EVALUATION OF CHANGES IN HUMUS FORMATION CONDITIONS IN HOLOCENE STEPPE ECOSYSTEMS OF PRICHERNOMOR'E

F. N. Lisetskii

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The uptake and transformation of organic matter were studied in phytocenoses characterizing the basic evolutionary stages of the vegetation cover of the Prichernomore'e steppes in the Holocene period. It was established that the change in the specific composition of the phytocenoses due to anthropogenic influence on the steppe ecosystems has led to a decrease in the amount of organic matter (up to 45 cwt/ha) and humus (up to 9 cwt/ha) present in the soil. The levels required to maintain the rate of humus formation were determined according to the ecological conditions of the region under investigation.

Analysis of the evolution of the vegetation cover may be the most important key in providing an explanation of the characteristic features of ecosystems. A comprehensive evaluation of the soil-vegetation matter exchange process can be used to reconstruct the genetically predetermined evolutionary phases of an ecosystem. Not only is explanation of the present "accumulated" state of the ecosystem thereby possible, but an information basis for forecasting can also be established by aggregation of the reciprocal reactions obtained by the retrospective method. Solving the former is also prognosticative because in order to foresee an unknown state of affairs already present and not only about to emerge in the future the essence of forecasting is also valid (Bauer et al., 1971).

Of all the components of the natural environment the soil has the most mirror-like quality (Targul'yan and Sokolov, 1978). Compared with genetic investigations of mature soil, pedoreconstruction of the separate evolutionary stages gives significantly more information. To analyze the topic under investigation it was vital to select periods of sufficient duration to exceed the characteristic time taken by the humus formation process (according to Targul'yan, and Sokolov, 1978, hundreds, thousands of years). The steady change in the rate of the humus formation process at the separate evolutionary stages (Sokolov, 1984) associated with temperate belt soil development means that the time taken from zero-point to mature profile state in friable soil types is of the order of 1000-3000 years (Stevens and Walker, 1970; cit. acc. to Aleksandrovskii, 1983, p. 21).

As a result of palynological investigations of Holocene soil profiles the basic evolutionary stages of the vegetation cover have been established in recent years. This establishes the preconditions for resolving the inverse problem: the study of soil evolution and, in particular, of the humus formation conditions under the influence of a changing vegetation composition. Throughout the Holocene period (the last ten thousand years) the vegetation of Prichernomor'e has had a steppe character. A more detailed analysis of investigation results, however, (Dinesman, 1977; Aleksandrovskii, 1983; Pashkevich, 1981) shows that the separate evolutionary stages of the vegetation cover associated with action of the anthropogenic factor can be distinguished.

In the Boreal and I phase of the Atlantic period the vegetation of Prichernomor'e was represented by gramineous-cespitose-cereal steppes. From the mid-Holocene (7700 years ago) onwards there appeared the first signs of the influence of grazing and burning. These factors began to have a particularly fundamental influence on the territory under investigation

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from the mid-fourth century B.C. (Pashkevich, 1981). As xerophytization of the sheep's fescue-needle grass steppes began to take place the amount of needle grass in the grass-stand composition dropped and the role of *Festuca sulcata* increased considerably. This agrees with statistically-based evidence (Tarasov and Sukachev, 1981) that sheep's fescue becomes abundant as soil moisture decreases (from 15 to 8%). Special investigations (Shalyt and Kalmykova, 1935b) have shown the fast recovery and increased fruitfulness of sheep's fescue after scorching.

The influence of grazing degradation on the vegetation cover of cespitose-cereal steppe is seen also in an increase in the amount of sagebrush (Dinesman, 1977), which leads to a change in the chemical composition of the organic matter taken up by the soil. Compaction o the upper soil layer from grazing leads to even greater moisture evaporation, and, in the final event, also to alkalization of the soil profile (Mordkovich, 1982), which, in its turn creates more favorable conditions for the proliferation of sagebrush.

From the late Holocene period (3200 years ago) on, and particularly in the Scythian era grazing and burning became the most important factors in vegetation evolution. For 2000 years after the Scythians, alternating nomadism and cattle-rearing had analogous effects on nature (Kirikov, 1983). It should be noted that burning is a change which does not overstep the resistance threshold of an ecosystem. Burning of steppe litter to improve pasture and also in time of war is one of the most ancient forms of anthropogenic influence on vegetation. Moderate grazing is important to the life of an ecosystem since it limits litter formation and destroys fresh weeds (Mordkovich, 1982). Progressive agricultural activity by man, however, has altered the relative influence of wild ungulates and domestic animals on the steppe vegetation. The wild horse (tarpan), which was quite numerous in the 18th century and competitive with domestic cattle-raising, was exterminated as the virgin areas disappeared. In 1863 in the remote steppe of the Kherson district a 5-6 head herd of tarpans still remained.

Thus, an overall view of the formation of the zonal appearance of the steppe vegetation can only be gained by taking the action of ungulates (moderate grazing), and of burning, botł natural and otherwise, into consideration. In our opinion, the influence of the antropogenic factor should not be examined simply through the destruction of a climax, representing it as if it were a mature community under absolute reservation conditions. Following the poyclimax concept, it is valid to separate out the climax conditions of ecosystems caused by the emergence of new agricultural practices which influence the vegetation cover. Thus, the duration of the separate vegetation alternations, characterized as the fundamental changes in productivity, the ash composition, and consequently, also the rate of the humus formation process, is sufficient for the formation of mature soils.

Our retrospective analysis of the related change in vegetation and soils was based on the ergodic theorem. The interaction of the natural processes means that, instead of having to take measurements at the time, evaluation of the productivity level can be made at specially selected space-time sequences of the ecosystem.

From 1981-84 we studied the features of the uptake and transformation of vegetation matter for distinct landscapes. Plots were selected in the Nikolaevski and Odessa oblasts of the Ukrainian SSR with similar ecotope conditions and the most typical of the conjugate sequences of phytocenoses where the soil formation process had taken place at one time or another: sheep's fescue-needle grass association (virgin soil), needle grass-sheep's fescue association (virgin soil), and gramineous-needle grass-sheep's fescue association (pasture).

The quantity of the above-ground phytomass of the grass-stand was evaluated by the measured plots method (25 × 25 cm) repeated 4-6 times with subsequent drying of the samples to absolute dry weight. For the green phytomass the relative deviation ranged from 9-13%, and only on pasture at isolated periods could it be higher (up to 18%). For the twigs and litter on the whole a more significant variation was noted, and was particularly characteristic of pasture, where the distribution of dead vegetation matter is mosaic-like. Here the relative deviation was 20-30%. The phytomass of the below-ground organs was determined by taking soil monoliths with a 1 dm^3 volume repeated three times in the 0-10 and 10-20 cm layers. The roots were washed in a 0.25 mm gauge sieve and divided into rootstock, active and inactive roots. After prolonged elutriation the relative deviation did not exceed 8%.

The decomposition rate of the sheep's fescue roots was determined in a field experiment. The roots of the living plants were given a brief wash in the unpulverized state, were

TABLE 1. Dynamics of the Quantity of Vegetation Matter in the Aboveground Layer of Some Prichernomor'e Biogeocenoses (results of 327 measurements)

<table>
<tr><th rowspan="2">Plot location</th><th rowspan="2">Phytocenosis type and its anthropogenic changeability</th><th rowspan="2">Measurement date</th><th colspan="2">Aboveground mass, g/m²</th><th rowspan="2">Liter, g/m²</th></tr>
<tr><th>green parts</th><th>dead parts</th></tr>
<tr><td rowspan="10">Nikolaevski oblast, Nikolaevski region, Bug estuary valley</td><td rowspan="10">Sheep's fescue-needle grass association (virgin soil)</td><td>26.VIII.81</td><td colspan="2">778,7</td><td>—</td></tr>
<tr><td>18.IX.81</td><td colspan="2">—</td><td>212,2</td></tr>
<tr><td>22.III.82</td><td>0</td><td>276,4</td><td>87,8</td></tr>
<tr><td>21.VI.82</td><td colspan="2">913,0</td><td>398,4</td></tr>
<tr><td>29.VIII.82</td><td colspan="2">1207,0</td><td>157,6</td></tr>
<tr><td>22.XI.82</td><td>25,6</td><td>772,2</td><td>135,4</td></tr>
<tr><td>25.III.83</td><td>13,6</td><td>654,4</td><td>197,5</td></tr>
<tr><td>20.VII.83</td><td colspan="2">1321,2</td><td>194,1</td></tr>
<tr><td>26.VIII.83</td><td>334,4</td><td>845,1</td><td>236,1</td></tr>
<tr><td>26.VIII.84</td><td>462,6</td><td>497,5</td><td>237,1</td></tr>
<tr><td rowspan="13">As above</td><td rowspan="13">Needle grass-sheep's fescue association (virgin soil)
Burning, neighboring plot</td><td>19.VI.81</td><td>299,2</td><td>—</td><td>187,2</td></tr>
<tr><td>22.III.82</td><td>0</td><td>81.7</td><td>170,0</td></tr>
<tr><td>21.VI.82</td><td>270,6</td><td>—</td><td>199,4</td></tr>
<tr><td>31.VII.82</td><td>184,3+268,6</td><td>119,5</td><td>—</td></tr>
<tr><td>26.IX.82</td><td colspan="2">284,1</td><td>181,0</td></tr>
<tr><td>22.XI.82</td><td>42,2</td><td>608,2</td><td>198,4</td></tr>
<tr><td>25.III.83</td><td>31,4</td><td>137,7</td><td>217.1</td></tr>
<tr><td>26.VIII.83</td><td>70,9+190,5</td><td>429,3</td><td>107,0</td></tr>
<tr><td>18.XI.83</td><td>—</td><td>485,1</td><td>220,3</td></tr>
<tr><td>17.VI.83</td><td>150,1</td><td>13.9</td><td>101,6</td></tr>
<tr><td>26.VIII.83</td><td>80,1+154,0</td><td>83.9</td><td>79.3</td></tr>
<tr><td>18.XI.83</td><td>—</td><td>168.7</td><td>103.0</td></tr>
<tr><td>26.VIII.84</td><td>72,6+113,4</td><td>110,5</td><td>176,7</td></tr>
<tr><td rowspan="14">Odessa oblast, Kominternovski region, upper part of Gluboki ravine incline</td><td rowspan="14">Gramineous-needle grass-sheep's fescue association (pasture)</td><td>26.VI.81</td><td>143,4</td><td>—</td><td>149,2</td></tr>
<tr><td>10.VIII.81</td><td>77,1</td><td>—</td><td>80,0</td></tr>
<tr><td>14.V.82</td><td>—</td><td>49,4</td><td>—</td></tr>
<tr><td>16.VI.82</td><td>124,8</td><td>—</td><td>—</td></tr>
<tr><td>20.VII.82</td><td>107.7</td><td>—</td><td>—</td></tr>
<tr><td>8.VIII.82</td><td>75,1+109,1</td><td>57,3</td><td>—</td></tr>
<tr><td>3.IX.82</td><td colspan="2">215,9</td><td>75,6</td></tr>
<tr><td>8.XI.82</td><td>24,4</td><td>71,8</td><td>68,6</td></tr>
<tr><td>22.III.83</td><td>14,2</td><td>124,8</td><td>142,1</td></tr>
<tr><td>18.V.83</td><td>77,1</td><td>25,4</td><td>81,4</td></tr>
<tr><td>8.VI.83</td><td>114,8</td><td>13,6</td><td>84,1</td></tr>
<tr><td>12.VIII.83</td><td>51,8</td><td>14,5</td><td>178,2</td></tr>
<tr><td>10.XI.83</td><td>—</td><td>52,7</td><td>129,0</td></tr>
<tr><td>23.IX.84</td><td>34,7</td><td>72,8</td><td>127,9</td></tr>
</table>

Note. In the period of subdominant species predominance its productivity was shown by addition to the dominant mass.

weighed when dry, and placed in glass fiber bags. The root decomposition rate in the rhizosphere of the needle grass-sheep's fescue association (virgin soil) was evaluated according to the loss in mass of samples placed on 26 August 1981 at depths of 10-12, 24-26, and 55-57 cm. The bags were collected three times for each period. The soil of the plot was chernozem southern sandy weakly drained (A horizon thickness 26 cm, humus 60 cm). In the limits of the humus horizon the indicators for the physicochemical soil properties varied as follows: humus content 3.5 to 2.3%, carbonate content 12%, the sum of the absorbed bases 24.2 to 20.6 meq/100 g, the ratio of absorbed calcium to magnesium from 25 (10 cm) to 16 (55 cm). The field experiment in the gramineous-needle grass-sheep's fescue association plot was set up on 4 September 1981. The soil was chernozem southern heavy loam weakly drained. The root decomposition rate was determined at a depth of 10 cm. The humus content here was 2.8%, carbonate content 4%, the sum of the absorbed bases 24.9 meq/100 g, the ratio of calcium to magnesium was 9.

Stipeta cappillatae is the formation closest to the indigenous grouping of the zonal appearance (Shelyag-Sosonko, and Kostylev, 1981). In the needle grass-sheep's fescue association a more or less significant surge in productivity of the subdominant species *Stipa capillata* was possible at the end of summer. At certain periods its contribution to the total above-ground mass reached 40%. The green mass of sheep's fescue was maximal in the ear formation phase (in June) (Table 1). In nine months (until the appearance of the first shoots in the following year) 54-57% of the aboveground mass of sheep's fescue decompose. After burning the structural elements of the aboveground mass reattain their original values after only two years (see Table 1).

TABLE 2. Phytomass of the Belowground Organs of Needle Grass-Sheep's Fescue Association (chernozem southern sandy, virgin soil), g/m²

Measurement date	Soil layers, cm	Rootstock	Roots	
			active	inactive
21.VI.82	0—10	48.5	834,5	283.0
	10—20	16.5	240.0	130.0
	0—20	65.0	1074,5	413.0
22.XI.82	0—10	129.0	556,5	304.5
	10—20	8.0	147.0	87.5
	0—20	137.0	703.5	392,0
17.VI.83	0—10	41.5	758.9	294.9
	10—20	3.2	168.7	118.5
	0—20	44,7	927,6	413,4
18.XI.83	0—10	49.0	762.7	565.3
	10—20	10.0	102.1	185,9
	0—20	59.0	864.8	751,2

TABLE 3. Root Decomposition Rate in Needle Grass-Sheep's Fescue Association

Soil layers, cm	Root mass, g/m² (max./min.)	Annual growth, g/m²	Duration of root exchange, yrs*	Root renewal rate†
0—10	1117,5/861,0	256.5	4,36	0,23
10—20	370,0/234.5	135,5	2,73	0,37

*Ratio of maximal root phytomass to annual growth.
†Quantity, inverse duration of root exchange.

TABLE 4. Phytomass of Belowground Organs of Gramineous-Needle Grass-Sheep's Fescue Association (chernozem southern heavy loam, pasture), g/m²

Measurement date	Soil layer, cm	Rootstock	Roots	
			active	inactive
8.VI.83	0—10	26.9	874,5	202.8
	10—20	4.2	204.9	51.2
	0—20	31.1	1079,4	254.0
11.X.83	0—10	140.5	653.8	308.7
	10—20	29.8	129.7	161.9
	0—20	170.3	783.5	470.6

A biological feature of sheep's fescue is that maximum accumulation of belowground mass is achieved by the end of the fructification phase (Bazhetskaya, 1972). Thus, the maximal root quantity was determined in this period. The second period selected was at the end of the vegetation period (Table 2). The annual growth was calculated according to the range of seasonal phytomass change in the active and inactive roots. In addition, root abjection can reach 200 g/m² a year (Lucas et al., 1977). Calculation of the root renewal rate in 1982 (Table 3) was carried out according to Dal'man (1968). The root renewal rate in the 0-20 cm layer was on average 30% of the total root mass. This quantity clearly varies insignificantly in the annual dynamics. However, measurements carried out in November 1983 after a fire showed a significant increase (up to 45%) in the 0-20 cm layer of the inactive root proportion of the total mass of belowground organs as compared with the analogous 1982 period. According to the field experiment results obtained over a one-year period, in the 10-12 cm layer 32% of sheep's fescue roots decomposed, 22% in the 24-26 cm layer, and over a two-year period 54 and 51%, respectively. Analysis of observations on humidity dynamics show that the upper 10 cm of soil are dryer in spring and wetter in autumn, than the deeper layers. The decomposition process of sheep's fescue roots in the 10-12 cm layer can be considered basically completed after three years (decomposition level is 83%). This agrees with the evaluations shown in Table 3.

In the gramineous-needle grass-sheep's fescue association (periodic grazing conditions) the proportion of needle grass becomes significant only in isolated years. In the detritus composition the amount of cattle excrement is small (up to 34 g/m^2). A typically basic constituent of the aboveground mass of pasture is Austrian wormwood (an average 10%). Results of an experiment using capron bags showed that from winter to summer (duration of decomposition was 6 months in 1982 to 1983) the loss in twig mass was 32.3%, and of litter 25.7%. There was no snow and it was very warm in the winter of this period. It is interesting to note that similar investigations carried out on pasture under conditions of direct contact of the material with the snow cover (Bleak, 1970) gave similar results: over a 5 month period 27-31.5% of the twigs decomposed. According to the phytomass of the belowground organs, pasture is practically indistinguishable from the virgin land plot (Table 4). The smaller quantity of inactive roots may be caused by the high rate of the decomposition processes in soils with heavy size distribution, which confirms experimental results for sheep's fescue root decomposition. In a one-year period (from 9.4.81 to 9.4.82) 51% of sheep's fescue roots decomposed. The experiment in the following year was carried out with separate root fractions.

We were unable to find any data in the literature on any difference in the transformation of active or inactive roots. In the mean time, the addition of these data and the investigation into the phytomass structure of the belowground organs means that the root renewal rate can be calculated with accuracy. In one year 52.3% of the active roots decomposed and 36.6% of the inactive. By correlating these fractions (see Table 4) the proportion of decomposed roots after their maximum accumulation measures 49% for a one-year period. A similar result was obtained using the Dal'man method. The level of root decomposition reached 60% over a two-year period (from 1981 to 1983).

Analysis of the results presented in Table 1 leads to the conclusion that in associations with needle grass dominant the uptake of organic matter together with leaf fall is at least 1.5 times greater than in associations where sheep's fescue predominates. A study of needle grass associations in Askania-Nova (Shalyt and Kalmykova, 1935a) showed that in the 0-20 cm layer 1.5 times more roots accumulate each year than in the associations of our investigations where sheep's fescue was dominant.

The results obtained form the basis for a retrospective analysis of the formation stages of the steppe ecosystems during the Holocene period. Mean values of the humification coefficient taken from the literature were used to convert the initial organic waste mass into the quantity of newly-formed humus matter: 0.10-0.12 for surface wastes, 0.21 (in sandy soils), and 0.24 (in heavy loam) for roots.

In the early and part of the mid-Holocene period (a span of 3500 years) the humus formation process involved an annual uptake intensity of 60 cwt/ha vegetation matter from leaf and 50 cwt/ha from root drop in the 0-20 cm layer. New humus was formed at a rate of 23-24 cwt/ha. It can be assumed that under these conditions a soil was formed in the Prichernomor'e territory which, as a result of the stabilizing correlation of the rates of mineralization and humification of organic matter and the environmental factors, had the highest humus content. Subsequently, for 3280 years, the influence of grazing and burning led to a significant drop in the uptake of vegetation matter (up to 26 cwt/ha from leaf fall, and up to 39 cwt/ha from root drop) and, correspondingly, a drop in humus formation (up to 19-20 cwt/ha in heavy loam and up to 15-16 cwt/ha in heavy size distribution soils). Increased alkalinization of the soils had a definite influence on steppe productivity.

From the late Holocene on, further anthropogenic influence on the steppe ecosystems led to a sharp drop in humus formation at the cost of the above-ground mass (0.7-0.8 cwt/ha), and the total amount in heavy loam soils was 18 cwt/ha with an average uptake of vegetation matter of 72 cwt/ha per year. Soils developed under exactly such conditions in the Prichernomor'e territory which were used for cultivation 130-150 years ago. Under the influence of the first human agricultural activity they were already characterized by a loss in humus resources in the 0-20 cm layer measuring 25%. The investigations we carried out on the Nizhni Trayanovoi rampart, a defense construction built about 2000 years ago, showed that in the period of farming use the southern chernozem lost 19% of its arable layer humus resources.

The results set out above were used to establish the optimal amount of humus formation in soil-protected arable systems for the immediate future. The maintenance of this amount is determined by the most important condition of purposeful management of the rate of the cultivated soil formation process. In addition, evaluation of the parameters of how certain climax conditions function means that long term real levels of soil fertility can be projected for concrete ecological conditions.

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