Distribution Patterns of Soils and Vegetation in the Foothills of the Tienshan and Altai Mountains in Central Eurasia

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CONTENTS

Abstract

Extensive surveys on distribution patterns of soils and vegetation were carried out in the foothills and mountain slopes of the Tienshan and Altai Mountains. Clear trends were observed for the distribution in terms of vertical zonation as well as west-to-east transition.

In the Tienshan Mountains, soils at higher elevation were affected mainly by increasing precipitation and hence had lower pH and higher content of organic matter. For example, in the northern foothills of the Tienshans next to the China-Kazakh border (Ketmen Range), the following relationships were obtained using multiple stepwise regression ($n = 34$, $p < 0.15$) for determining respectively the soil pH, soil organic carbon (SOC) and carbonate carbon (CO3-C) in the 30 cm surface layer:

pH(H_2O)0–20 = 33.5 – 3.52 ln (elevation [m]) – 0.441 cos (slope direction) (r2 = 0.85**)
SOC0–30 (Mg ha–1) = – 696 + 105 ln (elevation [m]) + 30.7 cos (slope direction) sin (slope gradient) (r2 = 0.65**)
CO3-C0–30 (Mg ha–1) = – 290 – 33.7 ln (elevation [m]) – 46.8 sin (slope gradient) (r2 = 0.46**)

where slope direction changes from N (0º) to N (360º) via E (90º), S (180º), and W (270º) as a numerical parameter. Calcisols were distributed in the lowermost regions (below 1,300 m), and afterwards Kastanozems (1,300–1,550 m), Chernozems (1,550–1,800 m), Phaeozems (1,800–2,400 m), and Umbrisols (above 2,400 m) were found with an increase in elevation. Chernozems, Phaeozems, and Umbrisols were often covered with broad-leaved or Picea forest typically on the northern slopes.

Such forest covers, however, noticeably decreased in Chinese Tienshan.

On the other hand, in the Altai Mountains, soil organic matter seems to decrease at higher altitudes presumably due to the decrease of temperature as well as the growing period. In northeastern Kazakhstan, the zonal soils in the plain were Kastanozems whereas in the mountains Chernozems, Luvisols (or Phaeozems in middle to western regions) and Cambisols successively dominated. In the Chinese Altai, dry soils such as Calcisols were found towards higher elevation (above 1,000 m) and a zone of Luvisols was absent. Thus, in both mountains, west-to-east transition toward drier moisture conditions was clearly observed, i.e., soils exhibited several dry features (high pH, shallow carbonate layers and low organic matter content) and distribution of forest vegetation decreased in Chinese Xinjiang.

Average monthly air temperature (AT) and annual precipitation (PPT) can be simulated based on secondary datasets from established meteorological stations as follows:

$$\text{AT (°C)} = 51.2 - 0.901(\text{Latitude [degree]}) - 0.00574(\text{Elevation [m]})$$
$$\text{PPT (mm)} = 2670 - 28.6(\text{Latitude [degree]}) - 125(\text{Soil pH})$$

Using these equations, relationships between climatic conditions and distribution patterns of soils and vegetation are described. Based on these results, the regional mapping of soils and vegetation derived primarily from the climatic dataset can be realized.

1. Introduction

Central Eurasia experiences rather dry climatic conditions customary for regions where annual precipitation does not exceed 500 mm. The total produce in the area is, therefore, strictly limited by the scarcity of available water. In the past, extensive livestock farming was the only feasible option for human livelihood in the plains. However, the mountain foothills and hill slopes of the Tienshan and Altai Mountains exceptionally provide a habitat of high biomass productivity due to increased precipitation as well as a good supply of river water. These mountainous areas have thus been very important in supporting human activities such as livestock farming and agriculture both in the past and the present. To clarify the present distribution patterns of vegetation, net primary production and soil resources in these regions, it is imperative to discuss human activities in the past, assess the human impact on natural ecosystems (i.e., soils, vegetation, water circulation and carbon cycle). It is also necessary to provide a large-scale plan for land use in the future.

Central Eurasia was politically separated between the Jin Dynasty and the Russian Empire since the 18th century and, consequently, scientific information relating to soil resources was accumulated based on the individual soil classification systems of the two respective nations, i.e., the China Republic and the former Soviet Union. It is necessary therefore for the distribution pattern of soils to be delineated again using the international classification system so as to be able to be eligible for understanding of human activities on a trans-regional scale. One of the objectives of the present work is to provide basic information on distribution patterns of soils in the mountain foothills and hill slopes of the Tienshan and Altai Mountains using a new international classification scheme—the World Reference Base for Soil Resources (WRB) (ISSS-ISRIC-FAO 1998, 2006).

It is generally known that there is an obvious relationship between climate and soil types, if parent materials are approximately identical. One of the central dogmas for understanding soil-vegetation associations is the concept of ‘zonality’, a rationale for soil classification in the former Soviet Union. While the soil classification system of the United States, i.e., Soil Taxonomy (Soil Survey Staff 2006), once excluded this concept, the WRB scheme seems to be more familiar with the Soviet classification by categorizing soils into 32 reference soil groups (RSG) at the highest level. If a simple relationship is observed between soils and climatic conditions such as mean annual temperature or annual precipitation, the following two possibilities can be realized:

1) If information of past climate is available, maps for spatial distribution of possible soils and vegetation at that time can be depicted using GIS technique; and

2) By combining with carbon dynamics models, the environmental history of carbon dynamics as well as future changes due to human activities can be simulated.

Therefore, the second objective of the present work is to specify climatic and other environmental conditions that determine regional distribution patterns of the respective soil groups and associated vegetation.

2. Materials and methods

Soil survey and analysis: Extensive surveys on distribution patterns of soils and vegetation were carried out in the foothills and mountain slopes of the Tienshan and Altai Mountains during the period of 2006 to 2008. The survey areas extended from West Tienshan in southern Kazakhstan to east of Urumqi, west Xinjiang, China in the northern Tienshan Mountains, whereas three distinct regions from West Altai in northeast Kazakhstan to Altay City in northern Xinjiang, China, were included in the southwestern part of the Altai Mountains (Figure 1). In total 154 plots were surveyed; including 38 forest plots and 116 grassland plots (Table 1).

The surveyed plots were separated into seven sub-regions: West Tienshan (WT), Transili Alatau (ZA), Ketmen Range (XJw) and south of Kuyton City (XJe) in the Tienshan Mountains and West

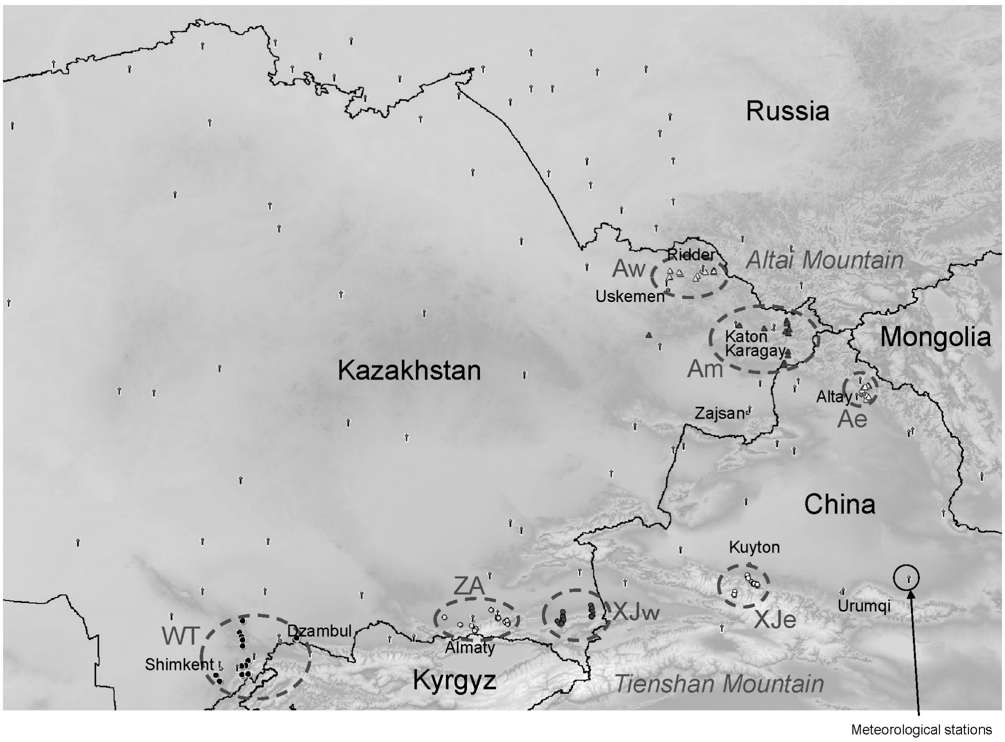

Figure 1. Location of study sites and meteorological stations.

Altai (Aw) and Katon Karagay Valley (Am) in northeast Kazakhstan and north of Altay City (Ae) in Chinese Xinjiang (Figure 1 and Table 1). Soil survey was conducted at different elevations and different slope angles. The dominant vegetations were described and position, elevation, slope directions and slope gradients were determined by a handy GPS or a clinometer.

Table 1. Summary of sampling plots.

Area	Number of samples		
	Total	Grassland	Forest
Tienshan Mountain			
West Tienshan (WT)	31	29	2
Transili-Aratau (ZA)	15	10	5
Ketmen range (XJw)	34	28	6
Kuyton region (XJe)	23	18	5
Altai Mountain			
West Altai (Aw)	12	3	9
Katon Karagay (Am)	18	13	5
Altay region (Ae)	21	15	6
Total	154	116	38

Soil samples collected were transported to Japan followed by chemical analyses of the following items: pH (H_2O) with a glass electrode using a 1:5 soil: solution ratio, total carbon by an NC analyzer (Vario Max CN, Elementar Analysensystem GmbH), and carbonate carbon by the back-titration method.

Collection of meteorological data: Monthly meteorological data (air temperature and precipitation) were collected from the database prepared by the Global Historical Climatology Network. In total, respectively 77 and 17 sets of data were available for estimation of mean annual temperature and annual precipitation (Figure 1).

3. Results and discussion

3.1. Vertical zonation of soils and vegetation observed in the Ketmen Range (XJw) of the Tienshan Mountains

Figure 2 presents landscape and soil profiles at different elevations or slope directions, with analytical data relating to organic and inorganic carbons in the soil. Clear trends were observed for their distribution in terms of vertical zonation. In the XJw region, a desert-like landscape was observed below 1,300 m (Figure 2a). According to the WRB soil classification, the soils in this zone were mostly classified as Calcisols or Cambisols, with little organic matter accumulation and, hence, very light colors throughout the soil profile. In the classification system of the former Soviet Union, however, determines the soils to bethese soils are classified as Northern Sierozem, in which spring ephemeral vegetation dominates, and are discriminated from typical desert soils such as Brown and Gray Brown soils. Above about 1,400 m from sea level, height and biomass of vegetation increased and surface soil colors became darker, especially on the northern slopes (Figure 2b). Organic matter contents in the surface soils increased, satisfying the diagnostic criteria of mollic horizon, and the depth of the carbonate layers became lower, owing to enhanced leaching conditions. The soil was classified into Kastanozems, which were typically observed on the northern slope at this elevation range. Then above approximately 1,550 m from sea level, there were Chernozems, which contained higher amounts of soil organic matter and hence had a darker surface layer (i.e., the value of Munsell soil chroma is not higher than 2) (Figure 2c,d). The vegetation consisted of mainly small broad-leaved forest mixed with tall grasses. This forest is locally called the 'fruit forest', in which we can easily find wild apples or roses. Above 1,800 m from sea level, the carbonate layers of soils often disappeared from the bottom of the profile, and hence the soils were classified into Phaeozems (Figure 2e), which were similar to Chernozems but did not have carbonate layers within 50 cm below the mollic horizons. The vegetation on Phaeozems was usually spruce (Picea sp.) forest. Between 2,000 and 2,500 m above sea level, spruce forest scattered in northern slopes and soils were found to be more acidic (Figure 2f). At these elevations, Umbrisols often occurred due to increased leaching conditions. As the altitude increased the forest vegetation almost disappeared and highland grassland dominated after 2,500 m above sea level (Figure 2g). Dominant soils were Umbrisols or sometimes Cambisols.

Thus in north-oriented slopes, Calcisols were distributed in the lowermost regions (below 1,300 m), and then Kastanozems (1,300–1,550 m), Chernozems (1,550–1,800 m), Phaeozems (1,800–2,400 m), and Umbrisols (above 2,400 m) were distributed in this order with an increase in elevation, whereas in south-oriented slopes each of the soils occurred at higher elevations than on the

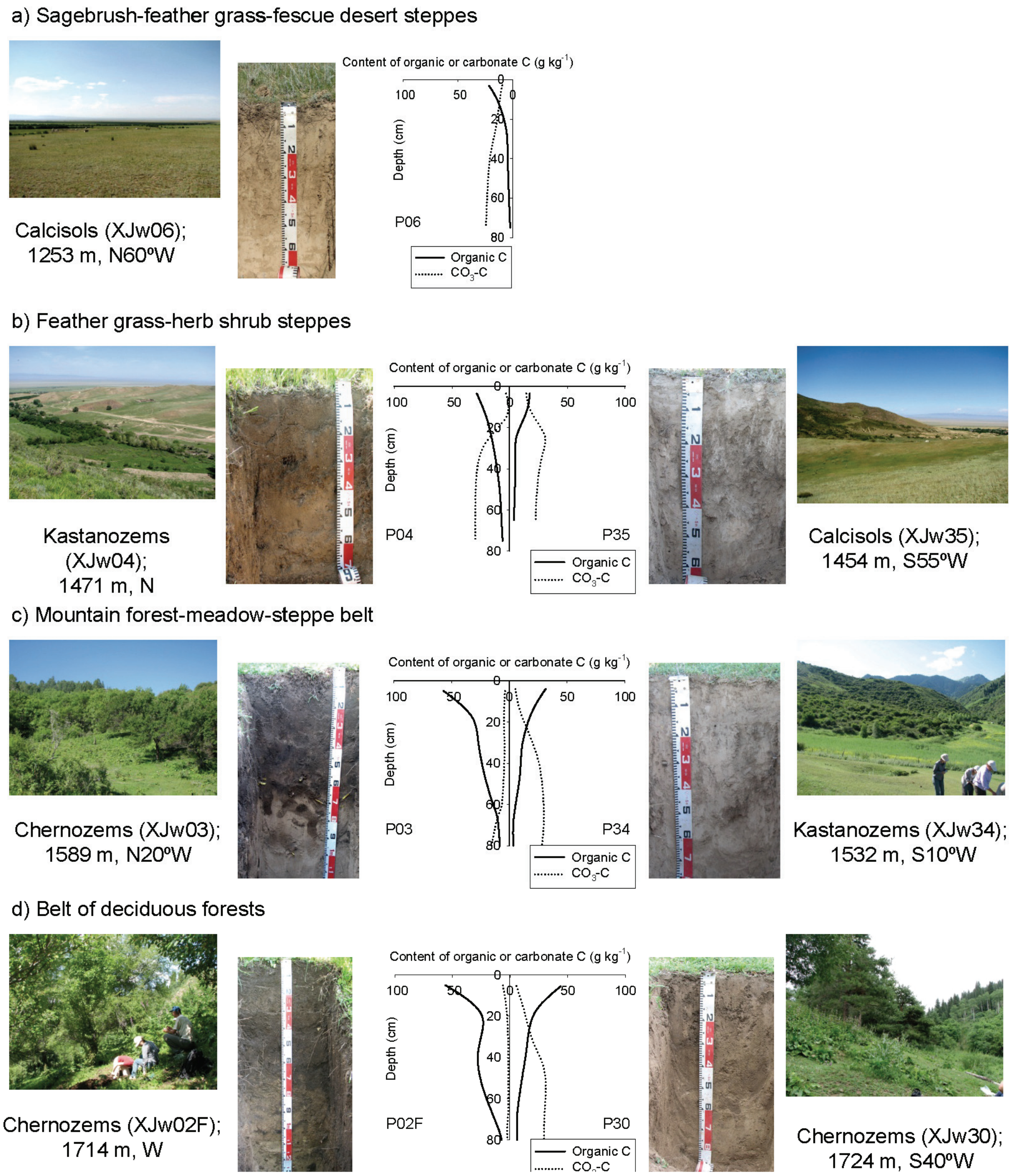

Figure 2. Landscape and soil profiles with vertical zonality in Ketmen Range (XJw).

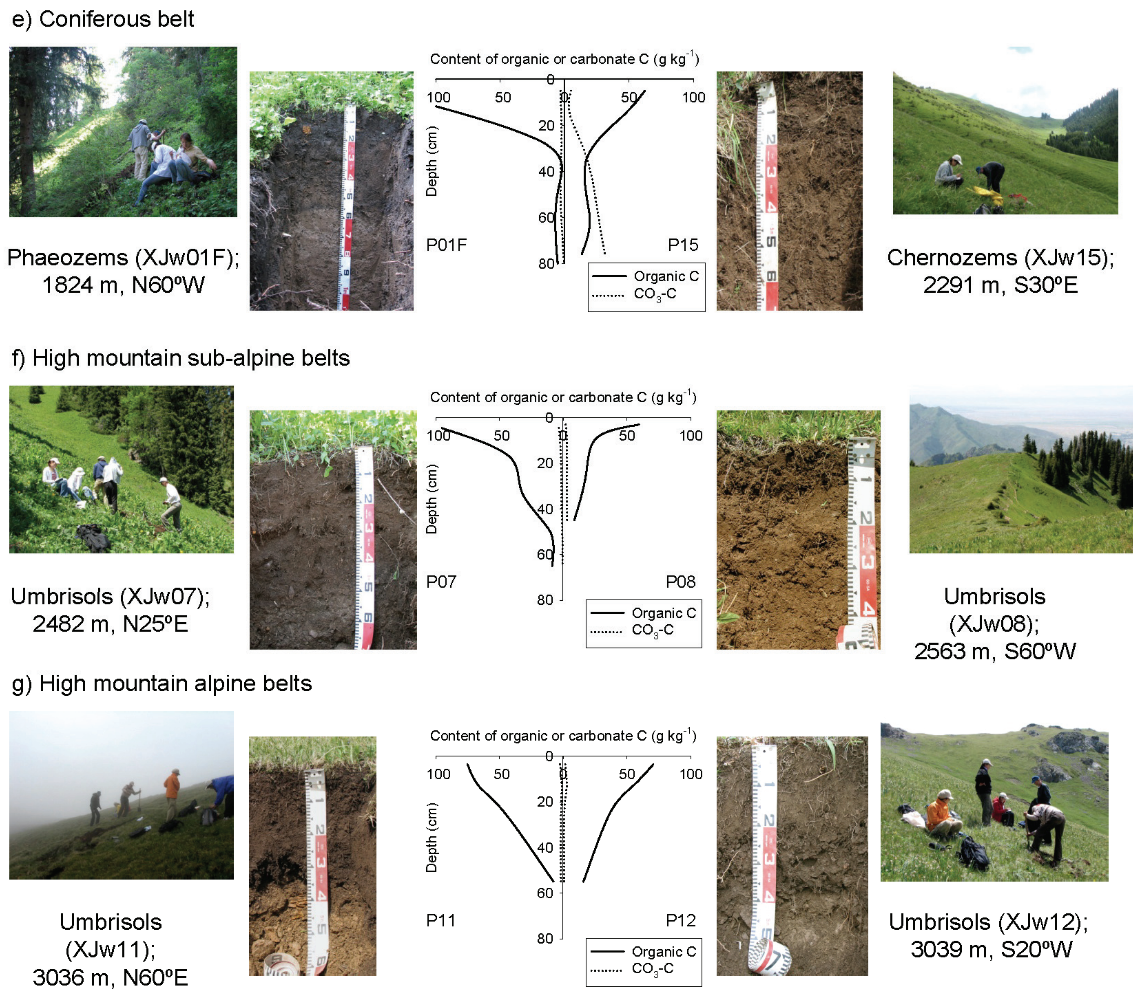

Figure 2. Landscape and soil profiles with vertical zonality in Ketmen Range (XJw). (Continued)

north-oriented slopes. Among the soils, Chernozems, Phaeozems and Umbrisols on the north-oriented slopes were often covered with broad-leaved or coniferous forest.

Figures 3 and 4 represent pH (H_2O) in upper 20-cm layers of soil and the organic and inorganic carbon stocks in upper 30-cm layers of soil at each of the plots, respectively. In the XJw region, soils at higher elevations were apparently affected by an increase of precipitation or a decrease of evapo-transpiration along with temperature decrease, and hence had lower pH and higher contents of organic matter as well as decreasing contents of carbo-nate carbon. The following relation-

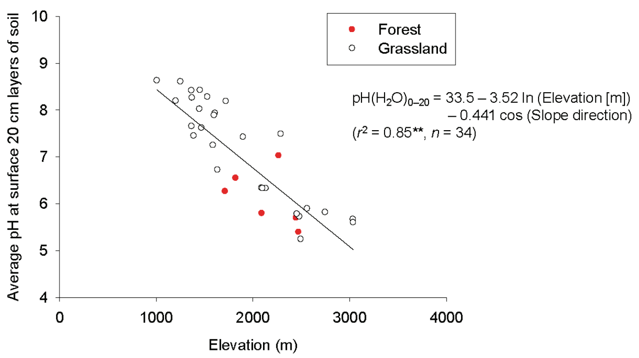

Figure 3. Relationship between elevation and surface soil pH in soils from Ketmen Range (XJw).

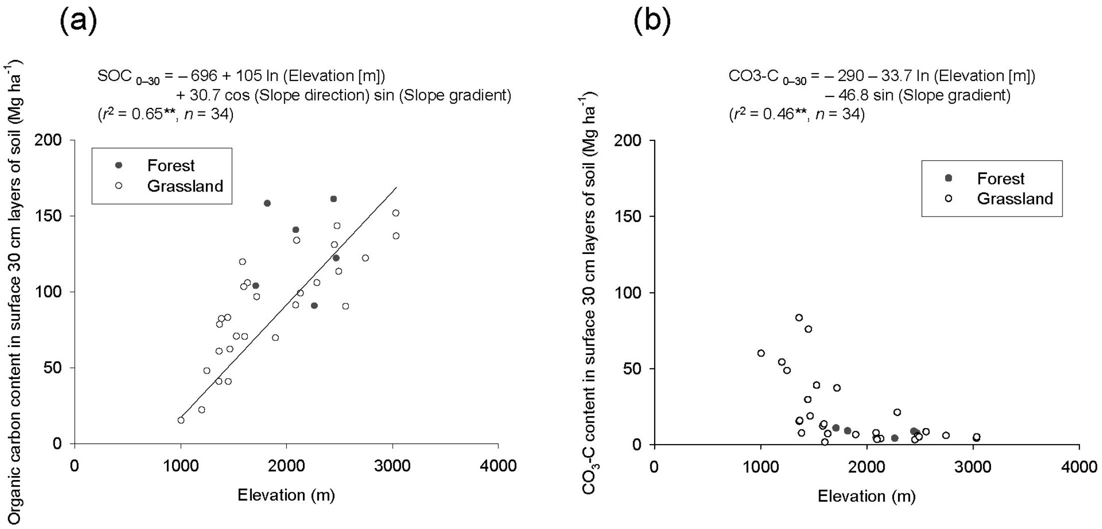

Figure 4. Relationship between elevation and (a) organic and (b) inorganic carbon contents in 30 cm layer of soil surface from Ketmen Range (XJw).

ships were obtained using multiple stepwise regression (n = 34, p < 0.15) for determining soil pH, soil organic carbon (SOC) and carbonate carbon (CO3-C) in the surface layers of soil:

pH (H_2O)0–20 = 33.5 – 3.52 ln (elevation [m]) – 0.441 cos (slope direction) (r2 = 0.85**)
SOC0–30 (Mg ha–1) = – 696 + 105 ln (elevation [m]) + 30.7 cos (slope direction) sin (slope gradient) (r2 = 0.65**)
CO3-C0–30 (Mg ha–1) = – 290 – 33.7 ln (elevation [m]) – 46.8 sin (slope gradient) (r2 = 0.46**)

where slope direction changes from N (0º) to N (360º) via E (90º), S (180º), and W (270º) as a numerical parameter. Thus a larger part of variations for these soil parameters could be explained by environmental factors relating to elevation or slope direction. The remaining variance is probably caused by soil texture; i.e., contents of the fine mechanical fractions of soils.

3.2. Comparison of distribution patterns of soils and vegetation in different regions of the Tienshan and Altai Mountains

Figures 5 and 6 show landscape and soil profiles at different surveyed plots in the Tienshan (except for XJw region) and Altai Mountains, respectively. Figures 7 and 8 give the relationship between elevation and surface soil pH (average of 0–20 cm layers of soil) in each of the study regions of the Tienshan and Altai Mountains, respectively. Distribution patterns of soils and vegetation in each of the

Table 2. Quantity of reference soil groups (RSG)* in each of the study regions.

Rigion	Number of samples						
	Cambisols (CM) and Leptsols (LP)	Calcisols (CL)	Kastanozems (KS)	Chernozems (CH)	Pheozems (PH)	Luvisols (LV)	Umbr (U
Tienshan Mountain							
West Tienshan (WT)	11	5	3	0	2	10	0
Transili-Aratau (ZA)	1	2	2	3	2	0	5
Ketmen range (XJw)	2	5	5	5	6	0	11
Kuyton region (XJe)	5	6	10	0	2	0	0
Altai Mountain							
West Altai (Aw)	1	0	1	1	0	7	2
Katon Karagay (Am)	5	1	3	2	6	0	1
Altay region (Ae)	4	6	3	0	8	0	0
Total	29	25	27	11	26	17	1[illegible]

* Classified according to World Reference Base for soil resources (WRB) (2006).

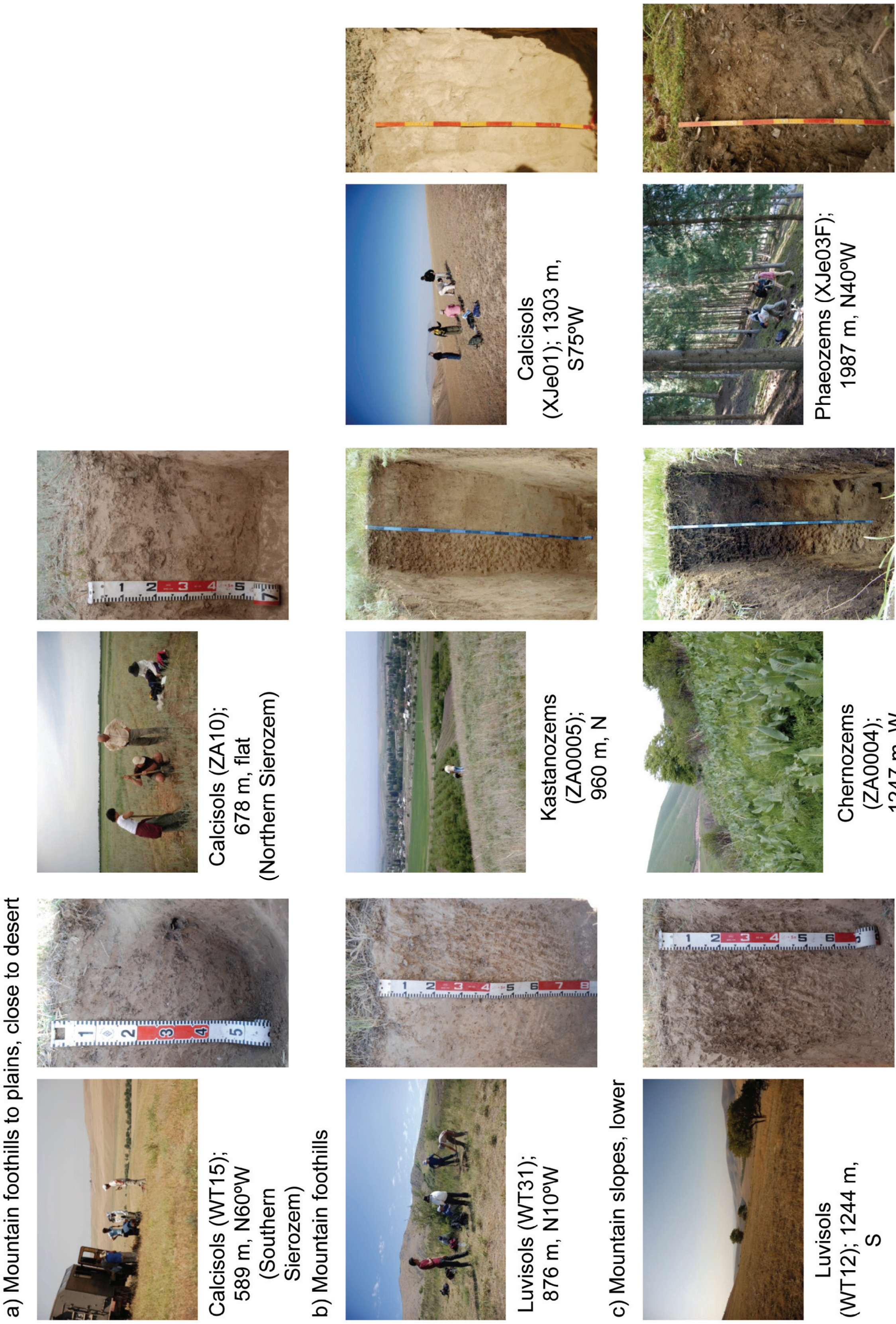

Figure 5. Landscape and soil profiles in the study plots of Tienshan Mountains.

Figure 5. Landscape and soil profiles in the study plots of Tienshan Mountains. (Continued)

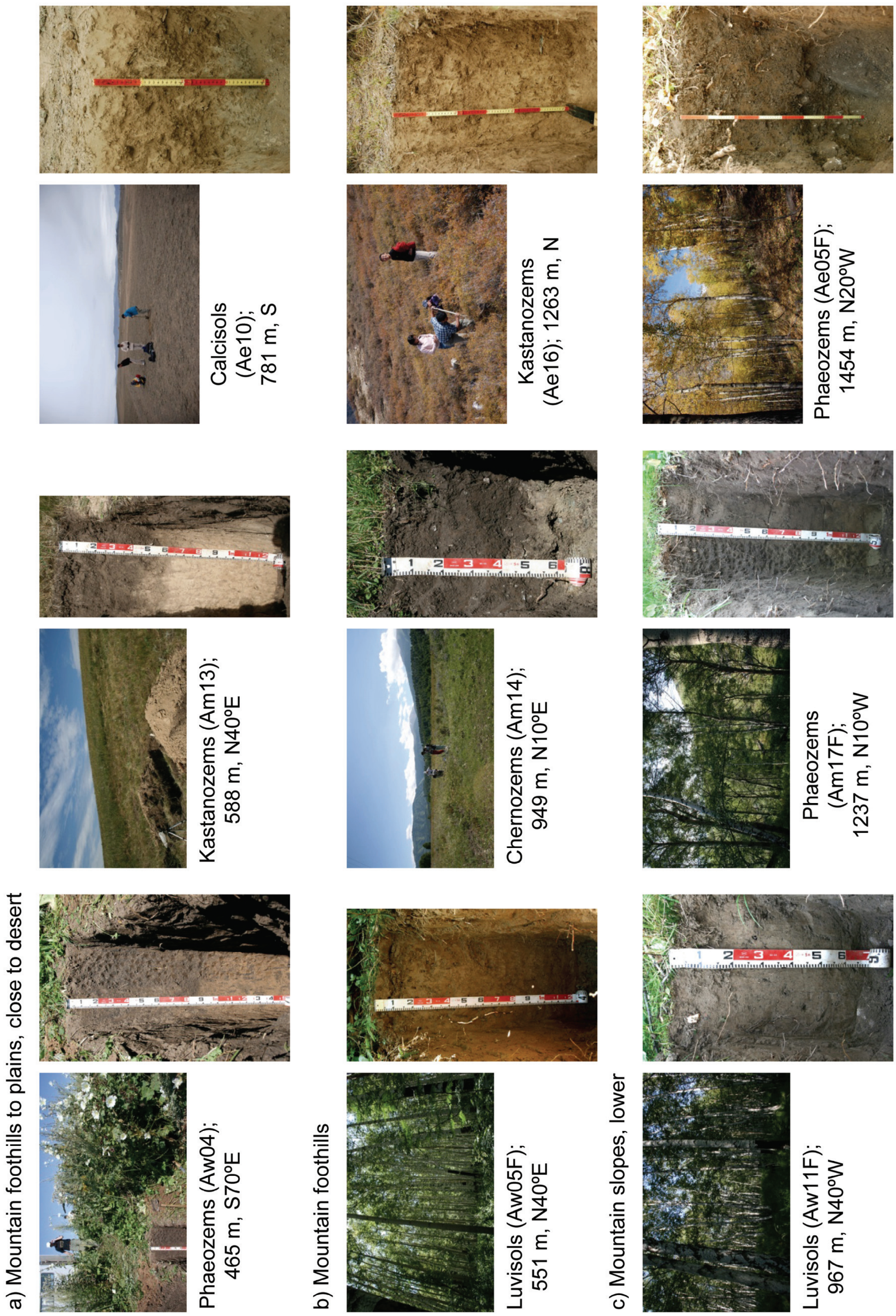

Figure 6. Landscape and soil profiles in the study plots of Altai Mountains.

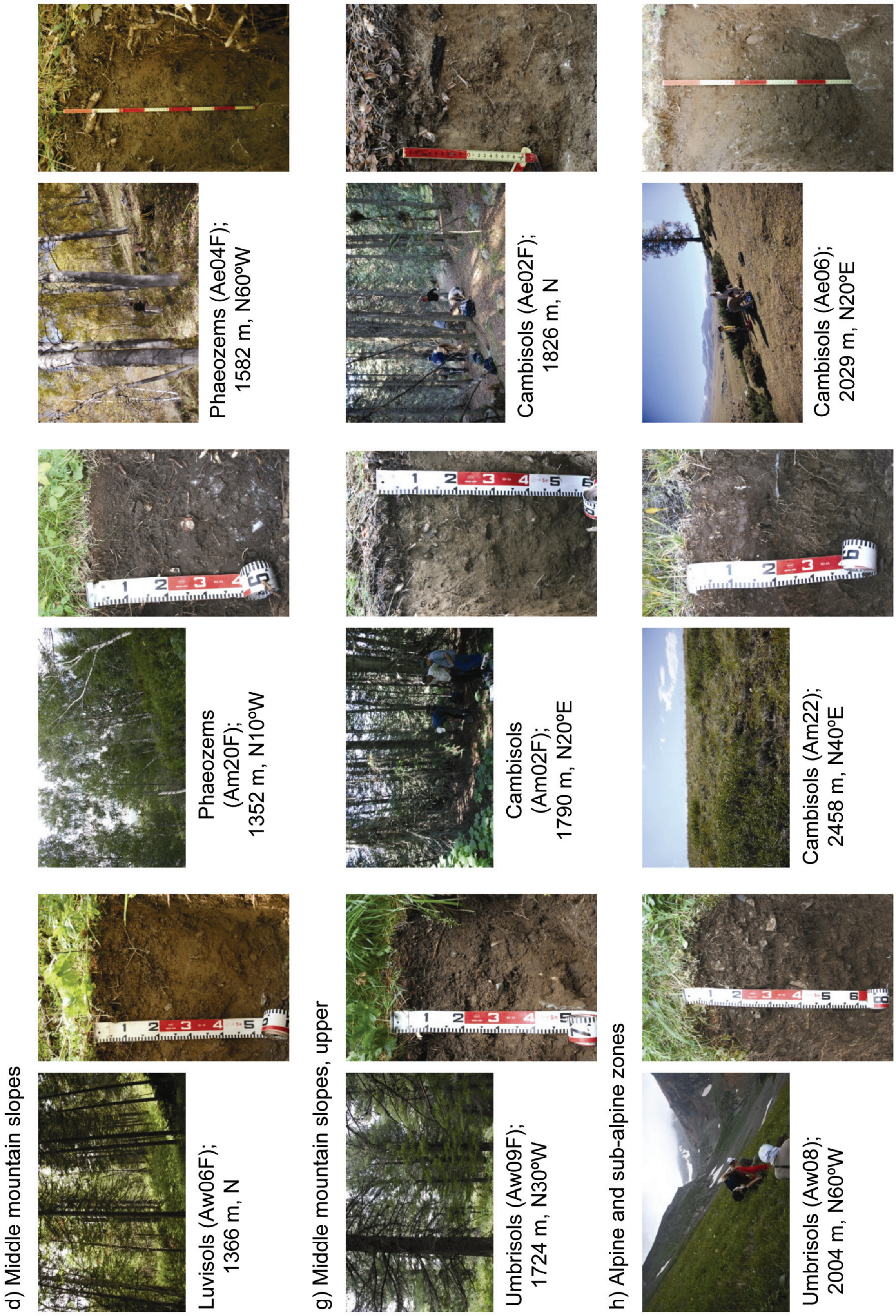

Figure 6. Landscape and soil profiles in the study plots of Altai Mountains. (Continued)

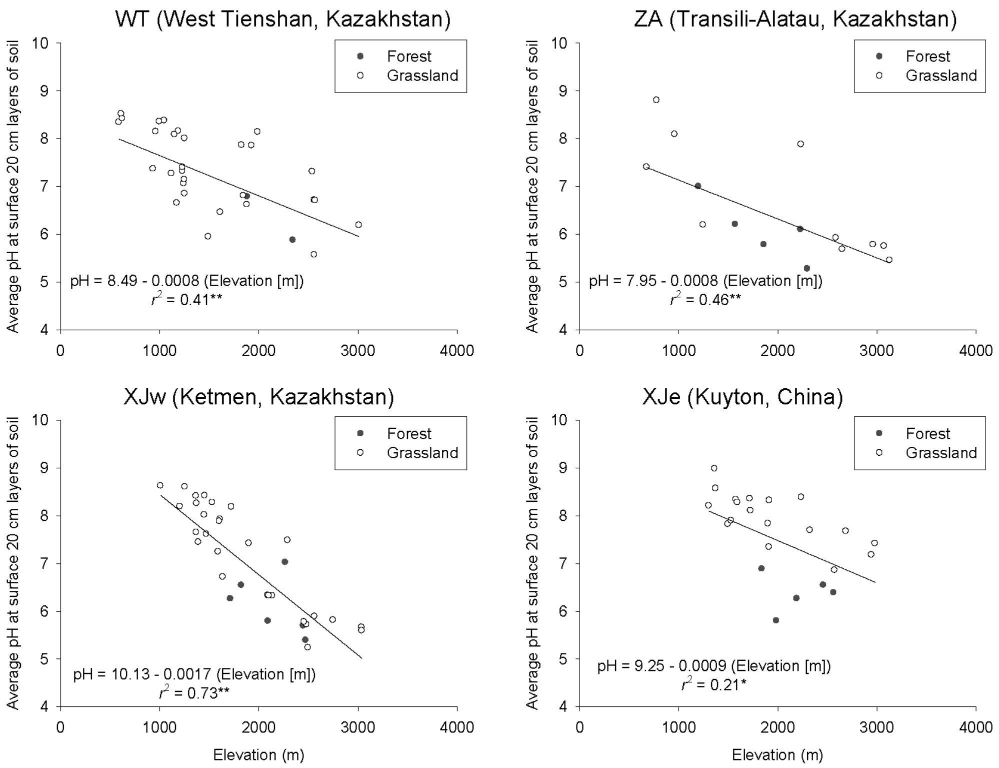

Figure 7. Relationship between elevation and surface soil pH in each of the study regions of the Tienshan Mountains.

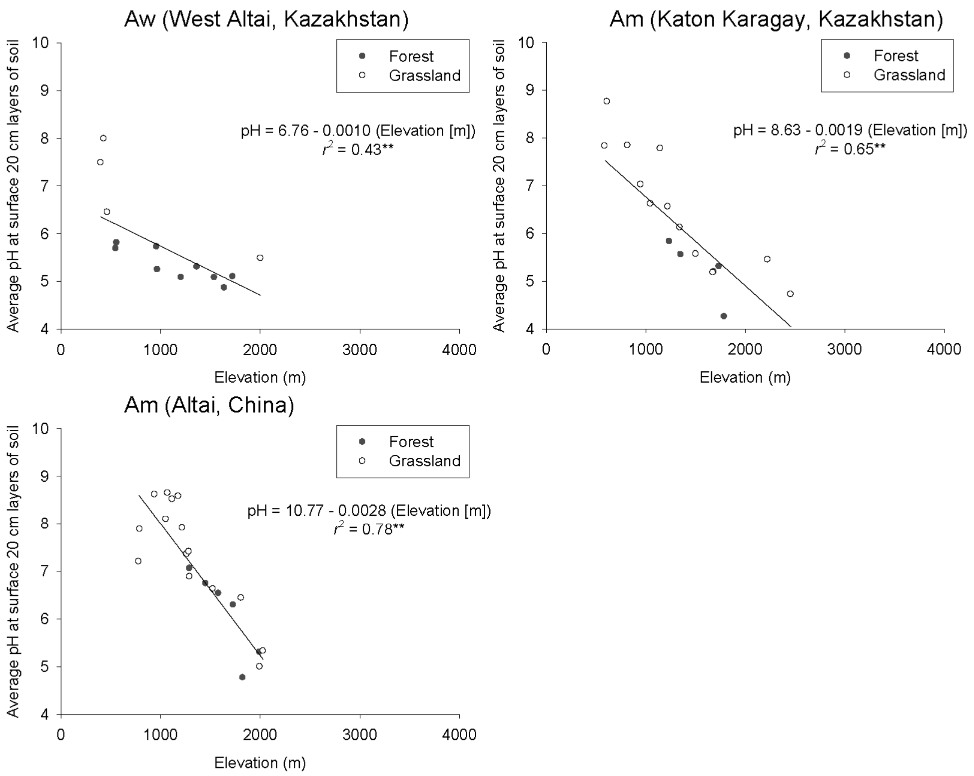

Figure 8. Relationship between elevation and surface soil pH in each of the study regions of the Altai Mountains.

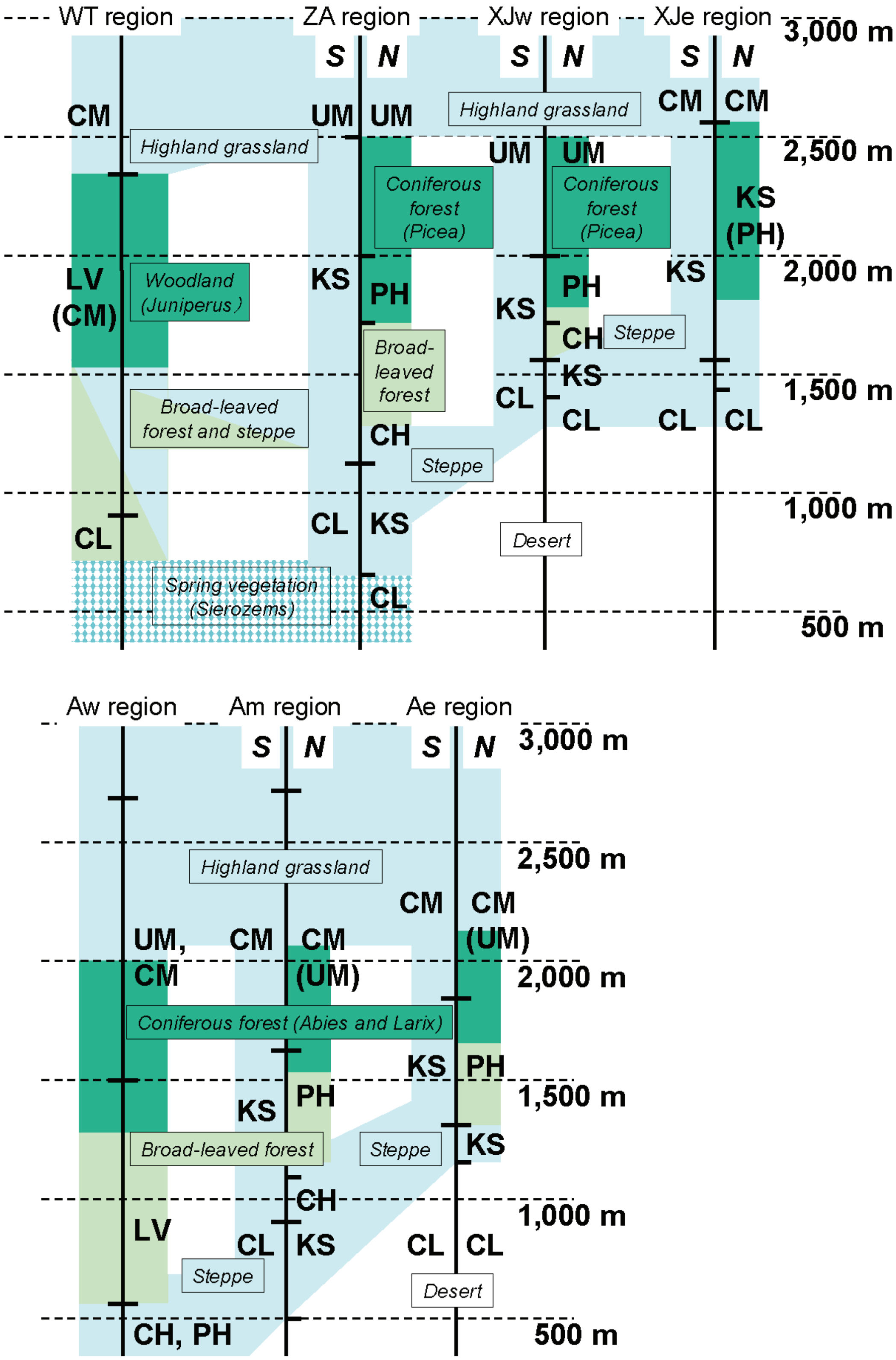

Figure 9. Distribution patterns of soils and vegetation in northern foothills of Tienshan (upper) and Altai (lower) Mountains.

egions are summarized in Table 2 and Figure 9.

XJe region (Chinese Tienshan). As shown earlier, forest vegetation was observed on the north-oriented slopes of the middle elevation range in the XJw region. Such forest covers, however, noticeably decreased in Chinese Tienshan (i.e., the XJe region). There was no deciduous forest and only limited conifers (Picea sp.) distributed scarcely on north-oriented slopes. More intensive human activities in Chinese Xinjiang, compared to southern Kazakhstan, may have accelerated forest degradation. At the same time, as shown in Figure 7, surface soil pH in the middle to high mountain ranges was considerably higher in XJe than in the remaining regions of the Tienshan Mountains, suggesting that a drier climatic condition might have been the influence for fewer forest vegetation there. As summarized in Figure 9, Kastanozems with thin mollic horizons and shallow carbonate layers were the only dark-colored soils in XJe and no Chernozems were observed, probably due to lower water availability. In addition, Northern Sierozem (Soviet classification) associated with spring ephemeral vegetation was almost lacking. Thus it could be easy to suppose a drier moisture condition in Chinese Tienshan compared to western parts of the Tienshan Mountains.

ZA region (Transili Alatau). Compared to the case of XJw, the border of steppe vegetation and desert is lower in ZA. At the same time, the distribution of broad-leaved forest shifted to lower elevation. The dark-colored soils with mollic horizons start from 700 m above sea level and expand to high mountains. Since the Junggar-Alatau Mountain which borders the Taldy Kurgan City also gives a similar vertical zonation (but each border shifts approximately lower down by 200 m) (data not shown), the bottom of Ili basin, i.e., the low elevation area of XJw, is considered to be affected with a Föhn phenomenon.

WT region. The Karatau Mountain, which stretches from southeast to northwest as a junction of the Tienshan Mountains, separates a warmer climate of southern Kazakhstan from the colder one of the Ili and Shu watersheds. In West Tienshan, the southwestern part of the Tienshan Mountains after the Karatau junction, the dark-colored soils such as Kastanozems of the steppe or Phaeozems of the spruce forest almost disappear; instead, sparse savanna-like vegetation dominated by Juniperus spp. was observed on Luvisols, which were characterized by clay translocation in a soil profile. The presence of a hot and dry summer may interfere with the domination of forest vegetation as well as the formation of a dark-colored mollic horizon. The differentiation of soils and landscape between north- and south-oriented slopes was poor in this region. Even in the bottom plains of the mountain foothills, clay formation and profile development of soils were obvious on Southern Sierozem (Soviet classification), which can be an indication of potentially high productivity. In addition, the presence of spring ephemeral vegetation on Sierozems (Calcisols) in northern foothills in the western half of Tienshan (WT, ZA and XJw regions in Kazakh territory) should be emphasized from the viewpoint of potential advantage for livestock production.

Ae region. Because of high latitude with low temperature, the upper limit of forest vegetation was lowered to approximately 2,000 m above sea level in the southwestern Altai Mountains. Since the Junggar basin had arid climatic conditions, lower foothills close to Altay City in Chinese Xinjiang were occupied by desert vegetation and Calcisols. Above 1,200 m, shrub-like vegetation dominated on Kastanozems. In mountain hill slopes, short transitional zones of deciduous broad-leaved forest, dominated by Populus or Betula spp. (approximately 1,400 m above sea level), were soon replaced by coniferous forest (Abies and Larix spp.) in the high mountains. In the high mountains of Altai, dominant soils were Cambisols on highland grassland vegetation, instead of Umbrisols in the Tienshan Mountains, presumably because of lower net primary production due to the short period of summer.

Am region. This region seemed to be a transitional one, distributed around Katon Karagai Valley, northeastern Kazakhstan. The zonal soil on plains was Kastanozems and distribution of dark-colored soils such as Kastanozems, Chernozems, and Phaeozems extended from the plains to the middle mountains, by approximately 1,600 m above sea level, which corresponded to the distribution of deciduous broad-leaved forests. Then at higher elevations coniferous forests composed of Abies or Picea spp. dominated on Cambisols, followed by highland grassland.

Aw region. The zonal soil on the plains in this latitude was Kastanozems in the Kazakhstan territory, whereas it was Calcisols in Chinese Altai. In the Aw region, it is notable that the forest vegetation dominated by broad-leaved species started from 500 to 600 m above sea level and the soils which were dominant were Luvisols. In the lower half of the forest zone deciduous broad-leaved forest dominated, whereas in the upper half coniferous species were dominant. Major soils shifted from Luvisols to Cambisols along with increase of elevation. Highland grassland was seen in the area above 2,000 m. In the Altai Mountains a conspicuous difference between western and eastern regions was mainly observed in low-elevation areas; i.e., all the borders between desert and steppe, steppe and forest zones, and deciduous broad-leaved and coniferous forests shifted to higher elevations due to wet to dry climatic transition from west to east. The difference among the slopes between elevation and surface soil pH in each of the regions was consistent with the transition of landscapes described above.

As summarized in Table 2, it is remarkable that Luvisols were observed above the Kastanozems or Chernozems zones only in both the most western regions, i.e., WT of Tienshan and Aw of Altai Mountains. In the eastern regions, Phaeozems dominated instead of Luvisols next to Kastanozems or Chernozems.

3.3. Simulating distribution patterns of soils and vegetation using environmental parameters as secondary dataset

In order to discuss the relationship between soil occurrence or vegetation type and climatic conditions, climatic data such as temperature and precipitation is indispensable; however, it is usually difficult to collect such data in mountainous regions. Therefore, we tried to establish equations to estimate the mean annual temperature and annual precipitation in the study regions using the available secondary dataset. Actual data of mean annual temperature and annual precipitation were collected from the database prepared by the Global Historical Climatology Network. In total, respec-

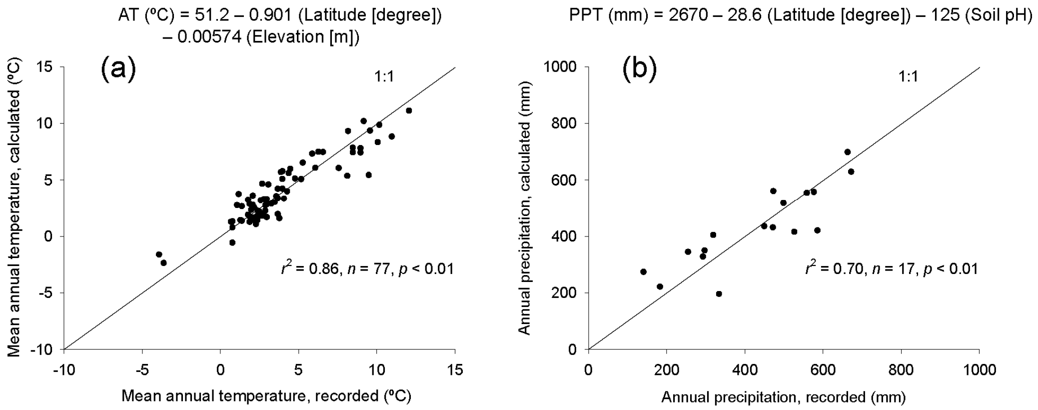

Figure 10. Comparison of (a) mean annual temperature (AT) and (b) annual precipitation (PPT) recorded at meteorological stations and those calculated using secondary parameters.

tively 77 and 17 datasets were available for estimation of mean annual temperature and annual precipitation (Appendix 1).

As shown in Figure 10a, it is possible to estimate mean annual temperature (AT) accurately using the latitude and elevation data of the stations:

AT = 51.2 – 0.901 (Latitude [degree]) – 0.00574 (elevation [m]) (n = 77, r2 = 0.86**)

Compared to the case of the estimation of air temperature, annual precipitation was not simply correlated with location data. As introduced in the earlier section, soil pH was considered to be a function of degree of leaching, if mineralogical composition of soils is similar. Using this idea, annual precipitation (PPT) could be estimated using both the location data and soil pH determined near the meteorological stations as follows (see Figure 10b):

PPT = 2670 – 28.6 (Latitude [degree]) – 125 (Soil pH) (n = 17, r2 = 0.70**)

Although it should be validated more strictly using more numbers from the database, we used this relationship to estimate climatic conditions of our surveyed plots.

Based on these equations, climatic conditions for respective soil groups were analyzed and presented in Figure 11 in terms of regions (a), reference soil groups (b), and vegetation (c). As shown

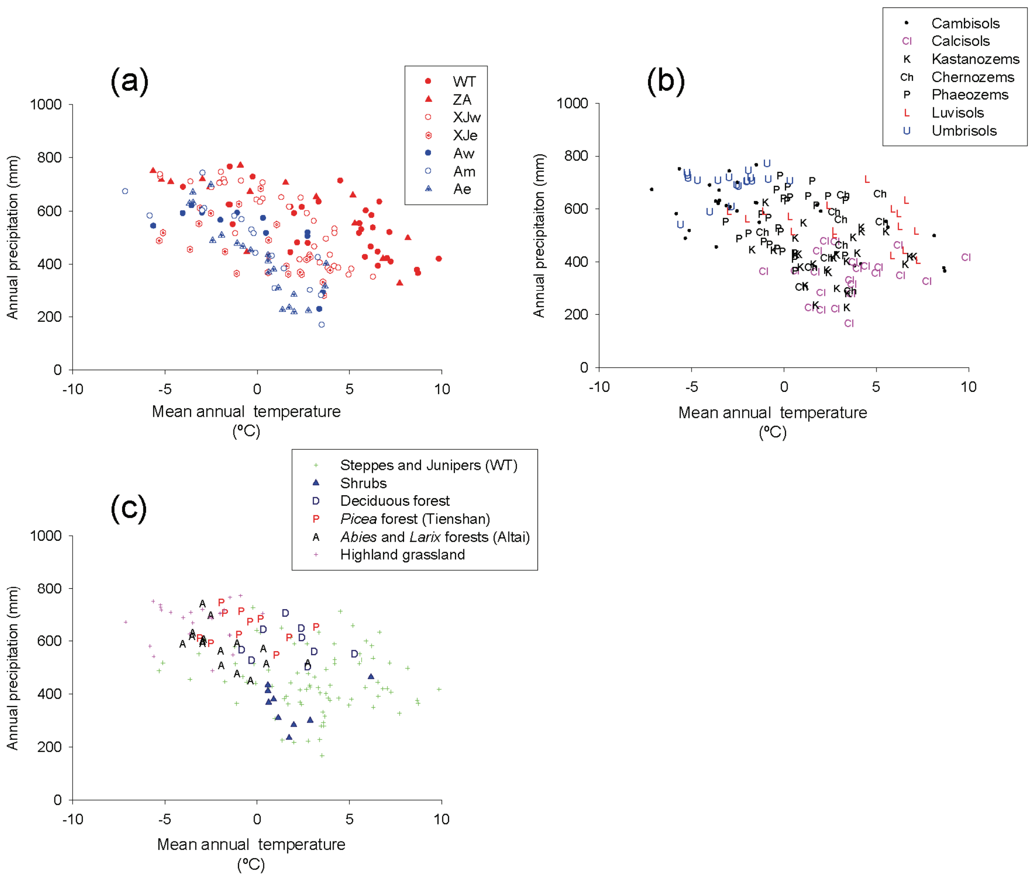

Figure 11. Distribution patterns of (a) sampling plots, (b) respective soil groups and (c) vegetation in terms of climatic conditions.

in Figure 11a, our plots in the Altai Mountains were generally situated for climates with lower temperature and precipitation than those in the Tienshan Mountains, except for those from the easternmost region, XJe. According to Figure 11b, the driest soil was Calcisols, which was estimated to be distributed in a dry region with precipitation below 400 mm, whereas the dampest soil was Umbrisols, which occurred under cool moist conditions with annual precipitation and average air temperature of above 600 mm and below 0ºC, respectively. The dark-colored soils with mollic horizons, such as Kastanozems, Chernozems, and Phaeozems, were distributed in a rather narrow range of climatic conditions. Luvisols occurred in two different zones; the first was in the cold regions with mean annual temperature around zero and the second was in the warmer regions above the high-temperature limit of dark-colored soils. According to Figure 11c, in drier regions, some small shrub-like vegetation occurred on the dry limit of steppes. Deciduous forests appeared to prefer more wet and warm conditions than coniferous species. Among the coniferous species, Picea sp. distributed in more humid regions than Abies sp.

Although the climate estimation is still tentative, this approach should give us valuable information relating to distribution patterns of soils and vegetation. As mentioned in the introduction, the following two possibilities based on the regional mapping of soils and vegetation derived primarily from the climatic dataset can be realized:

1) If the information on past climates is available, maps for spatial distribution of possible soils and vegetation in that time can be described using GIS technique; and

2) By combining with carbon dynamics models, the environmental history of carbon dynamics as well as its future changes due to human activities can be simulated.

4. Conclusions

In each of the study regions, both common and different types of distribution patterns of soils and vegetation were observed:

1) As elevation increased, soil-forming environments commonly shifted from dry to moist or more leaching conditions.

2) However, the degree of such transition and the consequent occurrences of respective soil groups or vegetation were specific for each of the regions.

Soil pH commonly exhibited a decreasing trend with elevation due to increasing precipitation as well as decreasing temperature (and hence evapotranspiration). It could be a good indicator of climatic conditions relating to the water balance. In both the Tienshan and Altai Mountains, a west-to-east transition toward drier moisture conditions was clearly observed.

The trial for estimating climatic conditions in the mountains using secondary dataset successfully gave the following equations:

$$\text{AT (ºC)} = 51.2 - 0.901(\text{Latitude [degree]}) - 0.00574(\text{Elevation [m]})$$

$$\text{PPT (mm)} = 2670 - 28.6(\text{Latitude [degree]}) - 125(\text{Soil pH})$$

Using these equations, relationships between climatic conditions and distribution patterns of soils and vegetation could be well described. Based on these results, the regional mapping of soils and vegetation derived primarily from climatic dataset were realized.

References

Forest Department of Xinjiang and Altay(2004): Two-river source comprehensive scientific investigation of Altay Mountains in Xinjiang (in Chinese). pp. 273. Xinjiang Publisher for Science and Technology.

ISSS-ISRIC-FAO(1998): World Reference Base for Soil Resources. *World Soil Resources Reports* 84. Food and Agriculture Organization of the United Nations, Rome.

ISSS-ISRIC-FAO(2006): World Reference Base for Soil Resources 2006 – A framework for international classification, correlation and communication. *World Soil Resources Reports* 103. Food and Agriculture Organization of the United Nations, Rome.

Soil Survey Staff (2006): Keys to soil taxonomy, tenth edition. U.S. Government Printing Office, WA.

Appendix 1. Climatic data collected from the Global Historical Climatology Network1).

Station name	Latitude (degree)	Longitude (degree)	Elevation (m)	Air temperature (°C)	Precipitation (mm)	Soil pH[2]
Chimkent	42.30	69.59	506		528	8.34
Blinkovo	42.23	70.09	1105		673	6.65
Jabagly[3]	42.47	70.58	1317	9.5	474	7.15
Dzambul	42.85	71.30	665	11.0		
Talas	42.52	72.20	1211		320	8.38
Frunze	42.83	74.50	756	10.1		
Tokmak	42.83	75.20	776		453	
Turkestan	43.27	68.20	201	12.1		
Chulak Kurgan	43.77	69.09	514		173	
Ujuk	43.78	70.90	369		220	
Novotroick	43.70	73.70	452		300	
Alma-ata	43.23	76.90	846	8.5	587	8.09
Turgen[3]	43.33	77.62	1194	8.2	560	7.00
Yining	43.95	81.30	663	8.5	260	
Bayanbulak	43.03	84.10	2459	–3.9		
Urmuqi	43.78	87.60	753	6.3	256	8.57
Kzyl-orda	44.77	65.50	126	9.2		
Tasty	44.80	69.09	179	10.2		
Ulanbel'	44.80	71.00	266	9.6		8.62
Ili, Railway station	44.10	77.40	672		267	
Panfilov	44.17	80.00	635	9.0		
Jinghe	44.62	82.90	303	8.2		
Qitai	44.02	89.50	745	5.9		
Ushtobe	45.17	78.00	459		254	
Taldy Kurgan	45.02	78.30	562		387	
Karamay	45.60	84.80	479	9.0		
Baytik Shan	45.37	90.50	1495	2.7		
Betpak-dala	46.03	70.20	327		142	8.62
Balhas	46.90	75.00	430	5.3		
Uc-Aral	46.17	80.90	381	6.6		
Bahty	46.65	82.70	437		276	
Tacheng	46.73	83.00	539	7.6		
Hoboksar	46.78	85.70	1309	3.8	139	
Hoboksar2	46.63	86.18	1269	3.7		
Fuyun	46.98	89.50	820	3.7	190	
Baitag	46.12	91.60	1205	2.1		
Bulgan Hovd	46.10	91.60	1195	1.9		
Karsakpaj	47.83	66.70	415	4.0		
Dzezkazgan	47.80	67.70	368	6.1		
Mointy	47.20	73.30	627	4.8	169	
Urdzar	47.12	81.59	498		455	
Zajsan	47.47	84.90	591	4.0		
Kaba-he	47.88	86.20	437	4.4		
Altay	47.73	88.00	701	4.0	184	8.65
Fuyun2	47.03	89.60	1070	2.9		
Kzyl-zar	48.30	69.59	355	3.9		
Barshatas	48.17	78.40	672	4.3		
Kokpekty	48.75	82.30	624	1.2	320	8.76
Buran	48.00	85.20	407		191	

[1] Data source: http://www.worldclimate.com/

[2] Data were obtained from former studies by the authors.

[3] Data were collected from former studies by the authors.

[4] Data was cited from Forest Department of Xinjiang and Altay (2004).

Appendix 1. Climatic data collected from the Global Historical Climatology Network1). (Continued)

Station name	Latitude (degree)	Longitude (degree)	Elevation (m)	Air temperature (°C)	Precipitation (mm)	Soil pH[2)]
Kaba he-2	48.05	86.30	503	5.2		
Altay, mountain[4)]	48.05	88.08	1800	–3.6	664	4.77
Turgaj	49.63	63.50	96	4.5	204	
Karaganda	49.80	73.09	540	2.8	298	
Karaganda2	49.80	73.13	538	3.0		
Karkaralonsk	49.42	75.50	845		326	
Bol'soe Narymskoe	49.20	84.50	393	2.7		7.83
Katon Karagay	49.13	85.60	1053		451	6.62
Kara-tyurek	49.98	86.40	1955		578	5.45
Semijarka	50.87	78.30	144		226	
Semiparatinsk	50.35	80.20	224	3.1	264	
Ust' Kamenogorsk	50.03	82.50	284		473	6.45
Leninogorsk	50.33	83.55	809	1.9	500	5.69
Ust-kan	50.92	84.70	1037	0.8		
Onguday	50.73	86.10	832	0.8	380	
Atbasar	51.82	68.30	315	1.1		
Shortandy[3)]	51.59	71.05	392	2.2	335	7.97
Celinograd	51.13	71.30	340	1.8	288	
Rubcovsk	51.50	81.20	217	2.1		
Krasnoshchekovo	51.67	82.70	236	4.1		
Zmeinogorsk	51.15	82.20	410	3.0	643	
Pavlodar	52.28	76.90	103	3.6		
Kljuci	52.25	79.09	142	3.7		
Rodino	52.50	80.20	161	3.5		
Volciha	52.02	80.30	208	2.6		
Alejskaja	52.52	82.70	180	3.3		
Kustanaj	53.22	63.60	166	2.0	298	6.37
Kokchetav	53.28	69.30	278	2.0	294	6.53
Russkaya Polyana Kaza	53.78	73.80	128	2.8		
Irtyssk	53.35	75.40	92	1.4		
Mihajlovka	53.82	76.50	103		321	
Karasuk	53.70	78.00	107	2.4		
Slavgorad	53.97	78.59	115	2.8	300	
Krasnoozersk	53.97	79.20	128	1.8		
Rebriha	53.07	82.30	214	2.5		
Shelabolikha	53.40	82.60	153	2.9		
Zverinogolovskaja	54.47	64.80	84	3.0		
Blagovescenskoe	54.37	67.00	147	2.4		
Petropavlovsk	54.83	69.09	93	0.8		
Isilkul	54.90	71.20	125	2.3		
Poltavka	54.37	71.70	117	2.4		
Borisovskij zerno	54.62	72.50	106	2.2		
Odesskoe	54.20	72.90	119	1.9		
Omsk	54.93	73.40	86	0.7	336	
Cerlak	54.17	74.80	110	2.4		
Kupino	54.37	77.20	105	2.1	318	
Zdvinsk	54.70	78.59	105	1.4		
Kocki	54.30	80.50	157	1.3		
Ordynskoe	54.37	81.90	123	2.0		