3.09	
	Fallow	1.50	1.50	.14	1.82	.127	1.76	20	2.35	35.00	1.13	2.31	2.26	3.41	1.10
	Mulch	1.30	1.30	.12	1.56	.123	1.70	17	2.00	32.32	1.04	2.24	2.19	3.22	1.04
	Barley	1.04	1.04	.07	1.04	.120	1.66	10	1.16	30.25	.99	1.99	1.95	3.06	0.91

Table 2 (Continued).

Soils	Treatments	Fe		Zn		Cu		Mn	
		%	E.R.	ppm	E.R.	ppm	E.R.	%	E.R.
Chestnut	Original	5.75		126		125		.11	
	Fallow	5.80	1.01	130	1.02	150	1.20	.11	1.00
	Mulch	5.55	0.96	127	1.00	145	1.16	.10	0.91
	Barley	4.00	0.69	120	0.94	110	0.88	.07	0.63
Rendzina	Original	1.15		90		56		.02	
	Fallow	2.75	2.39	157	1.75	61	1.08	.05	2.50
	Mulch	2.70	2.34	155	1.73	61	1.08	.04	2.00
	Barley	1.65	1.43	121	1.35	40	0.71	.03	1.50
Terra Rossa	Original	6.90		135		86		.11	
	Fallow	6.60	0.95	186	1.37	89	1.03	.14	1.27
	Mulch	6.55	0.94	178	1.31	79	0.91	.11	1.00
	Barley	6.35	0.77	170	1.25	60	0.67	.08	0.73

Table 3. Chemical analysis of original and eroded soils for plant nutrients at 16% slope with their enrichment ratios.

Soils	Treatments	O.M.		Total N		Total P		Available P		Total K		Exchangeable K		NH4OAc extractable Mg	
		%	E.R.	%	E.R.	%	E.R.	ppm	E.R.	meq/ 100 g	E.R.	meq/ 100 g	E.R.	meq/ 100 g	E.R.
Chest-nut	Original soils	1.34		.097		.134		10		35.90		2.37		2.57	
	Fallow	3.24	2.41	.26	2.68	.170	1.27	35	3.5	35.81	0.91	4.81	2.03	4.50	1.75
	Mulch	2.99	2.23	.21	2.16	.168	1.25	32	3.2	34.10	0.90	3.10	1.50	3.67	1.42
	Barley	2.34	1.74	.16	1.65	.162	1.20	25	2.5	33.80	0.89	2.80	1.11	2.93	1.14
Rendzina	Original	0.27		.029		.180		34		5.89		0.25		1.19	
	Fallow	1.50	5.30	.14	4.66	.271	1.50	50	1.47	10.71	1.80	1.08	4.30	2.74	2.30
	Mulch	1.33	4.92	.12	4.00	.260	1.44	45	1.32	8.30	1.40	0.90	3.06	2.06	1.73
	Barley	1.07	3.96	.10	3.33	.254	1.38	30	0.88	6.03	1.02	0.60	2.04	1.28	1.07
Terra Rossa	Original	1.00		.077		.072		8.5		30.75		1.02		3.09	
	Fallow	2.50	2.50	.16	2.07	.137	1.90	27	3.17	32.61	1.06	2.56	2.50	3.69	1.19
	Mulch	1.67	1.67	.15	1.87	.130	1.81	24	2.82	28.91	0.90	2.20	2.11	3.06	0.12
	Barley	1.58	1.58	.09	1.11	.126	1.66	15	1.76	25.71	0.80	2.05	2.00	2.85	0.87

Table 3 (Continued).

Soils	Treatments	Fe		Zn		Cu		Mn	
		%	E.R.	ppm	E.R.	ppm	E.R.	%	E.R.
Chestnut	Original	5.75		126		125		0.11	
	Fallow	6.50	1.13	188	1.48	205	1.64	0.093	0.84
	Mulch	6.10	1.04	176	1.39	200	1.60	0.093	0.84
	Barley	5.62	0.93	166	1.31	184	1.47	0.088	0.80
Rendzina	Original	1.15		90		56		0.02	
	Fallow	2.35	2.04	151	1.68	63	1.12	0.029	1.45
	Mulch	2.00	1.73	148	1.64	58	1.03	0.025	1.25
	Barley	1.52	1.30	118	1.31	53	0.94	0.019	0.95
Terra Rossa	Original	6.90		135		86		0.11	
	Fallow	6.85	0.99	192	1.42	83	0.96	0.099	0.90
	Mulch	6.45	0.93	160	1.18	80	0.93	0.093	0.84
	Barley	6.25	0.90	152	1.12	73	0.85	0.068	0.61

Table 4. Significance of the effects of soils, treatments, and slopes upon the losses of soil and nutrients at 1% (xx) and 5% (x) levels.

		Soil loss	O.M.	N	Total P	Available P	Total K	Exchangeable K	NH_4OAc extractable Mg	Fe	Zn	Cu	Mn
Soils	Chestnut					xx						xx	
	Rendzina	xx	xx	xx			xx	xx		xx	xx		xx
	Terra Rossa				xx								
Treat-ments	Fallow												
	Mulch												
	Barley	xx		xx		xx		xx	xx	x		x	x
Slopes	8%												
	16%	xx	xx	x		x		x	x			xx	

enrichment ratio to 2.41 for Rendzina and Chestnut, respectively, with those from Terra Rossa being similar to Chestnut. Organic matter losses on 16% slope were highly significant as compared with those from eight percent slope. High organic matter losses can probably be attributed to its low specific gravity, which permits ready suspension and removal, as reasoned by Slater (1942).

Nitrogen Losses

Data on N losses indicated that all soils under study (Tables 2, 3, and 4) varied with regard to their enrichment ratios. The Rendzina, though containing less original percentage of N, lost four times as much N as was contained in the soil proper under fallow treatment. Plots under barley reduced the losses to about two times, as the plants utilize the N for their growth, thereby causing a reduction in the amount available in the original soil and subsequently in the eroded soil. Similar results were obtained by Neal (1944). Results from Chestnut and Terra Rossa were alike and their enrichment ratios with all treatments are fairly close together and are statistically nonsignificant. Highly significant is the Rendzina in comparison with the other two soils. This may be due in part to the different minerological composition of the Rendzina in addition to the higher amount of Rendzina soil eroded, which brought more available N into the sludge. Fallow and straw mulch did not show significant difference. The loss of N at 16% was higher than that of the eight percent slope but the increase was significant only at five percent level.

Phosphorus Losses (Total and Available)

Tables 2, 3, and 4 summarize the total as well as the available P losses. High enrichment ratios are observed from Terra Rossa as compared with Chestnut and Rendzina for total P. In the case of fallow treatment, Terra Rossa lost 1.96 times the total P of the original while barley and mulch treatments gave no significant reduction in losses. This trend was the same with other soils with regard to treatment. These results support the findings of Rogers (1941) who found an enrichment ratio of 1.3 for total P. The differences between the Terra Rossa and Rendzina and Terra Rossa and Chestnut are highly significant whereas comparisons between Rendzina and Chestnut are nonsignificant with regard to total P losses. The losses at 16% slopes are nonsignificant as compared to eight percent slopes.

On the other hand, available P losses are higher than those of total P. The enrichment ratios varied for available P from 3.10 to 2.35 and 1.59 in case of Chestnut, Terra Rossa and Rendzina, respectively, on eight percent slopes. Chestnut and Rendzina are significantly different with regard to available P losses. Although the data reflect some difference between Chestnut and Terra Rossa, they are not significant. These results are in line with those of Massey and Jackson (1952) that eroded material from a Fayette silt loam soil contained 3.4 times as much available P as the soil proper.

There is considerable reduction in available P losses by treatments. In most of the cases, the amount has been reduced by half by growing barley. On average, barley treatments gave reductions which were highly significant as compared to fallow and straw mulch. On the other hand, fallow and straw resulted in similar results which were nonsignificant.

Potassium Losses (Total and Exchangeable)

Rendzina lost the highest amount of total K among the three soils (Tables 2, 3, and 4), the eroded material containing two times as much total K as the original soil, whereas, in the cases of Chestnut and Terra Rossa there was little enrichment. Only the difference between Rendzina and the other two soils was significant. Superficially there were differences among the three treatments; barley gave less losses, but these differences were nonsignificant. It is known that most of the total amount of this element is usually in unavailable form and plants cannot make use of it. This is reflected in these results. Stoltenberg and White (1953) indicated that few data are available on nutrient losses from agricultural areas where the analytical methods have included those chemical forms readily available to plants.

Tables 2, 3, and 4 show the losses of exchangeable K. Higher enrichment ratios have been obtained as compared to total K. Rendzina, Chestnut and Terra Rossa lost approximately five, two and two times exchangeable K, respectively, as that contained in their original soils. These varied with different treatments. There is a highly significant difference between the soils and also between the crop treatments. In the case of exchangeable K, Chestnut and Terra Rossa are significantly different from each other, as well as from Rendzina. In the light of the above results, it may be said that the soils under study, differ in their clay minerological compositions and have different K bearing minerals. Among the treatments, mulch has not given marked difference as compared to fallow in reducing the loss of exchangeable K. On the other hand, significant differences at the one percent level have been obtained by the barley crop. It is due to the uptake of exchangeable K by growing plants which caused reduction in that available for transport in the eroded material. There is significant effect of 16% slope over eight percent slope in increasing the exchangeable K losses at five percent level. It can be concluded that losses of exchangeable K are higher than total K losses which support the views expressed by Stoltenberg and White (1953). The greater loss of available K suggests that the eroded material contains a larger proportion of clay and fine particles than the soil from which it was eroded, and the association of exchangeable K with the clay fraction results in a corresponding increase. Solution of this very mobile element into the runoff water is probably also a contributing factor. These results are also in agreement with other workers that the enrichment ratio for available K is much higher than the enrichment ratio for total K (Neal, 1944; Massey et al. 1953).

NH_4OAc Extractable Magnesium

Data in Tables 2, 3, and 4 show that the three soils in the eight percent slopes have close enrichment ratios to each other and all eroded material had only the same amounts of NH_4OAc extractable Mg as their origins. The difference is nonsignificant among three soils. On the other hand, on the 16% slope, soils differed but were not significant. Treatments had significant effects. The barley crop reduced the losses causing a highly significant differences as compared to fallow, whereas, it did not show differences statistically significant to mulch treatment. Of importance, is the significant difference observed between the slopes in the cases of the Chestnut and Terra Rossa. It is probably due to the differential action of erosion; which results in the removal of very fine particles, which in turn, bring with them the exchangeable cations.

The Mg losses were greater on 16% slopes for Chestnut and Rendzina than for Terra Rossa. This is probably due to the increased removal and exchange of Mg due to presence of high calcium contents, of the first two soils. These results also agree with the conclusions of Barrows and Kilmer (1963, pp 303-315) that the loss of Mg by erosion is of comparatively minor importance.

Micro-Nutrient Losses

Fe Losses

Tables 2, 3, and 4 indicate that Fe losses are greatest from the Rendzina soil. It lost twice as much as the amount in the original soil. The values of enrichment ratios for Chestnut and Terra Rossa are fairly close to each other, and are nonsignificant, whereas, enrichment ratios for Rendzina in relation to either are highly significant. There is little difference among the treatments except again in the case of the barley crop which is significant to fallow at the five percent level.

Zn Losses

In regard to Zn (Tables 2, 3, and 4) the soils are highly significant one from the other. Rendzina lost higher amount than to other two soils. This difference was significant whereas, difference between Chestnut and Terra Rossa was nonsignificant. There was no significant difference among the treatments as well as between slopes.

Cu Losses

On average Cu losses were more in the case of Chestnut as compared to Rendzina and Terra Rossa (Tables 2, 3, and 4). Chestnut lost about 1.5 times Cu as the soil proper, indicating significant difference from the other soils. The Rendzina and Terra Rossa were not significantly different with 0.99 and 0.89 enrichment ratios, respectively. Among treatments the only significant difference is between barley and fallow. Losses of Cu are higher at 16% slope than at eight percent having significant difference at one percent level of significance.

Mn Losses

Tables 2, 3, and 4 indicate the losses of Mn. The enrichment ratios from Rendzina varied from 1.50 to 2.50 times that of their soils. Though the Chestnut and Terra Rossa are also subjected to Mn losses, the extent of losses are not as great as from Rendzina. Difference between the Rendzina, Terra Rossa and Rendzina, Chestnut are highly significant while Chestnut and Terra Rossa are nonsignificant and only barley treatment had significant difference when compared with fallow. There is no significant difference between the slopes with regard to Mn losses.

In general it is concluded that micro-nutrient losses differ with their soils; Rendzina losing more of the elements, with highly significant difference compared to the other two soils. Cropping to barley proved to result in reducing losses to a highly significant extent. Slopes have not shown consistant significant differences showing that the micro-nutrients losses are not increased in the same proportion as the slopes. High losses from Rendzina can be attributed to the absence of a highly developed clay complex to enable it to hold and adsorb the various elements. These are therefore, easily washed away by water, thus increasing the concentration in the eroded material. Also, because of the high calcium carbonate contents of the Rendzina (70%), the total amount of clay in this soil is considerably less than that of the other two soils.

Results from this study support the findings of different workers that it is a misconception to assume that erosional damage is proportional to the weight of soil removed or to the total amount of nutrients removed. The total amount of organic matter and nutrients removed from highly productive, well fertilized fields may be considerably larger than the amounts removed from poorer fields (Kohnke and Hickok, 1943), but the percentage losses may be more damaging to the poor fields. For example, from most of the results, it is seen that erosion losses are more damaging to Rendzina, a poor soil, than is Chestnut and Terra Rossa; on a quantitative basis the nutrient losses are higher from the latter two soils. The amount of nutrients lost from Rendzina are less (10 lb in the case of organic matter), but enrichment ratios for Rendzina, Chestnut, and Terra Rossa are 5.3, 2.4, and 2.5, respectively.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

An experiment was conducted at the Agricultural Research and Education Center of the American University of Beirut, Lebanon, to assess the plant nutrient losses and soil loss by water erosion on three soils (Chestnut, Rendzina, and Terra Rossa) of the Beqa'a. The soils were eroded by artificial sprinkler as well as by natural rains on micro-plots 2 X .5 meters in size at 8 and 16% slopes. The treatment employed on each of the soils were fallow, straw mulch and barley crop. Significance of the effects of soils, treatments and slopes upon the losses of soil and nutrients at one percent (xx) and five percent (x) levels are summarised in Table 4 and detailed in Appendix A.

Differences were observed among the soils with regard to soil loss with different treatments and slopes. The Rendzina lost higher amounts of soil than to other two soils (which was highly significant) fallowed by Chestnut and Terra Rossa, differences between the latter two, however, being nonsignificant. Among the treatments, barley showed highly significant differences from fallow and mulch, while the fallow and mulch showed no significant differences between one another. Losses from soils at 16% slopes were much higher than those from eight percent slopes and these increases were highly significant.

Considerable losses of organic matter and total N were observed, the highest losses being from Rendzina. Approximately 3.5

and 4 times organic matter and N were present in the eroded material as in the original soils on eight percent slopes and five times as much at 16% slopes. Significant reduction was displayed by the treatments in minimizing N losses but this was not so in the case of organic matter. Losses of organic matter were increased by higher slopes whereas, N showed no marked difference.

The losses for total P varied with the soils, Terra Rossa having lost significantly higher amounts of total P than the other two soils. However, no significant difference occurred between the Chestnut and Rendzina. Similarly, there was highly significant difference among the soils with regard to available P losses. Chestnut was subjected to higher losses than to other two soils, being highly significant different. In comparing cropping treatments, barley showed highly significant reductions in losses of available P, but not in the case of total P, over fallow and mulch treatments. This effect is attributed to uptake of available P by the growing plants.

The losses of exchangeable K were higher than total K. Rendzina lost higher amounts of both forms, the enrichment ratios for total and exchangeable K from this soil on eight percent slopes being approximately two and five, respectively. In the case of total K, barley gave no marked reduction in losses, while significant decrease was observed for exchangeable K.

There was no statistical difference between the soils with regard to NH_4OAc extractable Mg, however, losses were more in case of Rendzina and Chestnut than Terra Rossa. Only the barley crop proved to be effective in reducing losses.

Considering micro-nutrients losses, the following generalizations can be stated: Soils differed significantly although losses were small; Rendzina showed higher enrichment ratios for iron, zinc, and manganese , while the other two soils showed no significant differences between one another. Cropping to barley resulted in reducing the losses to a highly significant degree. There was no marked effect of slopes upon micro-nutrient losses.

From the above mentioned results, it can be concluded that the soils varied with regard to soil and nutrient losses in the following decreasing order. Rendzina < Chestnut < Terra Rossa. Growing of crops (barley) proved to be effective in reducing losses of soil and available forms of plant nutrients, whereas, straw mulch gave little reduction over those from bare soils. The losses at 16% slopes were significant over those from eight percent slopes for macro-nutrients in available forms, but with the exception of Cu, it did not apply for micro-nutrients.

In the light of the limited results obtained in this short study, as well as from the previous review of literature, it is highly desirable that further study be given to the erosion problem of nutrient losses over a period of years and under actual field conditions with different rotations. In the light of the different behaviour of the three soils studied, further study on nutrient losses in relation to minerological composition is recommended to clarify the highly selective processes taking place by water erosion.

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APPENDIX

Appendix A

The following pages show the analyses of variance and L.S.Ds. of enrichment ratios for soil and various plant nutrient losses, on 8 and 16% slopes in relation to treatments and soils.

Soil losses

Source of variation	d.f.	T.S.S.	M.S.S.	F. Ratio	L.S.D. 5%	L.S.D. 1%
Soils	2	492.3232	246.1616	61.36^{xx}	2.52	3.01
Treatments	2	265.3161	132.6580	33.06^{xx}		
Slopes	1	1946.4640	1946.4640	485.19^{xx}		
Error	12	48.1408	4.0117			

Nitrogen losses

Source of variation	d.f.	T.S.S.	M.S.S.	F. Ratio	L.S.D. 5%	L.S.D. 1%
Soils	2	15.575	7.787	63.47^{xx}	0.44	0.60
Treatments	2	2.1788	1.0894	8.87^{xx}		
Slopes	1	1.1001	1.1001	8.97^{x}		
Error	12	1.4730	0.1227			

xx Significant at 1% level.

x Significant at 5% level.

Organic matter losses

Source of variation	d.f.	T.S.S.	M.S.S.	F. Ratio	L.S.D. 5%	L.S.D. 1%
Soils	2	30.5001	15.2500	33.15^{xx}	0.85	1.17
Treatments	2	3.4723	1.7361	3.77		
Slopes	1	6.7914	6.7914	14.76^{xx}		
Error	12	5.5028	0.4585			

Total phosphorus losses

Source of variation	d.f.	T.S.S.	M.S.S.	F. Ratio	L.S.D. 5%	L.S.D. 1%
Soils	2	0.7519	0.3759	29.14^{xx}	0.14	0.19
Treatments	2	0.0392	0.0196	1.52		
Slopes	1	0.0168	0.0168	1.30		
Error	12	0.1546	0.0129			

xx Significant at 1% level.

Available phosphorus losses

Source of variation	d.f.	T.S.S.	M.S.S.	F. ratio	L.S.D.	
					5%	1%
Soils	2	6.7942	3.3971	41.93^{xx}	0.35	0.48
Treatments	2	3.2082	1.6041	19.80^{xx}		
Slopes	1	0.6923	0.6923	8.55^{x}		
Error	12	0.9718	0.0810			

Total potassium losses

Source of variation	d.f.	T.S.S.	M.S.S.	F. ratio	L.S.D.	
					5%	1%
Soils	2	3.3242	1.6621	16.95^{xx}	0.39	0.54
Treatments	2	0.4602	0.2301	2.35		
Slopes	1	0.4455	0.4455	4.54		
Error	12	1.1760	0.0980			

xx Significant at 1% level.

x Significant at 5% level.

Exchangeable potassium losses

Source of variation	d.f.	T.S.S.	M.S.S.	F. value	L.S.D.	
					5%	1%
Soils	2	16.400	8.20	24.11^{xx}	0.73	1.02
Treatments	2	3.430	1.71	5.03^{x}		
Slopes	1	1.810	1.81	5.32^{x}		
Error	12	4.181	0.34			

NH_4OAc extractable magnesium

Source of variation	d.f.	T.S.S.	M.S.S.	F. value	L.S.D.	
					5%	1%
Soils	2	0.3963	0.1981	3.42	0.30	0.36
Treatments	2	0.5542	0.2771	4.78^{x}		
Slopes	1	0.4387	0.4387	7.57^{x}		
Error	12	0.6943	0.0579			

xx Significant at 1% level.

x Significant at 5% level.

Total iron

Source of variation	d.f.	T.S.S.	M.S.S.	F. value	L.S.D. 5%	L.S.D. 1%
Soils	2	3.5034	1.7517	34.01^{xx}	0.28	0.39
Treatments	2	0.5673	0.2836	5.51^{x}		
Slopes	1	0.0133	0.0133	0.025		
Error	12	0.6183	0.0515			

Total zinc

Source of variation	d.f.	T.S.S.	M.S.S.	F. value	L.S.D. 5%	L.S.D. 1%
Soils	2	2.8050	1.4025	9.65^{xx}	0.48	0.66
Treatments	2	0.1962	0.0981	0.67		
Slopes	1	0.2520	0.2520	1.73		
Error	12	1.7437	0.1453			

xx Significant at 1% level.

x Significant at 5% level.

Total copper

Source of variation	d.f.	T.S.S.	M.S.S.	F. value	L.S.D.	
					5%	1%
Soils	2	0.6162	0.3031	15.62^{xx}	0.17	0.24
Treatments	2	0.2110	0.1055	5.44^{x}		
Slopes	1	0.1840	0.1840	9.48^{xx}		
Error	12	0.2338	0.0194			

Total manganese

Source of variation	d.f.	T.S.S.	M.S.S.	F. value	L.S.D.	
					5%	1%
Soils	2	2.2075	1.1037	17.66^{xx}	0.31	0.42
Treatments	2	0.6326	0.3163	5.06^{x}		
Slopes	1	0.2202	0.2202	4.32		
Error	12	0.7503	0.0685			

xx Significant at 1% level.

x Significant at 5% level.