Agricultura 3: 12-18 (2004)

Erosion effects in the central steppe chernozem soils of Ukraine. I. soil properties

Mykola KHARYTONOV[1]*, Maria BAGORKA[1] and Paul T. GIBSON[2]

[1]Dnepropetrovsk State Agrarian University, Voroshilov st.25, Dnepropetrovsk Ukraine
[2]Southern Illinois University at Carbondale, Carbondale, Illinois, USA

The chernozem soils (rich, black mollisols) of the steppe are an important soil resource, but are being degraded by erosion. Experiments were conducted to identify in detail the effects of erosion on soil physical and chemical properties in order to guide preservation and reclamation efforts. These experiments compared three levels of erosion: E0 (not eroded), E1 (mild erosion), and E2 (moderate erosion), at 10 cm depth increments from 0 – 1 m. Eroded soils had significantly higher pH and carbonate values, and significantly lower humus and clay contents. For most soil macro- and micro-nutrients, E2 was 30-50% lower than E0. Among the 10 depths tested, significant differences occurred for most variables, including pH, carbonate, humus, clay, and all macronutrients. Micronutrient differences with depth occurred for Mn, Zn, and Cu, but not for Mg, Fe, Co, Ni, Pb, or Cr. There was a strong positive relationship with depth for pH and clay and a strong inverse relationship for carbonate, humus, N, C:N ratio, mobile P, Ca and Mn. A moderate inverse relationship with depth existed for K, Zn and Fe. In general, there were very strong correlations within a group of variables including pH, carbonate, humus, N, P, Ca, Mn and Zn. K and Cu exhibited strong correlations with many of the variables in the first group. Adding NPK increased yield for barley and maize in both non-eroded and eroded soils, with additional yield given by micro-nutrients, especially Co. In addition to rational use of fertilizer, a combination of carefully chosen crop rotation and other management strategies are needed in order to use and reclaim eroded soils.

Key words: erosion, soil profile, trace elements, humus, reclamation

INTRODUCTION

Ukraine consists of three major ecological zones - forest, forest - steppe and steppe. Within the forest-steppe and steppe, there is a substantial amount of rich black soil, classified as chernozem. Of Ukraine's total land of 60.4 million ha, about 40% is plowed cropland. The steppe is most heavily cropped, and occupies most of the southern half of the country (25 million ha). Of Ukraine's 15.5 million ha of high fertility soils, the primary steppe soils, the chernozems, occupy 77% or 11.9 million ha. (Ministry of Environmental Protection and Nuclear Safety, 1997; Bagorka, 2002; Kharytonov et al., 2002a). In the USDA system, chernozems fall into the broad grouping of mollisols (http://www.fao.org/DOCREP/003/Y1899E/y1899e15.htm. Generally, chernozems are fertile and rich in humus, but can be deficient in available phosphorous (P) and zinc (Zn). Ordinary chernozems are subdivided by the depth of the humic strata into deep (85 cm or more), medium (65-85 cm), or shallow (45-65 cm). In the Ukrainian steppe, wheat is the primary crop, but barley, peas, maize, rye, sugar beet, and sunflower are also important. Alfalfa is usually included in rotations because of its beneficial effect on soil fertility and structure. Perennial legume-grass mixes for pasture/forage are often used on marginal lands, including severely eroded fields (Masyuk 1999). The steppe zone average annual precipitation averages 470 mm, but varies by year from less than 350 mm to more than 550 mm. Yields vary widely from year to year due to this marginal and erratic precipitation (Masyuk 1999). Erosion increases yield instability by reducing the capacity of the soil to store moisture.

Degradation of the steppe soils has been occurring for decades due to mining, pollution, deforestation, erosion, and other causes (Kovda, 1970; 1989). Erosion is more severe on ploughed lands than on those covered with long term vegetation. Annually, 80 thousand additional ha of agricultural lands in Ukraine are classified as eroded. In 1961, 37% of the steppe area was classified as eroded. By 1994, this was 43.5%. This increase in erosion has accelerated during the process of agricultural reform that began at Ukrainian independence in 1991. Collective farms have not had the money to invest in erosion control, even though they have the technical experience to fight erosion effectively. Private commercial farms often have little incentive for soil conservation since they rent most of the land they farm from others,

---

*Correspondence to:
Dr. Mykola Kharytonov
Dnepropetrovsk State Agrarian University, Voroshilov st.25, Dnepropetrovsk Ukraine,
Office: ++38 56 246 3161
Fax: ++38 56 744 0867
e-mail: mykola_kh@yahoo.com

without long-term commitments. Since independence, subsistence farmers have produced a large amount of the total agricultural product (60% in 1998). They often lack capital, machinery or technical awareness to effectively combat erosion, and may lack motivation if they are using a specific plot only temporarily (Kharytonov et al. 2002a).

Soil compaction affects nearly all the tilled soil and increases run-off, which increases erosion and nutrient loss (Shakuri 1987). In Ukraine, up to 500 million tons of soil are washed out from the hill sides annually, resulting in the loss of 24 million tons of humus, 1 million tons of nitrogen, 700 thousand tons of phosphorus and 10 million tons of potassium. Erosion and lack of fertilization causes a negative balance of soil nutrients of 100 kg per hectare per year. In some regions the soil is deficient in physiologically important micro-elements such as zinc, cobalt, copper, and manganese (Kabata-Pendias and Pendias 1987). Low soil concentrations of trace elements, especially iodine and selenium, can cause declines in crop yields and cattle reproduction rates, and can give rise to some of endemic human diseases (Kovalsky 1971).

Since independence, increasing areas of crop land have been inadequately fertilized. Collective farms applied 21 kg of mineral fertilizers per ha of tillage in 1998 compared to 72 for 1991-1995 and 140 kg/ha in 1990 (Ministry for Environment Protection and Nuclear Safety 1998). Declines in available P and exchangeable potassium (K) in the soil have been documented.

Agroenvironmental policies are needed to encourage farmers to combat erosion and other forms of soil degradation, and to encourage research to develop and transfer appropriate soil and crop management technologies (Kharytonov et al. 2002a). In 1996-1998, land-improvement projects were designed for collective agricultural enterprises with an area of 9.36 million hectares (one fourth of the planted area). (Ministry for Environment Protection and Nuclear Safety of Ukraine). These included major anti-erosion measures, but most of these have been delayed due to lack of financing. In Dnepropetrovsk region alone, the need for erosion control is severe, since about half of the 2.1 million ha of arable land has a slope >1°, and 6% has slopes >3° (Bagorka 2002).

Understanding the effect of depth and of erosion severity on soil physical, chemical and biological properties can guide strategies of management of eroded soils (Gedrouts 1955; Masyuk et al. 1993; Kharytonov et al. 2002c). Experience in phytomelioration in mine land reclamation also has useful application in reclaiming eroded lands (Masyuk 1987). The objective of this study was to determine the relationship of depth within the soil profile and of erosion severity to numerous soil properties.

MATERIAL AND METHODS

Field experiments were conducted at the ecological field station of the Samarsky farm of Dnepropetrovsk State Agrarian University (DSAU), Dnepropetrovsk district, Dnepropetrovsk region, Ukraine. Soil for controlled experiments and laboratory analysis was obtained from the same location. This farm is located at 35° 15'N lat. and 48° 30' E long. This field station has had many years of use for intensive agricultural production and research (Kovda 1989) and is far enough from Dnipropetrovsk city (25-30km) to avoid problems from industrial pollution (Kharytonov et al. 2002b).

The experiments reported here compare soils from three types of landscapes: level soils (0-1% slope) with no observable erosion (E0), mildly sloped soils (1-3%) with mild erosion (E1, =10 cm topsoil loss), and moderately sloped soils (5-7%) with moderate erosion (E2, up to 30 cm topsoil loss). Coincidentally, in the study area, the mildly sloped soils have a northern exposure and the moderately sloped soils have a southern exposure. The soil type in the experimental area is characterized as central steppe chernozem in the FSU (former Soviet Union) system. The general texture is a clay loam to a heavy clay loam, with 30-55% clay (<0.01mm) and 11 – 37% silt. The level soils (E0) were more uniform in clay content (52-54%) than the E2 soils (45-55%), and both had more clay than the E1 soils (30-37%). By USDA texture classification, all of these are silty-clay loams. In keeping with the lower productivity status of the eroded soils, fertilizer was not applied, but the two years of alfalfa just before wheat promoted reasonable growth.

Characterization of Soil Properties. Numerous soil characteristics were determined for each erosion severity and each 10 cm depth increment from bulk samples. Generally, duplicate determinations were made and averaged. The depth increments were assigned to general soil horizons, according to the Russian soil taxonomy system proposed by Dokuchaev (1892). These are defined as follows (with correspondence to the Ukrainian soil taxonomy system of Sokolovsky (1956) noted in parentheses):

A (H) - upper horizon with very prominent humus accumulation
B1 (Hp) - upper transition horizon, with considerable humus
B_2 (Ph) - lower transition horizon, with little humus
C (P) – underlying parent material

The A, B_1, B_2 and C horizons encompassed depths of 0-40, 40-60, 60-80 and 80-100 cm for E0; depths of 0-30, 30-50, 50-70, and 70-100 cm for E1, and depths of 0-30, 30-50, and 50-100 cm for E2 (with the A horizon absent entirely due to erosion).

Determination of specific soil characteristics. A pH meter was used to determine pH after placing 20g of soil in 50 ml of water (pH (H_2O) or 50 ml of 1N KCl aqueous solution (pH (KCl) and mixing thoroughly. Humus concentration was determined by placing 0.1 g of soil in 10 ml of 0.4 N K_2Cr_2O aqueous solution, followed by titration with salt of Moore ($FeSO_4(NH_4)_2SO_4$) (Dokuchaev Soil Institute 1965). Humic acid and fulvic acid were determined by extraction followed by titration (Dokuchaev Soil Institute 1965). Carbonate was determined from the loss of mass that occurred as a result of HCl treatment. A sample of a 1g of finely ground soil was mixed with 40 ml of hot 0.1 N HCl weighed after drying. The loss of mass was expressed as a percentage of the initial 1 g used.

Particle size determinations were made as follows. First, 1 g of soil was treated with room temperature HCl, which dissolves most carbonates, although a small amount is left bound to cell particles. Upon drying, the dissolved carbonates escape as CO_2, and the loss of weight is recorded. The remaining soil is mixed thoroughly with 1 liter of water and allowed to sediment. At designated time intervals, aliquots were removed and per cent of specific particle sizes estimated based on sedimentation of progressively smaller particles. Fractions determined were (diameter in mm in parentheses): medium to coarse sand (0.25-1), very fine to fine sand (0.05 - 0.25), coarse silt (0.01 - 0.05), fine silt (0.005 - 0.01), silt/clay (0.001 - 0.005) and clay (<0.001). Values for fractions were summed to correspond with USDA definitions of sand (>0.05), silt (0.002 - 0.05) and clay (<0.002). Since the silt/clay fraction as measured (0.001 - 0.005) spanned the USDA definition, half of the silt/clay fraction was considered silt and half considered clay, since clay particles smaller than 0.001 were more prevalent than particles of fine silt. Allocating one-half of the silt/clay fraction to each had little influence on the overall proportion of clay vs. silt, since the fraction in question averaged 6% of the total soil weight, and was in no case greater than 10%. Physical clay (clay (FSU)) is a standard definition in the Former Soviet Union, and is the summation of particle sizes less than 0.01 mm diameter (clay and fine silt by USDA classification), plus the per cent lost by HCl pre-treatment, which presumably was fine-particle carbonates. Clay (FSU) is reported here in addition to the USDA categories in order to facilitate comparison of our results with other FSU results.

Percent of organic N (N%) and mineral N was determined by Kehldahl analysis of the bulk sample, including the organic matter (Dokuchaev Soil Inst. 1965). Nitrification energy was determined by the following procedure. A portion of a bulk sample for each erosion severity and depth was allocated to each of two 50 ml Erlenmeyer flasks. NO_3 concentration was determined for each flask immediately after collection of the soil, and again after 7 days incubation at 28 °C with daily addition of just enough water to keep the soil moist but not saturated. NO_3 concentration was determined using a ЭB-74 ion meter (Ion-meter factory, Gomel, Belorussia) and a nitrate selective ion electrode for NO_3 (Ion Meter Factory, Tbilisi, Georgia). Using 4 equally-spaced concentrations of KNO_3 from 10^{-2} to 10^{-5} M (approximately equivalent to 0.78 to 780 mg NO_3/kg of solution), a standard curve was prepared. For greater accuracy, this curve was divided into two segments (10^{-2} to 10^{-4} M and 10^{-4} to 10^{-5} M). The C:N ratio was calculated from determinations of N% (as above) and C%. C% was determined by as humus/1.72 (Dokuchaev Soil Institute 1965)

Urease and phosphatase were determined by the procedure of Galstyan (1974). Urease was determined for 10 cm depth intervals, phosphatase was determined for 3 pooled depths (0-20, 20-40, and 40-60). Phosphatase was recorded as mg phenolphtaleine produced in 3 hrs/100 g soil).

Mobile P was determined by the colorimetric method of Denizhe (Dokuchaev Soil Institute 1965), following each of two extraction methods: Machigin (Dokuchayev Soil Institute 1965, p. 124) and Chirikov (Dokuchayev Soil Institute 1965, p. 100). The method of Machigin is basically an extraction by a 1% solution of ammonia, while that of Chirikov involves extraction by 0.5 N acetic acid. Exchangeable K was evaluated by flame emission spectrophotometry after extraction by 1 % $(NH_4)_2$ carbonate. Ca and Mg were determined by titration with EDTA.

For determination of trace elements, 5 g of soil was extracted by shaking with with 50 ml of 1 N HCl and letting stand for one day. Concentrations were determined by comparison with prepared standards provided by the Laboratory of Standard Solutions, Physical-Chemical Institute, Odessa, using a Saturn 3 Atomic Absorption Spectrophotometer (North Donetz Engineering Design Bureau, Ukraine) using standard methods of flame spectrophotometry (Central Institute of Agrochemical Service 1989).

The barley and maize experiments involved two erosion levels (E0 and E2) and compared no fertilizer, a complete fertilizer (NPK of 60 kg/ha each in the form of nitrophoska 17-17-17 and a complete fertilizer plus micronutrients (Cu, Co, Zn each at 4 kg/ha). In addition, in 1994, E0 included additional treatments of Cu, Co and Zn, separately 4 kg/ha. The complete fertilizer was polymer based, with the expectation that fertilizer movement away from the target area would be minimized both within and across years. Polymer based fertilizers with trace elements were received for testing regarding agreement for cooperation with Institute of chemistry of the Nizhegorodsky State University (Russia 1985).

Statistical methods. Statistical significance and LSD's for erosion severity and for depth were calculated using analysis of variance. In addition, the linear regression with depth was determined, including r^2 based on the variance among depth means and r^2 based on the variance among erosion * depth values. In addition, correlations among all soil characteristics were determined. Statistical analysis of each experiment was performed on Excel (Microsoft, 2000), using the analysis package add-in. Where Excel did not provide a specific analysis sufficient for the complete analysis, combinations of analyses were carried out in the appropriate sequence to obtain all necessary sums of squares or sums of cross products (for example, two-factor analysis without replication followed by additional two-factor analyses with replication). From each erosion severity and profile depth, two samples of soil were analyzed. Erosion severity and depth were considered fixed-factor effects for purposes of constructing appropriate F-tests.

In the barley and maize fertilization experiments, years and replications were considered random-effects factors while erosion severity and fertilizer treatments were considered fixed-effect factors. F-test denominators were chosen accordingly.

RESULTS

The lowest pH (7.1) was observed in the top of the E0 profile, while the highest (8.9) was in the 90-100 cm strata of both E1 and E2. Eroded soils had a significantly higher average pH than non-eroded soils (Table 1). Carbonate concentration ranged from 0.2% (E0, 0-10 cm) to over 15% (E2, >50 cm depth; E0, 90-100 cm), and was significantly higher in eroded soils. Humus varied from 4.2% (E0, 0-10cm) to 0.1% (E2, 90-100 cm), and the average across depths was significantly lower in eroded soils. At the same depth, humic acid was significantly higher in E0 than in E1 or E2, as was the ratio of humic/fulvic acid (Table 2). The C:N ratio varied from 10.6 (E0, 10-20 cm) to 0.8 (E2, 90-100 cm), and averaged significantly higher in E0 than in E2. Clay content was

Table 1. Means of soil properties+ for different erosion severities and different depths

					%				mg/kg	mg NO_3/kg		
Erosion severity	pH(H_20)	Carbonate	Humus	Sand	Silt	Clay(USDA)	Clay(FSU)	N	MinN	Nitr.Ener.	Urease	C:N ratio
E0 (none)	7.90	7.7	2.38	7.2	51.4	41.4	56.4	0.17	20.7	13.7	126	7.67
E1 (mild)	8.51	10.0	1.73	11.5	66.8	21.8	34.7	0.13	16.1	9.5	135	6.78
E2 (moderate)	8.66	13.8	1.03	5.6	66.1	28.4	47.9	0.11	10.3	6.2	96	4.72
Mean	8.36	10.5	1.71	8.1	61.4	30.5	46.3	0.14	15.7	9.8	119	6.39
LSD (Erosion)	0.29	2.7	0.33	4.3	5.8	3.3	2.3	0.02	3.6	2.7	33	1.14
Significance of Erosion Severity	***	***	***	*	***	***	***	***	***	***	ns	***
Depth (cm)												
0-10	7.93	3.0	3.17	8.7	58.7	32.7	45.8	0.20	38.0	26.7	194	8.97
10-20	7.97	4.1	2.95	8.1	60.8	31.1	44.7	0.20	29.2	20.5	190	8.70
20-30	8.00	5.8	2.83	4.8	62.0	33.2	45.5	0.18	20.9	14.0	160	9.07
30-40	8.07	9.7	2.50	6.4	63.3	30.3	44.7	0.16	18.3	11.4	136	9.10
40-50	8.40	11.0	1.60	10.0	58.9	31.0	43.8	0.14	13.8	8.2	138	6.60
50-60	8.50	11.6	1.27	8.3	63.2	28.5	46.1	0.12	10.5	6.1	132	6.13
60-70	8.57	13.1	1.10	7.5	66.5	26.0	43.3	0.11	9.3	4.7	106	5.50
70-80	8.67	14.9	0.77	9.0	62.0	29.0	48.5	0.10	6.5	2.9	66	4.37
80-90	8.67	15.8	0.53	10.4	57.4	32.2	49.9	0.09	5.4	1.9	42	2.83
90-100	8.80	15.7	0.40	7.5	61.3	31.2	50.9	0.09	5.3	1.9	24	2.63
LSD (Depth)	0.52	4.9	0.60	7.8	10.6	6.1	4.2	0.03	6.5	5.0	61	2.07
Significance of Depth	*	***	***	ns	ns	ns	*	***	***	***	***	***

	mg/kg soil			meq/100 g soil					mg/kg soil				
Erosion severity	Mob.P(M)	Mob.P(C)	ExchK	Ca	Mg	Fe	Mn	Zn	Cu	Co	Ni	Pb	Cr
E0 (none)	14.6	64.8	222	23.6	5.6	533	154	8.9	4.4	5.2	8.4	11.9	3.0
E1 (mild)	10.8	54.7	127	18.0	3.6	495	128	5.9	2.8	4.0	5.9	10.1	2.3
E2 (moderate)	10.1	33.4	111	16.5	4.0	500	99	4.2	2.3	4.1	5.6	9.8	2.1
Mean	11.9	51.0	154	19.4	4.4	509	127	6.3	3.1	4.4	6.6	10.6	2.5
LSD (Erosion)	3.2	11.8	30	1.0	1.0	133	24	1.5	0.4	0.4	0.7	1.0	0.3
Significance of Erosion Severity	*	***	***	***	**	ns	***	***	***	***	***	**	***
Depth (cm)													
0-10	20.0	94.3	232	22.7	4.1	665	217	9.7	4.2	4.0	7.4	11.2	2.3
10-20	18.6	82.7	230	23.7	3.3	727	190	9.6	4.4	4.4	7.1	10.8	2.8
20-30	15.1	63.0	169	24.0	3.1	603	170	8.6	4.2	4.2	6.7	10.7	2.6
30-40	11.9	56.3	142	21.0	3.9	432	117	6.3	3.1	4.6	6.8	11.8	2.7
40-50	11.5	52.0	134	19.5	5.2	430	103	5.2	2.9	4.2	6.5	10.4	2.4
50-60	8.9	38.0	134	18.9	4.8	460	107	5.2	2.8	4.7	7.2	10.4	2.3
60-70	8.2	38.3	131	17.4	4.5	428	100	5.4	3.0	4.5	6.6	9.8	2.3
70-80	8.2	28.0	127	16.9	4.7	422	94	5.2	2.5	4.4	6.5	10.4	2.6
80-90	8.3	29.3	119	15.4	4.3	470	85	4.4	2.2	4.9	6.0	10.4	2.4
90-100	7.8	27.7	118	14.3	6.0	455	85	3.8	2.1	4.5	5.8	10.4	2.5
LSD (Depth)	5.8	21.5	54	1.8	1.9	243	44	2.8	0.7	0.7	1.2	1.9	0.6
Significance of Depth	**	***	**	***	ns	ns	***	**	***	ns	ns	ns	ns

*,**,***, ns indicate significance at P<0.05,<0.01,<0.001, and non-significant, respectively;+ MinN=Mineral N in kg/ha, Nitr.Ener.=nitrification energy as mg NO_3 per kg soil denitrified in 7 days, Urease = mg NH_4/kg soil / 24 hrs, Mob.P(M) and Mob.P(C) are mobile P, kg/ha, by method of Machigin and Chirikov, respectively; Exch.K=exchangeable K.

Table 2. Means of phosphatase activity (mg phenolphthaline / 3 h / 100 g soil) and humic properties for different erosion severities and different depths.

	Phosphatase Acitivity		%C(Carbon)	%C (humic acid)	%C (fulvic acid)	%C (nonhydrolyzed)	Acid Ratio (humic/ fulvic) C_h/C_f
Erosion Severity							
E0	9.5		1.74	0.51	0.25	0.98	1.90
E1	6.8		1.30	0.41	0.24	0.64	1.56
E2	4.0		0.76	0.24	0.23	0.29	1.03
Mean	6.8		1.27	0.39	0.24	0.64	1.50
LSD05	3.22		0.63	0.20	0.03	0.47	0.35
Depth (cm)		Depth (cm)					
0-20	10.00	0-10	1.86	0.60	0.35	0.91	1.72
20-40	7.40	10-20	1.73	0.52	0.36	0.85	1.46
40-60	4.57	90-100	0.21	0.04	0.03	0.15	1.31
LSD05	3.22		0.63	0.20	0.03	0.47	0.35
Depth r^2	0.92		0.999	0.9995	0.985	0.999	0.707
Signicance of Depth(Lin)	*		**	**	***	**	ns

*, **, and *** indicate significance at P < 0.05, 0.01, and 0.001, respectively.

substantially higher in E0 than in E1 or E2.

Almost all soil nutrients were highest in E0, intermediate in E1 and lowest in E2. For most soil nutrients, E2 was 30-50% lower than E0. In several cases, E1 and E2 were not significantly different. This lack of difference was especially noted in mobile P (Machigin), exchangeable K, Mg, Co, Ni, Pb and Cr. There were no significant differences among erosion levels for urease or Fe. Significant erosion effects for most micronutrients in similar soils were reported earlier (Masyuk et. al. 1993).

Among the 10 depths tested, significant differences occurred for most variables, including pH, carbonate, humus, clay (FSU), urease and all macronutrients (Table 1). Phosphatase and the ratio of humic to fulvic acid also decreased strongly with depth (Table 2). Micronutrient differences with depth occurred for Mn, Zn, and Cu, but not for Mg, Fe, Co, Ni, Pb, or Cr. There was no significant depth effect for USDA particle size distribution.

There was a strong positive linear relationship with depth for pH and clay (FSU) and strong inverse relationship for carbonate, humus, N%, mineral N, nitrification energy, urease, C:N ratio, mobile P, Ca and Mn (Table 3, note that values presented are r^2, not r, and that for convenience, r^2 values were labeled as negative if the r value was negative). A moderate inverse relationship with depth existed for exchangeable K, Zn and Fe, even though the general F-test for depths was not significant for Fe. A weak, but still significant linear relationship existed between depth and clay (FSU), Mg, Co, Ni, and Pb--all inverse except Mg. No clear trend with depth was present for clay (USDA), silt or sand.

With 30 observations per variable, correlations were significant (P=0.05) with an r2 value as small as 0.126, and highly significant (P=0.001) at 0.3159, although in a practical sense, this is still a weak correlation. For convenience, r2 values 0.3159-0.5 were labeled as a moderate correlation, 0.5-0.7 as a strong correlation, and >0.7 as a very strong correlation. In general, there were very strong correlations within the group of variables including pH, carbonate, humus, N%, mineral N, mobile P, Ca, Mn and Zn (Table 3). Exchangeable K and Cu exhibited strong correlations with many of the variables in the first group. Frequently, moderate or weak, but still significant correlations, were exhibited by silt, clay, urease, C:N ratio, Fe, Ni, Pb and Cr among themselves and with the above variables. Sand exhibited no significant correlations and Mg almost none. Therefore, these were not included in Table 2.

Fertilization of barley and maize (Tables 4 and 5) showed that adding NPK (at 60 kg/ha each) gave higher yield than the control in both non-eroded and eroded soils in both crops in both years, and that the addition of Zn, Cu and Co gave additional yield that was statistically significant in all but maize on the non-eroded soil in 1993. In the one case where individual micro-nutrients were tested, addition of Co gave yield equal to that with Zn, Cu, and Co all included. The addition of Zn or Cu alone gave no yield benefit.

DISCUSSION

The pH was only weakly related to depth, but was strongly related to carbonate and humus. The multiple regression of pH with humus, carbonate and clay gave an r^2 of 0.81, only slightly more than the individual correlations

Table 3. Statistical properties and matrix of r2 values of selected soil properties

					%			mg/kg								mg/kg					
Statistical property		pH (H_20)	Carbon- ate	% Humus	Clay (USDA)	Clay (FSU)	N	Mineral N	Urease	C:N ratio	Mob. P(C)	ExchK	Ca	Fe	Mn	Zn	Cu	Co	Ni	Pb	Cr
Mean		8.4	10.5	1.7	30.5	46.3	0.1	15.7	119	6.4	51	154	19.4	509	127	6.3	3.1	4.4	6.6	10.6	2.5
SD (all 30 values)		0.5	5.7	1.2	· 9.0	9.6	0.1	11.8	65	2.9	28	70	4.6	157	55	3.1	1.2	0.7	1.5	1.4	0.5
SD/Mean*100		6	54	70	29	21	37	75	55	46	55	45	24	31	43	49	40	16	22	13	21
Sign Eros		***	***	***	***	***	***	***	ns	***	***	***	***	ns	***	***	***	***	***	**	***
Sign Depth		*	***	***	ns	*	***	***	***	***	***	**	***	ns	***	**	***	ns	ns	ns	ns
r^2	Depth																				
Depth		***0.36***	**0.61**	**-0.70**	-0.01	0.03	**-0.70**	**-0.71**	**-0.72**	**-0.65**	**-0.59**	*-0.27*	***-0.48***	*-0.27*	**-0.57**	***-0.38***	***-0.36***	0.05	-0.07	-0.05	0.00
pH (H_20)	***0.36***	**1.00**	**0.65**	**-0.75**	*-0.29*	-0.06	**-0.75**	**-0.63**	*-0.21*	***-0.47***	**-0.75**	**-0.75**	**-0.70**	***-0.40***	**-0.66**	**-0.75**	**-0.67**	-0.10	***-0.40***	*-0.16*	*-0.30*
Carbonate	**0.61**	**0.65**	**1.00**	**-0.84**	-0.11	0.00	**-0.89**	**-0.83**	**-0.59**	**-0.58**	**-0.86**	**-0.53**	**-0.74**	**-0.53**	**-0.88**	**-0.82**	**-0.73**	0.00	***-0.33***	-0.11	*-0.16*
Humus	**-0.70**	**-0.75**	**-0.84**	**1.00**	0.11	0.00	**0.91**	**0.82**	**0.52**	**0.84**	**0.84**	**0.65**	**0.80**	***0.38***	**0.81**	**0.77**	**0.72**	0.00	***0.32***	*0.21*	*0.17*
Clay(USDA)	-0.01	*-0.29*	-0.11	0.11	**1.00**	**0.75**	*0.18*	0.09	0.01	0.05	0.09	***0.37***	***0.39***	0.03	0.10	*0.27*	***0.40***	**0.54**	**0.55**	***0.40***	***0.33***
Clay(FSU)	0.03	-0.06	0.00	0.00	**0.75**	**1.00**	0.01	0.00	-0.06	-0.01	0.00	*0.16*	0.09	0.00	0.00	0.04	0.10	**0.52**	*0.28*	*0.24*	*0.20*
N%	**-0.70**	**-0.75**	**-0.89**	**0.91**	*0.18*	0.01	**1.00**	**0.85**	**0.60**	**0.65**	**0.87**	**0.61**	**0.81**	***0.40***	**0.82**	**0.81**	**0.77**	0.02	***0.35***	*0.18*	*0.16*
Min N	**-0.71**	**-0.63**	**-0.83**	**0.82**	0.09	0.00	**0.85**	**1.00**	**0.59**	**0.58**	**0.89**	**0.57**	**0.60**	***0.43***	**0.83**	**0.65**	**0.56**	0.00	*0.27*	0.11	0.10
Urease	**-0.72**	*-0.21*	**-0.59**	**0.52**	0.01	-0.06	**0.60**	**0.59**	**1.00**	**0.57**	***0.44***	*0.14*	***0.49***	0.11	***0.41***	***0.32***	***0.38***	-0.02	*0.17*	0.08	0.03
C:N	**-0.65**	***-0.47***	**-0.58**	**0.84**	0.05	-0.01	**0.65**	**0.58**	**0.57**	**1.00**	**0.54**	***0.41***	**0.70**	0.12	**0.51**	***0.49***	**0.55**	0.00	*0.29*	*0.28*	*0.16*
Mob. P(C	**-0.59**	**-0.75**	**-0.86**	**0.84**	0.09	0.00	**0.87**	**0.89**	***0.44***	**0.54**	**1.00**	**0.66**	**0.62**	**0.52**	**0.87**	**0.77**	**0.63**	0.00	*0.25*	0.09	0.12
ExchK	*-0.27*	**-0.75**	**-0.53**	**0.65**	***0.37***	*0.16*	**0.61**	**0.57**	*0.14*	***0.41***	**0.66**	**1.00**	**0.65**	***0.36***	**0.67**	**0.75**	**0.71**	*0.16*	**0.51**	*0.27*	*0.27*
Ca	***-0.48***	**-0.70**	**-0.74**	**0.80**	***0.39***	0.09	**0.81**	**0.60**	***0.49***	**0.70**	**0.62**	**0.65**	**1.00**	*0.22*	**0.64**	**0.79**	**0.91**	*0.15*	**0.63**	***0.39***	***0.37***
Fe	*-0.27*	***-0.40***	**-0.53**	***0.38***	0.03	0.00	***0.40***	***0.43***	0.11	0.12	**0.52**	***0.36***	*0.22*	**1.00**	**0.59**	***0.47***	*0.28*	-0.01	0.05	0.00	0.02
Mn	**-0.57**	**-0.66**	**-0.88**	**0.81**	0.10	0.00	**0.82**	**0.83**	***0.41***	**0.51**	**0.87**	**0.67**	**0.64**	**0.59**	**1.00**	**0.86**	**0.66**	0.00	*0.23*	0.09	0.09
Zn	***-0.38***	**-0.75**	**-0.82**	**0.77**	*0.27*	0.04	**0.81**	**0.65**	***0.32***	***0.49***	**0.77**	**0.75**	**0.79**	***0.47***	**0.86**	**1.00**	**0.85**	0.07	***0.43***	*0.21*	*0.22*
Cu	***-0.36***	**-0.67**	**-0.73**	**0.72**	***0.40***	0.10	**0.77**	**0.56**	***0.38***	**0.55**	**0.63**	**0.71**	**0.91**	*0.28*	**0.66**	**0.85**	**1.00**	*0.21*	**0.65**	***0.39***	***0.35***
Co	0.05	-0.10	0.00	0.00	**0.54**	**0.52**	0.02	0.00	-0.02	0.00	0.00	*0.16*	*0.15*	-0.01	0.00	0.07	*0.21*	**1.00**	***0.46***	***0.38***	***0.34***
Ni	-0.07	***-0.40***	***-0.33***	***0.32***	**0.55**	*0.28*	***0.35***	*0.27*	*0.17*	*0.29*	*0.25*	**0.51**	**0.63**	0.05	*0.23*	***0.43***	**0.65**	***0.46***	**1.00**	**0.51**	**0.56**
Pb	-0.05	*-0.16*	-0.11	*0.21*	***0.40***	*0.24*	*0.18*	0.11	0.08	*0.28*	0.09	*0.27*	***0.39***	0.00	0.09	*0.21*	***0.39***	***0.38***	**0.51**	**1.00**	***0.35***
Cr	0.00	*-0.30*	*-0.16*	*0.17*	***0.33***	*0.20*	*0.16*	0.10	0.03	*0.16*	0.12	*0.27*	***0.37***	0.02	0.09	*0.22*	***0.35***	***0.34***	**0.56**	***0.35***	**1.00**

For convenience, R^2 values are designated as negative if the correlation is negative. For descriptions of variable abbreviations and units, see Table 1. *,**,***, ns indicate statistical significance at P<0.05,0.01,0.001, and non-significant respectively. Correlation with depth is the correlation of properties with the 10 cm depth increments. **Bold,** ***bold italics,*** and *italics* indicate r^2 absolute values > 0.5, >0.32 (P<0.001), and > 0.13 (P<0.05), respectively.

Table 4. The influence of polymer-based fertilizers on barley yield on eroded soil (t/ha)

	1993			1994			93-94 Avg		
Fertilizer	E0	E2	Avg	E0	E2	Avg	E0	E2	Avg
Control	2.06	1.07	1.57	3.44	3.04	3.24	2.75	2.06	2.40
NPK	2.57	1.37	1.97	5.15	4.10	4.63	3.86	2.73	3.30
NPK+Zn+Cu+Co	2.82	1.52	2.17	5.56	5.15	5.35	4.19	3.34	3.76
Average	2.49	1.32	1.90	4.71	4.10	4.41	3.60	2.71	3.15

LSD	
Erosion means (same fert., same year)	0.20
Erosion means across fert. (same year)	0.12
Erosion means across fert. & year	2.03
Fert means (same erosion, same year)	0.20
Fert means across erosion, same year	0.12
Fert means across year (same erosion)	0.14
Fert means across erosion & year	1.09

NPK indicates a complete fertilizer at 60 kg/ha for each nutrient. Zn, Cu and Co were added at 4 kg/ha each.

Table 5. The influence of polymer-based fertilizers on maize yield on eroded soil (t/ha)

	1993			1994			93-94 average		
Fertilizer	E0	E2	Avg	E0	E2	Avg	E0	E2	Avg
Control	6.30	5.96	6.13	2.56	1.60	2.08	4.43	3.78	4.11
NPK	6.52	6.37	6.45	3.20	2.24	2.72	4.86	4.31	4.58
NPK+Zn+Cu+Co	6.68	6.72	6.70	3.61	2.68	3.15	5.15	4.70	4.92
NPK + Zn				3.20					
NPK + Cu				3.20					
NPK + Co				3.61					
Average (not including individual applications of Zn,Cu,Co)	6.50	6.35	6.43	3.12	2.17	2.65	4.81	4.26	4.54

LSD05	
Erosion means (same fert., same year)	0.19
Erosion means across fert. (same year)	0.11
Erosion means across fert. & year	5.06
Fert. means (same erosion,same year)	0.19
Fert. means across erosion. same year	0.11
Fert. means across year (same erosion)	0.13
Fert. means across erosion & year	0.74

NPK indicates a complete fertilizer at 60 kg/ha for each nutrient. Zn, Cu, and Co were added at 4kg/ha, either in combination or separately.

with humus and carbonate, indicating little relationship with clay alone.

N% was strongly correlated with humus, and strongly negatively correlated with carbonate. The N%-carbonate correlation was probably a reflection of the negative correlation of carbonate with humus, and may be primarily a reflection of the correlation of both carbonate and humus with depth. The ratio of humic to fulvic acid was distinctly higher in the upper soil, and in non-eroded soils, indicating that the conversion to mature humus is more rapid in these soils, releasing nutrients more quickly for plant growth. N% was not as closely related to urease activity and nitrification energy as was expected. Perhaps this was due to urease being more closely related to ammonium forms of N than to nitrate/nitrite forms. The C:N ratio was considerably higher in E0 than E2, reflecting the greater difference in humus than in N% between erosion levels. Also, the C:N ratio dropped strongly between depths of 40 and 50 cm, probably due to ploughing effects.

Calculated from N%, the N reserve in the top meter of soil was 21 t/ha or more for the non-eroded soil, but 20 and 33% less for E0 and E1, respectively.

Mobile P was very strongly correlated with N%, but this may be because both mobile P and N% were very strongly with humus and strongly negatively correlated with carbonate concentration. In the case of mobile P, these correlations may result from much of the mobile P being derived from the humus fraction, and from higher carbonate and pH strongly reducing P availability. Due to differences in depths of data collection, it was not possible to correlate phosphatase activity with mobile P concentrations, but both decreased with depth in a roughly proportional manner. This is not surprising, since phosphatase acts on both humus and mineral P, and both decreased strongly with depth.

Exchangeable K was very strongly related to pH (negatively), to carbonate (negatively), to humus and to N%. It seems logical to assume that pH and humus had the most direct effect, and that the correlations to carbonate and N% were indirect. There is no obvious explanation why the expected correlation of exchangeable K with clay content did not occur.

Calcium was very strongly related to pH and carbonate (both negatively) and to humus and N%. Much of the calcium would be bound by carbonate, especially at high pH. It is probable that the humus and N% correlations are indirect. Although the buffering capacity of the soil was expected to be correlated with clay content, Ca was only moderately correlated with clay (USDA) and not at all with clay (FSU). The content of Mg was small, and not correlated with either measure of clay.

Mn, Zn and Cu were all strongly correlated with each other, and with pH, carbonate, N%, mobile P, exchangeable K, and Ca. Since Mn concentration is closely related to pH in these types of soils, these various correlations may be primarily a reflection of pH. Concentrations of Fe, Mn, Zn and Cu were significantly higher toward the soil surface, with a distinct discontinuity around 30 - 40 cm depth. It is assumed that this pattern represents absorption of these elements by the deeper roots and transference to the shoots and more plentiful shallower roots. There may also be influences from differing redox-potentials and soil organisms in the ploughed upper horizon.

Ni, Pb, and Cr were moderately correlated with each other, and with clay. As a group, these three tended to have similar correlation patterns with other soil characteristics. They were not correlated with depth, suggesting that the levels observed are inherent in the soil through the parent material. If they were from anthropogenic contamination, one would expect their levels to be greater at shallower depths, but they were not. Pb is often strongly correlated with humus in contaminated soils, but in this non-contaminated soil, the correlation was weak.

Erosion processes lead to reduction of trace elements concentration in soil as well. The investigations of effectiveness of new polymer-based fertilizers were conducted in the conditions of field experiments. Effectiveness of its fertilizers is connected with trace elements soil ions exchange. It guarantees of long-term functioning these fertilizers in soil for 4-5 years. The sources of trace elements are water-soluble wastes of some productions. The obtained results indicative of high effectiveness of polymer-based fertilizers for the washed black soil (Table 7, 8). Results of field experiments in the slopes with middle-expressed erosion black soils have showed that increasing of barley yield after polymer-based fertilizers application was 0.4-0.5 t/ha on the plain and up to the 1.0 ton/ha on the slope.

Obviously, erosion is detrimental in many ways, including the loss of the upper layer of soil where there are the highest levels of almost all plant nutrients. These higher concentrations, even in the absence of fertilization, reflect nutrient "pumping" from the lower levels of the soil by the deeper plant roots. These nutrients accumulate in the shallower plant roots and in the shoot. After the plants die, these nutrients are deposited in the upper soil by detritus. Their return to deeper levels in the soil is impeded by geochemical barriers, including gradients in humus, pH, carbonate, moisture, and re-dox potential (Kabata-Pendias and Pendias 1987). While these barriers are generally beneficial, they can also contribute to accumulation of detrimental levels of some elements, especially where hillside soil accumulates in the bottoms of ravines. Generally, though, as erosion carries away important nutrients, it also diminishes the beneficial effects of geochemical barriers, potentially increasing leaching losses.

CONCLUSION

Erosion in the chernozem soils of the central Ukainian steppe was detrimental throughout the 1 m horizon that was studied. While fertilization partially offset the yield losses due to erosion, additional management techniques are needed to restore the soil to full productivity. The strongly diminished humus, N, and other nutrients throughout the profile in eroded soils indicate the need for amelioration with deep-rooted, nitrogen-fixing crops. Perennial deep-rooted legumes, such as Lucerne (*Medicago sativa* L.) and sainfoin (*Onobrychis* sp.) may be especially beneficial because they have these needed characteristics and is able to tolerate the high pH of the lower horizons of the eroded soils. Other elements of rotation and management strategies, including optimal fertilization and encouragement of beneficial rhizosphere organisms, need to be developed to provide income and soil improvement at the same time (Patyka et al. 1993). Polymer-based fertilizers were shown to be effective, and theoretically should be more resistant to leaching, thus having special benefit on erodeable soils. Landscape areas with differing levels of potential and actual erosion need different management strategies (Masyuk 1987; 1999).

Acknowledgments

Credit is due to people who contributed substantially to the work reported here, including Nikolai Masyuk, Valentina Pashova, Nikolay Lukashenko, Natalia Torkhova and Evgeniy Krylov.

REFERENCES

1. Bagorka, MA. Agroecological peculiarities of fertility of eroded soils in the subzone of ordinary chernozems. Dnipropetrovsk State Agricultural Univ., Abstract of dissertation for Kandidat of Agricultural Science 2002:20p.
2. Central Institute of Agrochemical Service. Recommended methods for determination of heavy metals in soils and crops. Min. of Agric., Moscow 1989: 62p.
3. Dokuchaev Soil Institute. Agrochemical methods of soil investigation. Ed. by USSR Academy of Science. Science Publishers, Moscow 4th Ed. 1965:436p.
4. Galstyan, ASh. Armenian soil enzyme activity. Istan Publ, Erevan, Armenia. 1974:259p.
5 Gedroyuts KK. Comparative fertility of different soil horizons. Selected Issues Vol. 3, USSR Acad. of Sci. 1955:50-65.
6. Institute of Chemistry, Nizhegorodskiy, State Univ. Synthesis and investigation of polymer-based fertilizers with trace elements. Nizhniy Novgorod (Gorky) Russia 1985: 128p.
7. Kabata-Pendias, A, Pendias H. Trace elements in soils and plants, 2nd ed., Levis. Publ. Boca Raton. Fl. 1987:365p.
8. Kharytonov M, Bagorka M, Sherstoboeva E. The limitations and prospects to provide sustainable crops yield in the steppe zone of Ukraine. In: NATO advanced research workshop: The role of biodiversity conservation in the transition to rural sustainability: Using adaptive management, institutional analysis and sustainability appraisal to understand experience from North America and Europe, with special reference to Central and East Europe 2002a, Krakow, Poland (CD-ROM available through www.nato.int).
9. Kharytonov M, Gritsan N, and Anisimova L. Environmental problems connected with air pollution in the industrial regions of Ukraine. In: Global atmospheric change and its impact on regional air quality. Barnes, I. (Ed). NATO Science Series, IV: Earth and environmental sciences. Kluwer Academic Publishers, 2002b;16:215-222.
10. Kharytonov M, Torkhova N, Bagorka M. Agrogeochemical peculiarities of growing crops that traverse sloping landscapes. Agronomy and Biology (Sumy Agrarian University, Ukraine) 2002c;6:137-140.
11. Kovalsky VV. Biosphere regions: the basis of delineating biogeochemical regions. In: The biosphere and its resources. "Nauka" Publishing House, Moscow 1971:90-131.
12. Kovda VA. The problems of Earth biosphere and soil protection. Institute of Soil Science and Photosynthesis. Puschino, Russia 1989:122-3.
13. Kovda, VA. Contemporary scientific concepts relating to the biosphere.-In use and conservation of the Biosphere: Proceedings of the intergovernmental conference of experts on the scientific basis for rational use and conservation of the resources of the biosphere. Paris, UNESCO, 1970.
14. Masyuk, NT. Directed phyto-ameliorative syngenesis: its effectiveness in reclaimed lands. In: Turnover of biogeochemical substances in the biosphere. "Nauka" Publ. Moscow 1987:65-72.
15. Masyuk NT. Agrarian differentiation of Dnipropetrovsk region: Sustainable development. Conf. Proc.--Environmental Pollution & Ecological Safety, Dnipropetrovsk National Univ. (Ukraine) 1999:19-21
16. Masyuk, NT, Kharytonov MM, Reva L. The effect of soil geochemical and physical properties on the macro- and micro-element content of crops. Agrochemistry & Soil Sci. (Kiev) 1993;56:68-72.
17. Microsoft Corporation. EXCEL spreadsheet, Microsoft Office, 2000.
18. Ministry for Environment Protection and Nuclear Safety of Ukraine. Environmental protection of natural resources in Ukraine. 1994-1995. "Raevsky" Publ., Kiev 1997:96p.
18. Ministry for Environment Protection and Nuclear Safety of Ukraine. National report on the environmental conditions in Ukraine for 1998; (CD-ROM publication, available from www.grida.no).
19. Patyka VP, Tikhonovich IA, Philipyev ID, Gamayunova VV, Andrusenko I I. Microorganisms and alternative agriculture. Kiev, Urozhay Publishing House, 1993:176p.
20. Shakury BK. Peculiarities of biogeochemical turnover in eroded soils. In: Turnover of biogeochemical substances in the biosphere. "Nauka" Publ., Moscow 1987:73-9.
21. Sokolovsky AN. Agricultural Soil Science. Govt. Agricultural Publ., Moscow 1956.

Received: May 22, 2003
Accepted: December 7, 2004