

INFLUENCE OF LONG- AND SHORT-TERM CLIMATIC CHANGES ON CHERNOZEM SOILS: CENTRAL CHERNOZEM REGION OF RUSSIA

Yury G. Chendev

Department of Natural Resources Management and Land Cadastre
Belgorod State University, Belgorod, Russia 308015

Anthony R. Lupo (LupoA@missouri.edu)

Department of Soil, Environmental, and Atmospheric Sciences
University of Missouri, Columbia, MO 65211-7250

Aleksandr N. Petin

Maria G. Lebedeva

Department of Geography and Geoecology
Belgorod State University, Belgorod, Russia 308015

1. INTRODUCTION

In contemporary world geography, there still remains a paucity of information that reveals the multi-faceted interrelationship of soils with the other components of the natural environment. This is extremely important information in light of current global ecological problems, studies, and policy decisions, one of which is the problem of climate change. While these have been long discussed in the scientific circles, during the last few years this problem acquired new urgency in connection with new data, reflecting “long” sequences in paleo-climatic reconstructions and a comparatively short, but detailed series of instrumental meteorological and climatologic observations (e.g., Chambers and Ogle, 2002; Brönniman et al., 2008). We will continue the discussion based on the following questions: “In what direction might the change in global climate go?” and “Is this change subordinated by trend dependence or does it occur within cyclic climatic dynamics?” (e.g., Bunyard, 2001; Lupo, 2008). It is well known that soil is considered a rapidly changing system, which sensitively reacts to changes in environmental conditions and, firstly, to climate change (Buol et al., 1997). Therefore, it seems that in finding new approaches to the problem of climate change decisions it may be possible to find among others the study of soils as indicators of climate change. The role of soils in the study of chronological variations of climate is reflected in a number of publications, many of which are oriented toward the use of soils in reconstructions of long-period climate changes (e.g., Gennadiev, 1990; Buol et al., 1997; Aleksandrovskii and Aleksandrovskaya, 2005; Chendev, 2008). In the last three decades, fewer studies have been published about soils as indicators of a contemporary climate change (e.g., Ovechkin and Isaev, 1985; Solovyov, 1989; Chendev et al. 2012). The main purpose of this article is the identification of forest-steppe and steppe chernozem soils (Eastern European Mollisols) reactions to climate change with different periodicities.

2. THE PROBLEM, OBJECTIVES, AND METHODS

Contemporary soil cover within the territory of the East European forest-steppe and steppe natural zones began to form in the Early Holocene - approximately 10,000 years ago (e.g., Gennadiev, 1990; Spiridonova, 1991; Aleksandrovskii and Aleksandrovskaya, 2005). In

the study area, the Belgorod oblast (region) which is situated in western Russia or more generally the East European plains, climate repeatedly changed during the Holocene, which led to the time-spatial changes of the boundaries for natural geographic and soil zones. The natural-climatic periodization of the Holocene for East Europe according to Blytt-Sernander (Aleksandrovskii and Aleksandrovskaya, 2005) is widely known. Recently, however, the appropriateness for wide interpretation of this scheme, originally created for Scandinavia, is open for discussion (Aleksandrovskii and Aleksandrovskaya, 2005). Our understanding, from the point of view of age-long (long-periodical) climate change, in the territory of forest-steppe and steppe zones of the central part of the East European Plain it is better to use division of the Holocene into Early, Middle, and Late periods. According to contemporary ideas, the Early Holocene (10000-8000 yr BP) was characterized by a cool-cold and dry climate. The Middle Holocene (8000-4000 (3500) yr BP) was characterized by alternating temperature drops and rises under conditions of a generally dry climate; and the Late Holocene (last 4000-3500 yrs) was characterized by a reduction in the degree of continentality and an increase of the climate humidity (Aleksandrovskii and Aleksandrovskaya, 2005; Chendev, 2008). With respect to the evolution of chernozems during the Holocene in the East European Plain, there remain a number of only weakly-illuminated questions. Among these questions - the identification of the distance of the shift of the climatic border between forest-steppe and steppe that occurred at the beginning of the Late Holocene. The answer to this question is discussed in this article.

The well-known ideas of the Holocene natural periodization considered only long-period fluctuations in climate, whose tracks can be revealed in soil profiles. However, for secular variations in the climate background, there were short-period variations whose influence on soils and soil cover are studied only rarely at present. L. V. Klimenko (1992) analyzed seasonal behavior of temperatures, using the data provided by a meteorological network located in the southern half of the East European Plain (45°-55°N 30°-50°E) for the period 1891-1990. Klimenko (1992) concluded that the natural fluctuations of the temperature in both the summer and winter seasons for past 100 years show the presence of two large waves in temperature decreases during the summer time (1920s-1930s and 1970s-1980s) and coincident with them were temperature increases during the winter seasons. Klimenko (1992) explains these by finding that similar atmospheric processes occurring in different seasons can lead to different climatic effects. For example, since the beginning of the 1970s, cyclonic activity increased sharply, and in the cold season positive anomalies of temperature began to appear more frequently, but, in the warm season, negative anomalies appeared. The latter result is reflected by an increase in cloudy weather with precipitation (Klimenko, 1992).

According to Sazhin and Kozina (2000), in the Northern Hemisphere during the atmosphere circulation phase of 1890-1920s, the annual amount of precipitation exceeded the long-term climatic norm. In the 1920s, a new atmospheric regime became established, and this continued into the middle 1950s. During this epoch, global temperatures rose, precipitation decreased, which caused more frequent droughts and these occurred repeatedly in the ordinary-steppe and dry-steppe regions of East Europe. From the beginning of middle 1950s, and in the extreme southeast of Russia's European territory, the climate steadily moistened and reached a maximum in the 1990s-2000s. With increasing precipitation, the character of many natural processes significantly changed: within the chernozem zone, the level of the ground water increased; the composition of natural vegetation changed sharply. Hygrophilous forms of plants appeared and the activity of wind-erosion processes decreased. The authors (Sazhin and Kozina, 2000) suggested that during the first half of the 21st century, changes in climate and the connected changes in the regime of temperature-moisture potential will occur in a manner similar to the period of 1920s-1950s. This will lead to a sharp worsening in the natural climatic conditions for the development of agriculture within the southern East European Plain (Sazhin and Kozina, 2000).

The main subjects of our study are the chernozem soils, the most fertile soils of Eurasia, situated in the center of the East European Plain. For climate change, the following properties of chernozems were examined: their humus horizons thickness and depth of effervescence (depth of the upper boundary of carbonates in the soil profile). Also, we analyzed

temporal change in the areas of different genetic groups of chernozems (leached, typical, solonetzic) as the reflection of climate change.

According to the existing ideas, with an increase in climatic continentality (strengthening aridization of climate), the humus horizon thickness and the depth of effervescence decrease, while the areas of chernozems, characteristic for more arid climatic conditions increase spatially. A decrease in climate continentality (during moistening of climate) causes the opposite processes: the humus horizon thickness and the depth of effervescence grow and the areas of chernozems, formed under more dry climatic conditions, decrease.

Paleo-climatic reconstructions based on data on temporal changes of soil properties were done by the method of soil chronosequences. This method can be described as the study of chernozems covered by unequal-age burial mounds, with a subsequent comparative analysis of their humus horizon thickness and depths of effervescence. Additionally, the method uses a comparison of the ancient (buried) chernozems properties together with the properties of modern (background) chernozems formed on the natural topographic surface of the adjacent mounds. The results of the examination of soils as the objects of the paleo-climatic reconstructions were compared with the conclusions of other studies based on the use of other paleoclimatic indicators. Specifically, pollen spectra of the Holocene deposits and soils were used in earlier studies and here. In this article, one of the methods of soil chronosequences applications was the identification of climatic boundary position between the steppe and the forest steppe zones 4000 yrs BP and its comparison with the modern position.

Long instrumental meteorological observations, repeated measurements (observations) of soils and repeat cartography (comparison of maps for different years – see Chendev et al. 2012 for more details) were used to study the influence of short-term climate change (for the end of the 20th century – the beginning of the 21st century) on the properties and areas of chernozems. Short-term climate change was presented by moving average rows of air temperatures from 1890 to 2012, and mapped on examples of the Belgorod oblast for the periods 1951-1980 and 1971-2000. These rows and maps with literature data on the short-term climate change were the basis of our discussion on reasons of relatively fast changes of soil properties and soil areas. In this discussion we used observations and the large-scale soil surveys, which were conducted at 20-30-yr-long intervals.

In accordance with the existing ideas about the climatically induced shift of the southern boundary of the forest-steppe zone at the beginning of the Late Holocene (Aleksandrovskii and Aleksandrovskaya, 2005; Spiridonova, 1991), we set our goal to determine where the location of the boundary between the steppe and the forest-steppe zones existed at approximately 4000 yr BP. The method utilized here consisted of the calculation of the spatial change gradient of the humus horizons thickness for the watershed chernozems in the direction from a more humid forest-steppe to a more arid steppe chernozems (Fig. 1, transects I- III). The data from the morphogenetic properties of contemporary chernozems were generated from the materials of a large-scale soil survey of the Belgorod oblast (archive information, Soils of the State Farm, 1970; 1976; 1996; 2001). Each point of these transects characterizes the mean arithmetic thickness of the humus profiles from 10-15 locations that are situated surrounded the point of determination but not farther than 5 km from it (the small scale of the map presented in Fig. 1, does not allow the display these locations). The thickness of the northernmost chernozems was accepted as 100 %.

3. RESULTS

According to the results of modern studies (Aleksandrovskii and Aleksandrovskaya, 2005; Chendev, 2008), chernozems humus horizons thickness chronological variation clearly reflects the presence of two large climatic epochs: the epoch of climatic aridization, during which the humus horizons thickness was reduced, and the epoch of a moistening climate, during which an increase in the humus horizons thickness occurred. The boundary between these epochs corresponds to 4000 (not calibrated) yr BP. Specifically this boundary should be

considered as the beginning of the Late Holocene within the Central East European Plain. In particular, a trend toward improvement in the soil characteristics (an increase in the humus horizons thickness and the growth of the upper boundary of carbonates depth in soil profiles) as a consequence of increased humidity, was also observed for the first half of the Late Holocene within the Central Chernozem Region – in the territory of Belgorod oblast. This is reflected in Table 1.

TABLE 1
CHANGES IN THE MORPHOGENETIC PROPERTIES OF TYPICAL CHERNOZEMS WITHIN THE FOREST-STEPPE NATURAL ZONE OF THE CENTRAL EAST EUROPEAN PLAIN DURING THE LAST 4000 YEARS, IN % OF MODERN VALUES (BASED ON (CHENDEV, 2008))

Soil index	Chrono-interval		
	4000 yr BP n=3	3500-3000 yr BP n=8	2600-2200 yr BP n=15
Thickness of A + AB hoizons	71.67±2.92	76.50±1.93	103.33±2.80
Depth of effervescence	0	55.00±4.73	64.73±7.18

As can be seen from Fig. 1, under contemporary conditions, the value of the thickness decreases for every 100 km and varies from 18 to 31% (25% on average). If the 4000-yr-BP's thickness of the humus profiles for paleo-chernozems in the southern part of the forest-steppe zone was equal to about 72% of the background (modern) values (Table 1), then, according to our calculations, the steppe zone, at this time, could be found about 112 km to the north-west of its contemporary position. In the south-eastern direction, the annual amount of precipitation at the indicated distance decreased by 80 mm. Consequently, near the contemporary boundary of the forest-steppe and steppe, the climate of 4000 yr BP was probably about 80 mm more arid than contemporary, and the annual precipitation, at this time, could have been approximately 430-450 mm.

The influence of the short-term climate change on the properties and areas of forest-steppe chernozems have been examined based on the example of three key plots. Two of these plots are located in the territory of the Belgorod oblast (Fig. 2 plots 3, 4), and one is within the territory of the Kursk oblast (Fig. 2, plot 1). The periods of soil observations (1958-1976; 1981-2001) corresponded to different phases of helioclimatic cycle – the first period is relatively warm-dry, and the second period is relatively cool-wet. These climatic phases are shown clearly in Fig. 3, 4. Fig. 3 reflects the changes for the last 112 years of winter and summer air temperatures in relation to their mean values according to data obtained from the instrumental measurements on one of the oldest Russian meteorostations, Bogoroditskoye-Fenino, which is situated in Belgorod oblast (Fig. 2). Curves of summer temperature epochs show strong correspondence with those detected by Klimenko (1992) in the two large waves of temperature decreases during the summer season. According to Fig. 3, these occurred from 1917-1935 and 1973-1995. Summer cooling may be connected with intensification of cyclonic activity during these periods. Also (Fig. 3) we see a wave in temperature increase during the winter time – from 1976 till the 2002, which, possibly, also may be connected with increases in cyclonic activity. The presence of the indicated warm-dry and cool-wet climatic phases also is confirmed by a comparison of the climatic maps for the Belgorod oblast created at different time-points (Fig. 4). The comparison of the maps, which reflect average climatic indices during 1971-2000, with the maps that characterize climatic indices during the previous thirty-year

period (1951-1980) showed that, for the end of the 20th century, there were a distinct increase in the annual amount of precipitation and the evolution toward a less continental temperature regime. This was reflected by the shift to the north of the January isotherms and especially to the south of the July isotherms (Fig. 4).

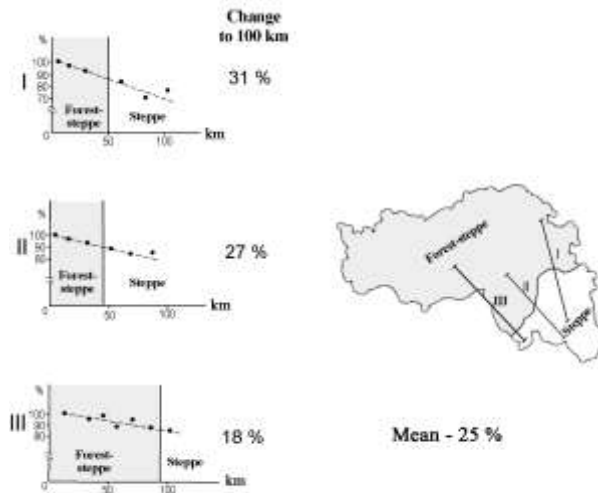


FIGURE 1
 LINEAR CHANGES OF THE CHERNOZEMS HUMUS PROFILES (A+AB) THICKNESS
 NEAR THE MODERN BOUNDARY BETWEEN FOREST-STEPPE AND STEPPE
 NATURAL ZONES

According to the observed data obtained for the Kursk oblast, Bashkakova *et al.* (1984) established that there was a reduction in the humus content both in arable and in virgin chernozems of the Central Chernozem Preserve (Table 2; key plot No. 1 on Fig. 2). As has been discovered, during the period from 1958 to 1981, dehumification (decrease in content of soil organic matter) under virgin steppe was occurring in the soil profile to a depth of 100 cm. For the study period, the intensity of dehumification in the arable land in 1927 was even less than under virgin steppe without grass mowing (Table 2). Researchers now explain that the reduction of the contents of humus and of exchangeable bases in automorphic meadow-steppe chernozems is associated with changes in conditions of soil formation and nature of vegetation. These changes occurred as a result of the recent cycle of moistening climate influence, which begun at the end of 1960s and the beginning of 1970s. In this case, the dynamic equilibrium moved towards leaching of exchangeable bases and the increase in humus mineralization (decay) above humification (formation) of organic matter (Bashkakova *et al.*, 1984).

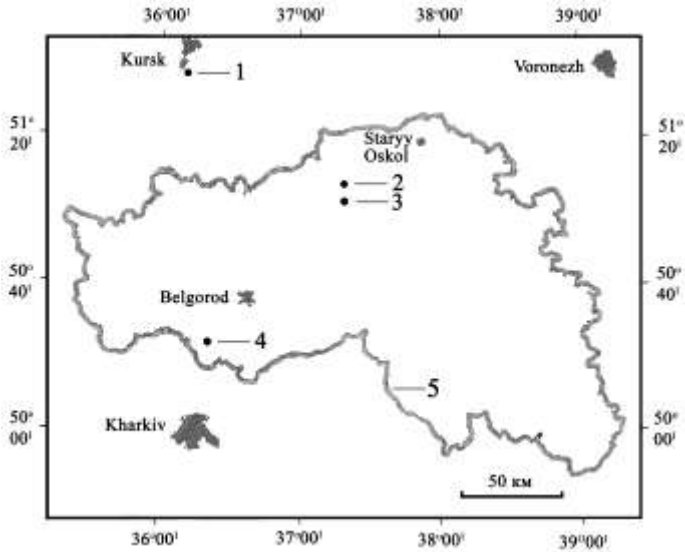


FIGURE 2
 THE LOCATION OF THE STUDY PLOTS USED TO STUDY THE SHORT-TERM PERIODIC CLIMATE CHANGES AND THEIR INFLUENCE ON SOILS. 1 – STRELETSKAYA STEP PLOT; 2 – BOGORODITSKOYE-FENINO PLOT 3 - YUR'EVKA PLOT; 4 –OCTYABR'SKII PLOT; 5 – BORDER OF THE BELGOROD OBLAST

The influence of short-periodic climate changes on soils and the soil cover can be studied by analysis of large-scale soil maps, as discussed above, compiled through identical procedures but for different periods. Suitable for this purpose are 1:10,000 scale soil maps of agricultural enterprises created by large-scale soil surveys at different times. For example, we have carried out the temporal-spatial analysis of the soil cover conditions in 1970 and 2001 within the territory of the state farm “Stepnoe” in the Gubkin District of the Belgorod oblast (key plot Yur’evka, Fig. 2). Also, in 1976 and 1996, the same analysis was done within the territory of the state farm “Dmitrotaranovskiy” in the Belgorod District of the Belgorod oblast (key plot Octyabr’skii, Fig. 2).

As has been shown in the comparative analysis, the areas occupied by typical and leached chernozems on the maps of 1970-1976 and 1996-2001 differ significantly (Fig. 5). In the contemporary period, the areas of leached chernozems generally increased while typical chernozems decreased. Furthermore, the obvious tendency was a reduction of the areas with solonetzic chernozems (plot Yur’evka, Fig. 5).

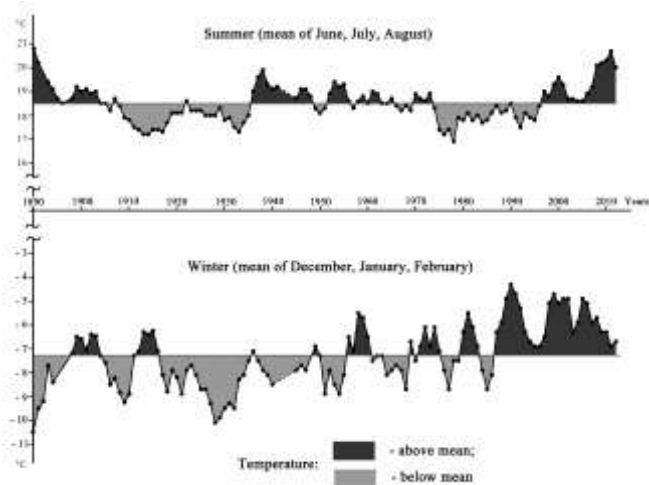


FIGURE 3
5-YEAR MOVING AVERAGE ROWS OF SUMMER AND WINTER AIR TEMPERATURES FOR 112-YR PERIOD OF OBSERVATIONS ON METEOSTATION BOGORODITSKOYE-FENINO, BELGOROD OBLAST

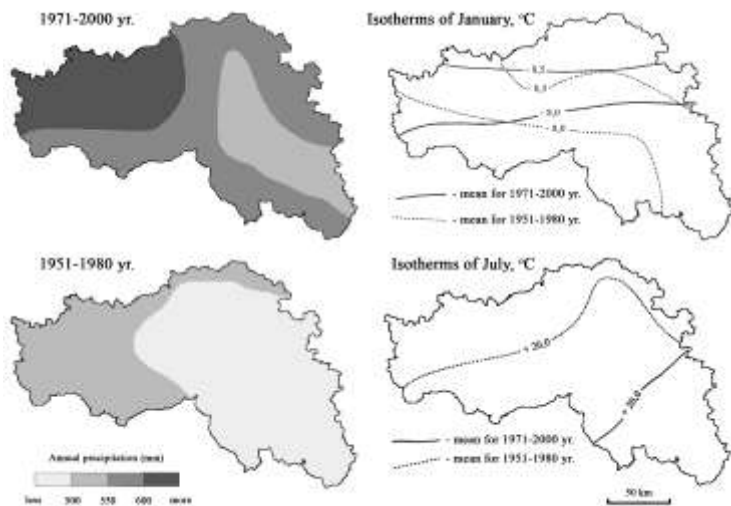


FIGURE 4
CLIMATIC INDEXES OF THE BELGOROD OBLAST FOR THE PERIODS 1951-1980 AND 1971-2000(ADAPTED FROM THE DATA OF (KLUKIN, 1982; GRIGORYEV AND KRYMSKAYA, 2005;)

Agriculture in the area may transform soils and soil areas but its influence becomes obvious for period between observations in 100 and more years (Chendev, 2008). Therefore, it is possible to assume that the discovered changes have been, in many respects, caused by climatic dynamics. For example, it is known that in the territory of the Belgorod oblast during

1971–2000, the total annual precipitation grew substantially (Fig. 4). According to Klimenko (1992), during the last quarter of the 20th century, there has been increased moistening of the climate in winter. During this period, the frequency of thaws increased. According to the observed meteorological data in the Belgorod oblast from the 1990s to the beginning of the 2000s, the steady snow cover frequently appeared only at the end of the winter periods and persisted only for 2–4 weeks. We considered that during the periods of winter thaws, precipitation in the form of wet snow or rain with the absence of soil freezing could initiate leaching of soils. In our opinion, this process was one of the main reasons for the rapid (years to decades) evolutionary dynamic transformation of typical chernozems into leached chernozems, and, probably, of solonchic chernozems into chernozems typical or leached (Fig. 5).

TABLE 2

HUMUS CONTENT (% AT MASS OF SOIL) IN ARABLE AND VIRGIN TYPICAL CHERNOZEMS IN STRELETSKAYA STEPPE PRESERVE FOR DIFFERENT PERIODS (BASED ON DATA (BASHKAKOVA *ET AL.*, 1984))

Depth. cm	Arable land since 1927		Virgin steppe		Mown steppe	
	1963 yr	1981 yr	1958 yr	1981 yr	1958 yr	1981 yr
0-5	8.8	7.1	11.17	9.1	11.12	8.7
5-10	8.5	7.1	8.76	7.3	7.88	7.2
10-20	8.5	6.7	7.72	6.4	6.76	6.5
20-30	7.5	5.7	6.57	5.4	5.58	6.5
30-40	6.8	4.9	6.03	4.8	5.02	6.0
40-50	6.0	4.1	4.95	4.3	4.62	4.6
50-60	5.7	3.8	4.29	3.3	4.03	4.2
60-70	5.2	3.2	3.72	2.8	3.69	4.0
70-80	4.4	3.1	2.98	2.6	3.23	3.3
80-90	3.7	2.5	2.60	2.2	3.08	2.5
90-100	3.6	2.1	2.28	2.0	2.84	2.3

4. CONCLUSIONS

Using a string of examples it has been established that chernozems are sensitive indicators of both long-term and short-term climatic changes. For the territory of the Central Chernozem Region of Russia, the existence of two long-period climatic epochs has been revealed in the second-half of the Holocene: the earlier part of the period was arid and the contemporary is moist. The duration of the Late Holocene within the study territory was 4000 years. The 4000-yr-BP boundary between steppe and forest-steppe was approximately 100-120 km to the north-west of its contemporary position. Near the boundary of “steppe- forest-steppe,” the annual amounts of precipitation were, on average, 80 mm lower than contemporary values (16% of the modern annual sum).

The change from the warm-dry to the cool-wet phases inside the secular climatic cycles was reflected noticeably in the properties and areas of chernozem soils. At the end of 20th century, climate moistening contributed to strengthening of the dehumification over the profile of automorphic chernozems and to the reduction of humus content in the upper meter of soils. The leaching of carbonates and of readily soluble salts contributed to the decrease in the areas occupied with typical and solonchic chernozems and to the increase in the areas occupied with leached chernozems. The discovery that these changes are cyclically repetitive events should be considered in the development of plans for the economic management of lands for the next few years and decades.

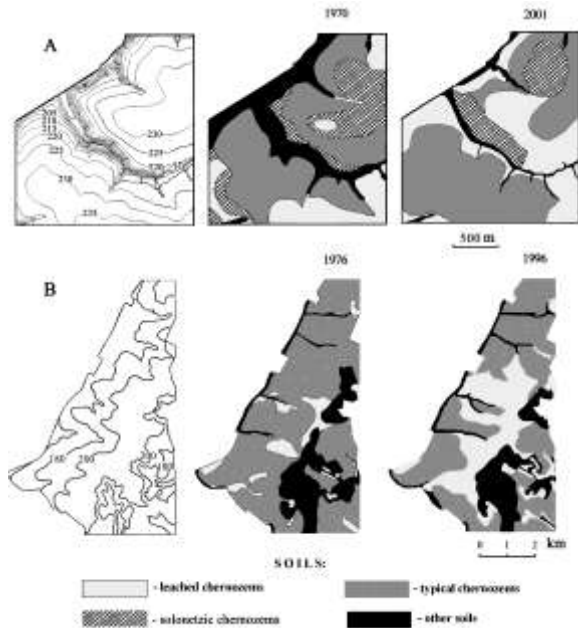


FIGURE 5
 MAPS OF RELIEF (LEFT FIGURES, ABSOLUTE HEIGHTS IN (M)) AND THE SOIL COVER OF KEY PLOTS YUR'EVKA (A) AND OKTYABR'SKII (B) FOR DIFFERENT SOIL SURVEYS PERIODS (MADE BASE ON THEIR DATA FROM (SOILS OF THE STATE FARM,1970; 1976; 1996; 2001)

5. REFERENCES

- Aleksandrovskii, A. L., and E. I. Aleksandrovskaya. 2005. *Evolution of Soil and the Geographical Environment*. Moscow: Nauka [in Russian].
- Bashkakova, L. A., and coauthors. 1984. Research of Physical Chemical Properties of Soils Under Cultivation and Virgin Vegetation based on the Example of the Central Chernozem Preserve. In: *The Geographical Study of the KMA Regions*, pp. 66-76. Kursk [in Russian].
- Brönniman S. et al., 2008: Climate Variability and Extremes during the Past 100 Years. *Advances in Global Change Research*. Vol. 33. Ed. by Berlin: Springer, 2008.
- Buol, S. W., F. D. Hole, R. J. McCracken, and R. J. Southard. 1997. *Soil Genesis and Classification*. 4th Edition. Ames, IA: Iowa State Univ. Press.
- Bunyard, P. 2001. The Truth about Climate Change. *Ecologist Report* 31(9): 4-11.
- Chambers, F, and M. Ogle, 2002: Climate Change: Critical Concepts in the Environment. Natural Forcing Factors for Climate Change on Timescales 10-1 to 105 Years. Vol.2. London: Routledge.

- Chendeв, Yu. G. 2008. *Evolution of Forest-Steppe Soils Within the Central Russian Upland during the Holocene*. Moscow: GEOS [in Russian].
- Chendeв, Y.G., A.N. Petin, and A.R. Lupo, 2012: Soils as indicators of climate change. *Geography, Environment, Sustainability* (A publication of the Russian Academy – Moscow State University) 1, 4-17.
- Gennadiev, A. N. 1990. *Soils and Time: Models of Development*. Moscow: Mosc. State. Univ. Press [in Russian].
- Grigoryev, G. N., and O. V. Kryimskaya. 2005. Climatic Conditions. In: *The Atlas “Natural Resources and Ecological State of the Belgorod Oblast”*, pp. 47-48. Belgorod [in Russian].
- Klimenko, L. V. 1992. Variations of Temperatures within Southern Part of the USSR European Territory during the 1891-1990 yrs. *Herald of Moscow University. Ser. 5. Geography* 1: 25-30 [in Russian].
- Klukin, N.V., 1982: The Atlas of Belgorod Oblast. Moscow [in Russian].
- Lupo, A. R. 2008. Anthropogenic Global Warming: a Skeptical Point of View. *Journal of Missouri Medicine* 105(2): 22-26.
- Ovechkin S. V., and V. A. Isaev. 1985. Periodic Additional Underground Moistening as a Factor of Soil Cover Evolution. In: *The Questions of Hydrology in Soil Fertility*, pp. 56-65. Moscow [in Russian].
- Sazhin, A. N., and O. V. Kozina. 2000. Contemporary Climatic Tendencies and Their Reflection at the Regional Level (on Example of Lower Volga Region). In: *The Scientific Discovery of the Surrounding Nature, the Dynamics of the Geographical Environment (Nature, Society, Policy): Transactions of XI congress of the Russian Geographic Society*. Vol. 5. Saint-Petersburg. P. 105-106 [in Russian].
- Soils of the State Farm “Dmitrotaranovskii,” Belgorod District, Belgorod Region, and Recommendations on Their Management. 1976. Belgorod, 80 pp. [in Russian].
- Soils of the State Farm “Dmitrotaranovskii,” Belgorod District, Belgorod Region, and Recommendations on Their Management. 1996. Belgorod, 76 pp. [in Russian].
- Soils of the State Farm “Stepnoe”, Gubkin District, Belgorod Region, and Recommendations on Their Management. 1970. Voronezh, 81 pp. [in Russian].
- Soils of the State Farm “Stepnoe”, Gubkin District, Belgorod Region, and Recommendations on Their Management. 2001. Belgorod, 78 pp. [in Russian].
- Solovyov, I. N. 1989. On the Question of Modern Evolution of the Soil Cover within the Chernozem Zone of the USSR European Part. *The Anthropogenic and Natural Evolution of Soils and Soil Cover: Theses of Reports, All-Union Conference*. Pushchino, January 10-12, 1989. P 257-259 [in Russian].
- Spiridonova, E.A. 1991. *Evolution of the Plant Cover in the Don River Basin in the Late Pleistocene-Holocene*. Moscow: Nauka [in Russian].