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SOIL PROCESSES AND PRODUCTIVITY IN RELATION TO CLIMATIC CYCLES IN KAZAKHSTAN

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ABSTRACT

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The amount of precipitation in a number of boreal zone regions changes greatly from year to year. The precipitation fluctuation curves are in conformity with those of the solar activity having 11-year or secular (80—90 years) periodicity.

Observations carried out in the lower reaches of the Syr-Darya River have shown that the river discharge fluctuations are subject to the same relationships. In wet years severe floods occur, with soils being swamped in depressions and the salinization process intensified on the highlands. In dry years the swamped soils dry up and turn into meadow-boggy soils, and the salinization process ceases due to the lowering of the ground water. In the alluvial-meadow soils of the Syr-Darya levees the soils become salinized in dry years, whereas in wet years the accumulated salts are washed away by floods. The hydrologic regime affects the irrigated paddies as well; in spring prior to flooding in wet years the groundwater table is higher than it is in dry years.

In drought years the moisture storage in the soils of the North Kazakhstan experimental stations is negligible and not enough for a good grass yield, whereas in wet years the yield is satisfactory. The natural addition of plant residues to the soil is also of a rhythmical nature, depending upon the moistening rhythm. In dry years biochemical processes in the soil are much less intensive than they are in wet years, and the composition of the resultant products is different. For example, nitrogen compounds in chestnut soils of the Tien Shan foothills in wet years are mainly represented by ammonia forms and in dry years by nitrate forms. Knowing these relationships would be of great scientific and practical value in forecasting agricultural production and taking preventive measures in due time against drought and other hazards. These relationships have not been well investigated yet and need further study.

INTRODUCTION

Soil formation and soil regimes (e.g., moisture and temperature) depend upon a number of factors, many of which are variables, drastically changing from year to year. For vast areas of the boreal zone with a continental climate, the most powerful factor is the climatic regime (precipitation and temperature) which is subject to severe fluctuations from year to year.

The changes in climate strongly affect the soil processes directly and can have important indirect effects as well upon the development of vegetation and the activity of soil microorganisms, cause considerable climate-dependent ground-water table fluctuations and change the volume of water in the rivers.

In extreme cases when precipitation is much lower for several years than the average, this results in drought which destroys sowings, meadows and pastures over vast territories in European and Asiatic steppes and North American plains.

In the deserts of Central Asia, the Syr-Darya and Amu-Darya rivers are fed by the Tien Shan, Pamir and Alai mountains. Along their way from the mountains to the Aral Sea (a distance of about one thousand kilometres), the rivers have formed vast delta-alluvial plains. Their floods, bed leakage and irrigation are the essential sources for soil moistening and maintaining ground water. A similar situation exists in the lower reaches of the Ili River which empties into Balkhash Lake as well as in the rivers flowing down the Kopet-dag. The flow of these rivers is completely dependent upon precipitation in the mountains, which varies greatly from year to year and as a result of which the flooded areas vary, too.

Much attention has been given to studies of precipitation fluctuations and there is a large literature on the subject.

The results of such investigations have been described from an up-to-date point of view by astrophysicists (Rubashev, 1964) and agroclimatologists—geophysicists (Drozdov and Grigoryeva, 1971; Uteshev, 1972). The analyses of the problem have made it possible to draw a number of conclusions:

(1) Changes in climatic indexes are of a cyclic nature, with distinct cycles of 11, 22 and 80—90 (secular) years. The 33-year Brukner cycles are not evident.

(2) Using an empirical and statistical method, a correlation between climatic cycles and solar activity can be established. These relationships have been successfully used in forecasts of precipitation in the U.S.A. by Abbot, in forecasting the Caspian Sea level in the U.S.S.R. by Drozdov and Grigoryeva and the ice body of the Arctic by Eigenson and Shnitnikov, as well as a river flow by Loginov (Drozdov and Grigoryeva, 1971).

(3) The physical mechanism of the relationships between solar activity fluctuation and climatic index variations are not understood and are being studied further. Nevertheless, there is promise in study of the problem with an empirical and statistical method, provided the statistical criteria are chosen correctly. There is no doubt as to the cyclic nature of tropospheric processes.

It is quite natural that moistening variations from year to year cause certain changes in soils.

Below is an attempt to assess the prospects of such changes and their role in the processes of soil development.

METHODS AND MATERIALS

The study was carried out by examining the abundant data resulting from geographic and stationary investigations in the course of years in the lower reaches of the Syr-Darya River, undertaken because of the problems of irrigating the delta-alluvial plains, and the northern part of the Kyzil Kum Desert. The methods used and the results obtained as a result of these studies have been published earlier (Borovsky and Pogrebinsky, 1958; Borovsky et al., 1959).

The data obtained were compared with the results of hydraulic measurements at the State hydrometric stations and with those of meteorological observations at the State meteorological stations (Uteshev, 1959) as well as with astronomical observations and analyses which results were generalized by Rubashev (1964) and by Drozdov and Grigoryeva (1971).

Included for the sake of comparison are the results of perennial observations of soil processes at experimental stations in North and South Kazakhstan, references to which are given in the text.

RESULTS

According to the meteorological observations in the territory of Kazakhstan for a period of approximately 90 years (since 1880) certain fluctuations of precipitations were determined, as are shown in Table I (Uteshev, 1959).

In the forest steppe soil zone (Petropavlovsk) the greatest amount of annual precipitation exceeds the norm by 4 times and the extremes differ from the average perennial value by 2 times. In the chestnut soil zone of the arid steppes (Tselinograd, Semipalatinsk) the maximum exceeds the minimum by 3.5—4 times; the maximum is 1.5 times greater than the long-time average, whereas the minimum is 2—3 times lower.

In the brown desert soil zone (Guryev) the maximum exceeds the minimum by 6 times, and it is 1.5 times greater than the perennial norm, whereas the

TABLE I

Precipitation fluctuations in certain places of Kazakhstan

Place	Zonal soils	Annual average	Precipitation amount (mm per year)	
			Maximum	Minimum
Petropavlovsk	leached chernozem and grey forest	317	619	164
Tselinograd	dark chestnut	302	460	114
Semipalatinsk	light chestnut	275	391	112
Guryev	brown	161	300	51
Kzyl-Orda	desert takyr	107	178	44
Alma-Ata	dark chestnut foothill	559	813	293

minimum is 3 times lower. On the territory adjacent to the northern part of the Kysyl Kum Desert (Kzyl-Orda) the maximum is 4 times greater than the minimum, it exceeds the average by 1.7 times and the minimum is 2.5 times lower.

In the irrigated areas of the high (848 m above sea level) foothills of the Tien Shan (Alma-Ata) with dark chestnut soils, the maximum is 1.5 times greater than the average perennial norm, whereas the minimum is 2 times lower, and they differ by 3 times.

The analysis of these figures shows that in the steppes from north to south over the course of several years when minimum amounts of precipitation occur, droughts become deeper and deeper resulting in extremely unstable water supplies for plants; whereas the maximum amounts of precipitation conform or even exceed the average levels of moistening in the zones of more humid locations farther north.

Shown in Fig.1 are the precipitation curves for certain localities of Kazakhstan and the southeastern part of the U.S.S.R., drawn up on sliding scale of 5-year periods from 1879 to 1955 (Uteshev, 1959, p.268). It is quite evident that dry and wet years repeat themselves in a schamtic way, thus forming dry and wet epochs. This sequence strengthens the role of precipitation fluctuations in soil development processes.

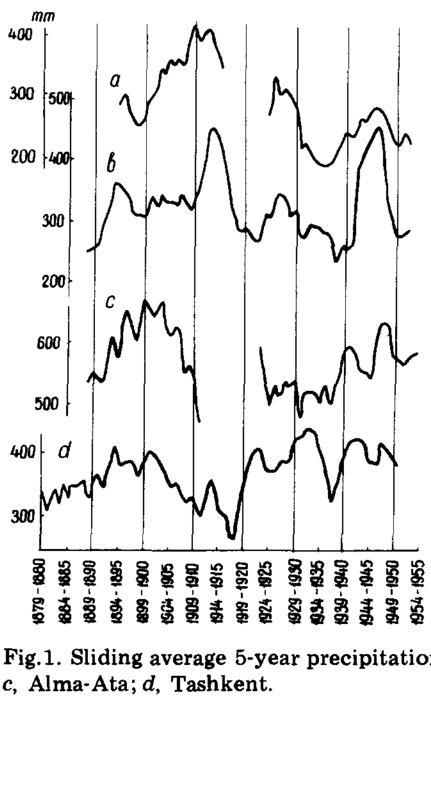

Fig.1. Sliding average 5-year precipitation amounts (mm): *a*, Tselinograd; *b*, Orenburg; *c*, Alma-Ata; *d*, Tashkent.

Using the method of the integral curve drawn up by Tokarev (1950), we can show the direct (for the European part of the U.S.S.R.) and mirror image (in Kazakhstan) conformity of the curves of precipitation and solar activity. The drought years in the European part of the U.S.S.R. correspond to the maximum and those in Kazakhstan to the minimum of the solar activity, the droughts being due to sharp differences in precipitation in these regions.

The lower reaches of the Syr-Darya River are located in the desert zone with poor atmospheric moistening (Table I,Kzyl-Orda point). Along the river there are located large areas of hydromorphic soils which are kept wet by river floods and irrigation. They occupy a total area of more than one million hectares.

The relief of the alluvial plain is of a honeycomb pattern: intricately interlacing elongated narrow elevations and accumulative bank levees of ancient and present-day streams with flat plate-shaped depressions among them. The local relief does not exceed 3 m. The elevations are filled with alluvial-meadow and solonchak soils of wick-type salinization, and the depressions among them with meadow-boggy and boggy soils. Detailed descriptions of this region, its geographical conditions, soils and ground water have been presented elsewhere (Borovsky and Pogrebinsky, 1958; Borovsky et al., 1959).

The water discharge of the river varies greatly from year to year as can be seen from Fig.2 where the data are correlated with Wolf's number curve (Vitimsky, 1964, p. 41; Vitimsky, 1973, Tables, Appendix; Chizhevsky, 1973, pp. 64—114). The minimum water discharge of the Syr-Darya coincides with positive and negative extremes of Wolf's numbers. This can be explained by the fact that the Tien Shan which feeds the river is situated in the region of west—east moisture transfer (European effect) but it is, at the same time, also dependent upon the Siberian effect via the Kazakhstan steppes, and it is here,

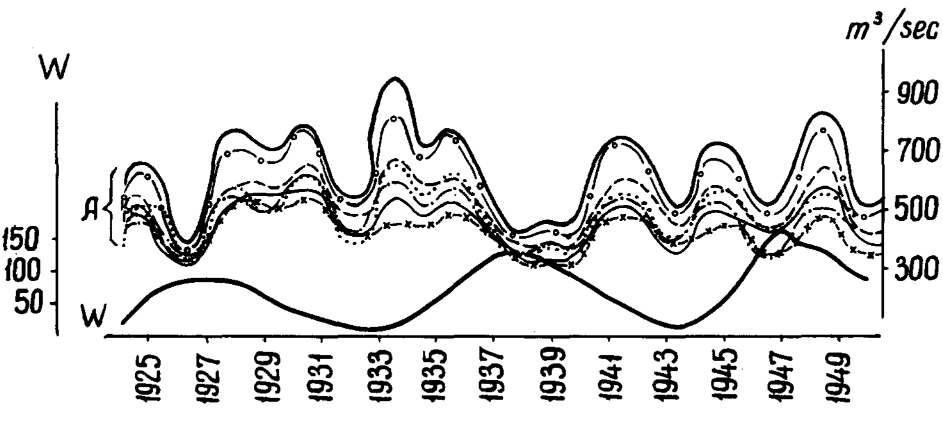

Fig.2. Correlation between average annual discharge of the Syr-Darya River and solar activity (in Wolf's numbers). Legend: *W*, rounded Wolf's numbers; *A*, average annual discharge in m^3/sec in stations (from top to bottom) Kampyr-Ravat, Zaporozhskaya, Kok-Bulak, Tyumen-Aryk, Kara-Uzyak, Karmakchi, Kazalinsk.

TABLE II

Water balance of the Syr-Darya River in km^3

Balance items	Hydrometric stations	1934	1947	1948	1949	1950	1951
Annual flow at station gauge line	Kok-Bulak	23.54	6.31	11.14	15.97	7.43	7.26
	Tumen-Aryk	17.0	5.45	9.65	13.40	6.16	6.70
	Kara-Uzyak	12.95	5.25	8.80	10.83	5.26	5.83
	Karmakchi	9.40	5.17	7.60	9.40	4.97	5.03
	Kazalinsk	7.20	3.98	6.27	7.38	4.12	4.42
Total flow loss	Kok-Bulak—Kazalinsk	16.34	2.33	4.87	8.59	3.31	2.84
Irrigation water intake	Kok-Bulak—Kazalinsk	5.82	1.67	2.99	4.03	2.04	2.17
Overflow and percolation loss	Kok-Bulak—Kazalinsk	10.52	0.66	1.88	4.56	1.27	0.67

probably, that the overlapping of the two cycles or rhythms takes place.

Table II shows the annual water flow measured at stations between a point where the streams leaves the mountains (Kok-Bulak) down to the present-day delta (Kazalinsk) over a number of years. In the 1934 abundant-water year, the river floods were enormous — 10.52 km^3 — as a result of which a great number of depressions were flooded and turned into swamps and even swampy lakes. During the dry years of 1947 and 1951, on the other hand, there were practically no floods, as a result of which the flow decrease was due mainly to irrigation and partly to bed leakage.

Thus, the flooding of boggy soils takes place only in case of high floods in wet years. These soils are covered by reeds (*Phragmites communis* L.) which transpire about 20,000 m^3/ha of water per year; open surface evaporation is over 1,000 mm per year. Taking into account the deep water percolation due to the local relief (not more than 3 m), the boggy soils cannot exist for more than one year without additional moistening.

Numerous observations have made it possible to determine that, with flooding, the oxidation—reduction potentials of soils decrease sharply so that sulfur, iron, manganese, nitrogen (of nitrogen compounds) are reduced (Borovsky, 1969).

Water seeping from flooded depressions is responsible for the elevation of the ground-water table in adjacent areas where wick-type salinization occurs. After a flood has subsided, the ground-water table lowers within a period of 1—2 years as much as 3—5 m, the soils dry up, the reeds are suppressed for lack of moisture; there appear grass varieties; the previously reduced compounds become oxidized and the soils gradually change into a meadow-boggy stage pending another flood. On the adjacent flat elevations of the land surface as additional moistening is stopped, the ground-water table lowers and salinization ceases.

The alluvial-meadow soils of the Syr-Darya levees are covered by tugai forest (*Elaeagnus angustifolia* L., *Popolus diversifolia* Schrenk., *Salix songarica* Anderss., *Halimodendron halodendron* Pall., *Tamarix pentandra* Pall.). The ground waters are at an average depth of 2 m, of low salt in concentration, of weak flowage and the fluctuation of the underground water table is closely connected with the hydrologic regime of the river. In dry years (1947—1948, for example), alluvial-meadow soils become gradually salinized, whereas in wet years the flood waters spill over the levees and wash away salts (1949), as seen in Fig.3, compiled from observations of a plot of alluvial-meadow soils at a distance of 30 km from Kzyl-Orda down the Syr-Darya bank.

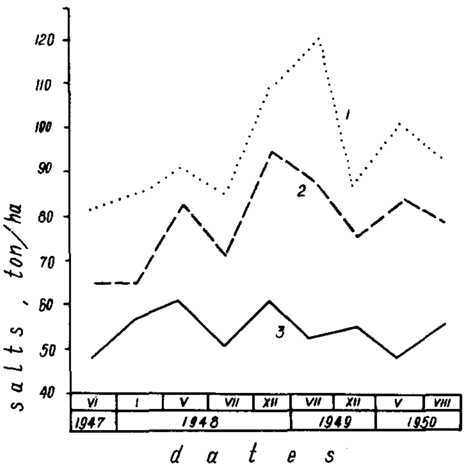

Fig.3. Changes of salinization of alluvial-meadow soil on the Syr-Darya bank at a stationary plot 30 km down from Kzyl-Orda. Legend: water soluble salt content in layers of *1*, 0—200 cm; *2*, 0—100 cm; *3*, 0—20 cm.

Man's activities (irrigation) greatly affect the soil regimes, but the effects are superimposed on the cosmic rhythms. The latter are not completely obliterated. Even in such intensively irrigated fields as paddies, the hydrologic regime of the region as a whole greatly affects the ground water, as seen in Table III; repeated dry years cause gradual lowering of the ground-water table.

Numerous experimental stations in Kazakhstan provide evidence that there are distinct relationships among soil moisture regimes, grass yields, other crop yields and nutrient regimes in the soil, on the one hand, and the cyclic fluctuations of atmospheric moistening, on the other.

For example, Kislyakov (1972), working on an experimental plot of southern chernozem and saline soils on the state farm "Kolos" of the Kokchetav Region, reported that in the virgin lands during the critical period for plant development, i.e. in May 1967 (a drought year) the water supply in a 0—100

TABLE III

Average depth of the ground-water level on the Kzyl-Orda experimental paddies in spring prior to rice flooding

Year	Hydrological characterization	Ground-water depth (m)
1947	dry year	2.17
1948	dry year	2.44
1949	wet year	1.95
1950	dry year	2.06
1951	dry year	2.56

cm layer was only 5.4 mm, while in 1969 (a wet year) it was 112.7 mm. In 1967 there was no grass yield, while in 1969 the average yield of hay on the plots was 17.5 metric centners per hectare (one centner equals 100 kg).

In fallowed fields of the Kustanay experimental station during the wettest period of wheat tillering (early summer), Dzhalankuzov (1972) found that a layer 0—100 cm thick in the 1967 drought year contained 241.9 kg/ha of nitrate nitrogen and in the 1969 wet year (the wettest one) 722.9 kg/ha. Therefore, biochemical processes were more vigorous in 1969 than in 1967 (a drought year). In irrigated potato fields of the Agricultural Institute on dark chestnut foothill soils near Alma-Ata, Malyar (1971) noticed that in wet years most of the soil nitrogen was represented by ammonia forms and in drought years by nitrate forms.

The above situation was to be found both on the reference standard non-irrigated plot and under irrigation (irrigation norm being 2.500 m^3/ha); thus irrigation did not eliminate the rhythm of natural processes due to general climatic factors.

In the irrigated regions of Central Asia, Kenesarin (1963) found a relationship between the ground water regime and the rhythm of solar activity and succeeded in using these relations to forecast increases in the ground-water table as well as assess the amount of reclamation work required to prevent soil salinization.

CONCLUSIONS

(1) The principal factors of soil formation — activity of microorganisms and climatic regimes — are of a cyclic nature connected with the rhythms of solar activity of 11 and 80—90 (secular) year periods.

(2) A number of soil processes, e.g. salinization—desalinization, bogging and drying, moistening regimes in steppes, natural additions of organic substances, numerous biochemical processes and elevation and lowering of the ground-water table show a clear connection with the cyclic nature of climatic factors due to solar activity.

(3) Proceeding from the perennial periodicity of the soil processes one can suppose that the borders between the geographic and soil zones cannot be stable in Kazakhstan, they are commonly displaced either northwards or southwards from a certain intermediate position in accordance with the periodicity of climatic factors.

The same rhythmic changes of the natural surroundings can account for many peculiarities of the soils of transition zones, e.g. forest steppe, and make it possible to settle the long-standing debate from quite a new position as to whether the forest encroached on the steppe or vice versa.

(4) the cyclic nature of meteorological, biological, soil and geological processes caused by cosmic factors is likely to be a special natural law and a significant stimulus for the evolution of the organic world.

To master these laws is of great scientific and practical interest as a basis for forecasting. They are, however, not well studied. Special studies are required on an international scale under a unified programme.

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