Chapter 16
Using the Innovative Lysimeter Technology in the German–Russian Research Project "KULUNDA"

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Abstract The interdisciplinary KULUNDA project unites the efforts of German and Russian scientists to tackle the problems of soil degradation and water scarcity in the Kulunda steppe of the Russian Altai Krai. From 1954 to 1963, approximately 42 million ha of the Southern Soviet steppe, of which 6.2 million ha are located in Western Siberia, were converted into a large-scale intensive agriculture area. The affected areas are highly vulnerable to wind erosion, resulting in decreased top soils and humus contents and therefore in decreased concentrations of sequestered carbon. The assessment and management of the soil water and solute balance are of great importance for crop yield potentials and the sustainable development of the territory. In 2013, the first weighable gravitation lysimeter station in Siberia was successfully installed in Altai Krai (Russia) under Kulunda dry steppe conditions. Weighable lysimeters allow the continuous monitoring of changes in soil monolith mass. This is the precondition for calculating actual evapotranspiration (ETa—major component in the terrestrial water cycle) with high precision. Knowledge regarding the development of ETa is essential to evaluate the impact of climate change on the future water balance.

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1 Introduction

The Altai region is one of the top grain-producing regions in Russia. Its total area of cultivated land is 5.4 million ha, of which 3.5 million ha are designated for grain and leguminous crops, including maize. The gross grain yield average for the period 2006–2010 is 4.4 million tonnes per year (Safonov and Safonova 2013). From 1954 to 1963, approximately 42 million ha of the Southern Soviet steppe, of which 6.2 million ha are located in Western Siberia, were converted into a large-scale intensive agriculture area. This area was highly vulnerable to wind erosion, resulting in decreased top soils and humus content and therefore in decreased concentrations of carbon. The adversely influenced soil water and nutrient regime as well as the declining fertility resulted in a decrease in crop yields (BMBF 2011–2016; Morkovkin et al. 2013). Between 1963 and 1965, more than 1 million ha of eroded land were set aside in Altai. Between 1960 and 1970, a set of measures aimed at soil conservation were implemented, including the establishment of plantations and shelter belts, conservative tillage, soil-protecting crop rotation, crop lane placement, mulch with straw, etc. However, the problem of "black storms" (wind erosion), which was resolved in the 1960s and 1970s, is currently reappearing. "Black storms" were recorded in the Altai region in the mid-1990s and in the 2000s (Safonov and Safonova 2013).

The region is part of the Southwest Siberian Kulunda steppe lowland and located between the Central Asian steppe and the North Asian forest–steppe. In the North, the Kulunda steppe borders on the Baraba forest steppe with a vegetation mosaic composed of steppe communities and birch "kolki" (birch islets). The Western part of the Kulunda steppe borders is on the Eastern part of the Irtysh valley in Kazakhstan. The Kulunda depression is located at altitudes of 100–140 m asl. The lowland is covered by a 50–60 m thick layer of pleistocene alluvial and 0.5–10 m of eolian sediments. The soil cover on the dry steppes of Kulunda consists of chestnut soils, meadow–chestnut soils, meadow soils, solonetz, and solonchaks with different degrees of hydromorphism. The chestnut soils significantly vary in texture as a result of the ancient limnic and eolian genesis of the territory. Sandy loams (15–19 % clay, 11–20 % silt, 65–70 % sand) are predominant, and their contents of humus (2–4 %) and carbon (5–8 %) are comparatively high (Bazilevich 1959; Rudaya et al. 2012).

In the continental climate of the Kulunda steppe, there are long, cold winters with little snow and short but hot and dry summers. Due to its open position, the steppe is often affected by cold air masses from the Kara Sea, and warm and dry air masses from Kazakh and Middle Asian steppes and deserts. Thus, the temperature is highly variable: May and September often have night frost, in late snow-free autumn periods the temperature can drop to −20 °C or lower, the spring sometimes has very dry periods, and dry winds are common throughout the year. The mean annual temperature is about 0 °C, the mean temperature of January (the coldest month) is −19 °C, the absolute minimum is −47 °C, the mean temperature of July (the warmest month) is +19 °C, and the absolute maximum is +40 °C. The frostless period lasts 112–120 days per year from May 15–25 to September 10–15. The annual precipitation is about 250–450 mm, and the precipitation in April–October is about 200 mm. The duration of a stable snow cover reaches 140–150 days (from November 10–15 to April 5–10). The mean depth of the snow cover is 15 cm (absolute maximum 35–38 cm). Such a thin snow cover does not protect the soil from frost, so in winter the soil freezes at 2 m deep (and even more). The amount of global radiation is 2–3 times higher than is required for the evaporation of this amount of precipitation (Chernikova 1971).

Kulunda is situated in the Eurasian steppe zone with a prevalence of grass communities (Lavrenko 2000). Numerous salt lakes are surrounded by plant associations that include *Festuca valesiaca*, *Goniolimon speciosum*, *Koeleria gracilis*, *Artemisia spec.*, *Kochia prostrata*, and *Achnatherum splendens*. Pine forests with *Pinus sylvestris*, which spread southward from the Kulunda steppe, are the most xerophytic Siberian forests (Ermakov et al. 2000). The east of Kulunda is covered by forest–steppe with isolated stands of *Betula pendula* and *Populus spec*. This vegetation type, called “kolki”, is botanically closer to European deciduous forests than to subarctic or boreal vegetation (Nimis et al. 1994).

“KULUNDA” is 1 of 12 regional projects financially supported by the funding measure “Sustainable Land Management” (Module A) provided by the Project Management Agency (PT-DLR) on behalf of the German Federal Ministry of Education and Research (BMBF; www.kulunda.eu). It unifies the knowledge of 16 partner institutions (universities and research facilities), which are organized in 11 subprojects (SPs). These are SP0—Scientific coordination and project management, SP1—Effect of land use, land cover and climate change on soil degradation, SP2—Soil water and solute balance, SP3—Land use impact on carbon sequestration, SP4—Interaction of vegetation with changing land use and climate, SP5—Geo-database and satellite image classification, SP6—Process-based modeling of carbon cycle and impact of land use change, SP7—Agronomic and technical solutions for innovative tillage and cropping system, SP8—Assessment of farm level costs and socioeconomic requirement of providing ecosystem services, SP9—Social and institutional drivers of land use change, and SP10—Stakeholder involvement and implementation. The German partner institutions of the project are Martin-Luther-University Halle-Wittenberg (MLU), Leibniz University Hannover, Georg-August-University Goettingen, Helmholtz Centre for Environmental Research—UFZ, Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Leibniz Institute for Regional Geography (IfL), Potsdam Institute for Climate Change Impact Research (PIK), the Senckenberg Community for Natural Research; and the medium-sized enterprise Amazonen-Werke H. Dreyer GmbH & Co. KG. The Russian partner institutions are Altai State University, Altai State Agrarian University and Institute for Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences. The head of the project is Prof. Dr. Dr. h.c. Manfred Fruehauf and the scientific coordinator is Dr. M. Kasarjyan (Martin-Luther-University Halle-Wittenberg, Faculty of Natural Sciences III, Institute for Geosciences and Geography; BMBF 2011–2016).

The main goal of the interdisciplinary KULUNDA project is to mitigate degradation and desertification processes in the Southern Siberian steppe sites used for agriculture, to stimulate, and, in the long run, to enhance carbon sequestration in soils of the Kulunda steppe (Haerdle 2013). The project also aims to increase crop yields and to implement sustainable land management practices for agricultural areas and thereby to contribute to rural and regional development. The knowledge gained and the results of the KULUNDA project will largely contribute to the research on climate change, sustainable land management practices, and rural and regional development (BMBF 2011–2016).

The assessment and management of water and solute balance of soils are of great importance for crop yield potentials and sustainable development of the territory. The overall objective of SP2 is to evaluate land management practices according to their impact on the soil water and solute balance in the Kulunda steppe of Altai Krai (BMBF 2011–2016). SP2 focuses on the scientifically based improvement in the monitoring techniques and the evaluation modules for decision-making processes toward sustainable land management. The results will help to establish and use sophisticated ecosystem models, as such models are excellent tools for forecasting the impacts of climate and land use changes on water and solute balances in agricultural landscapes (Nendel 2014). They require reliable, high-resolution input data on soil hydrological processes. Precision lysimeters may provide valuable data for the calibration of such models.

The objectives of this paper are (i) to inform readers about the design and construction of a weighable lysimeter station in the Kulunda steppe and (ii) to demonstrate the accuracy of the first measurements.

2 Materials and Methods

2.1 Hypotheses of Lysimeter Research in the Kulunda Steppe

It is well known that a weighable gravitation lysimeter is a sufficient tool to measure the relevant parameters of the water balance equation with high precision. No such data exist for the dry steppe conditions of Siberia, but they are essential for the evaluation of the former development of this region. Climate change, especially, is a main driver regarding the direction of future land use. The lysimeter measuring results will help to investigate and establish sustainable land management strategies for this region. The aim is to deepen the understanding of relevant processes concerning the interaction of land degradation and climate change to quantify fluxes of water, carbon, and other relevant matters. The results serve as the basis for simulating the effects of land management on the soil and matter balance using adequate models (for example the hydrological model HYDRUS). Beyond these central questions, it is possible to gain further information depending on corresponding scientific questions: In particular, information can be gained about the functionality of lysimeter technology under extreme climatica conditions, and comparative analyses can be carried out between different crops regarding their responses to water availability between frost and dry periods or during heavy rainfall events or fast snow melting in the spring, etc.

2.2 Purpose of Lysimeters

Lysimeters are useful devices to investigate water and solute transport, as well as transformation processes, using undisturbed representative soil monoliths (Meissner et al. 2007, 2014). They represent the link between laboratory- and field-scale studies and offer the opportunity to reproduce natural conditions in model systems. The lysimeter station that was installed in the Kulunda steppe consists of two vessels, which allows comparative analyses to be carried out between arable land which was converted from grassland and unconverted (nearly pristine) grassland. The vessels are weighable, which ensures that mass changes at the study site can be monitored continuously for any time period. Thus, it is possible to calculate water fluxes between the pedosphere and the atmosphere, in particular precipitation and actual evapotranspiration (ETa). Based on the measured parameters, ETa (in mm) can be derived using the following equation:

$$\mathrm{ETa} = P - S \pm \Delta W \tag{1}$$

where

P precipitation (mm),

S amount of seepage water (mm),

ΔW change in the quantity of stored water [mm] as determined from the mass change in the lysimeter over time (1 kg ≈ 1 L/m^{-2} = 1 mm)

If the water balance is calculated correctly, the solute load (L in mg m^{-2}) can be determined with high accuracy from the following relationship:

$$L = C_s \times S \tag{2}$$

where

C_s solute concentration in the seepage water (mg L^{-1}),

S amount of seepage water (L m^{-2} = mm)

Furthermore, the lysimeter delivers reliable information regarding seepage water quantity and quality. Only lysimeters permit a direct determination of the amount of water percolating through a soil profile and of the type and amount of solutes contained in it. Hence, they allow more reliable calculation of solute loads carried toward the groundwater than any other method (Gee et al. 2009). Although those processes may be not relevant to typical steppe soils under current climates, they could emerge under an altered climate and hydrological regime. Laterally inserted probes facilitate the measurement of the soil moisture content, soil moisture tension, and soil temperature. The provision of high-resolution data allows the detailed tracking of soil moisture development at different depths. This information is also important for other project partners who are trying to develop sustainable soil tillage techniques and procedures for this region. Furthermore, it is possible to extract soil water samples at different depths in order to get precise information about the water and solute transports in representative undisturbed soil monoliths. During the first measuring period, the lysimeter investigations focus on comparing water balance parameters for soils that are or are not agriculturally used. Based on these findings, specifications can be derived regarding crop rotation, management, fertilization, irrigation, etc.

2.3 Soil Properties

In order to operate comparative analyses between arable land and soils which are not used for agriculture, the monoliths were extracted at two sites with different land uses (Table 1). Following the FAO guidelines, the soils are identified as Calcic Chernozems (FAO 2006). The first monolith consists of a 25-cm-thick humic horizon including a plowed layer at the bottom. It is followed by a crossing AC horizon that is 50 cm deep at the bottom. Beneath, there is a subsoil C-horizon composed of parent material including calcareous deposits. The grain size distribution in the upper part of the profile (0–50 cm) indicates sandy loamy silt, beneath which there is silt loam and, below 70 cm, loamy sand. The site was under intensive agricultural usage for 60 years. The second monolith consists of a 30-cm-thick humic Ah horizon, followed by a 15-cm-thick crossing AC horizon and by subsoil composed of parent material which is interspersed with calcareous deposits. The upper 30 cm consists of sandy loamy silt, below which there is silty loam underlain by loamy sand at a depth greater than 70 cm.

2.4 Lysimeter Extraction and Installation

In 2013, the two-fold containerized (Polyethylene PE-HD) lysimeter station (UGT 2014) with two weighable soil monoliths provided by the company UGT—Environmental Measurement Devices Ltd. and the Helmholtz Centre for

Table 1 Soil properties of the lysimeter extraction sites

Name/No.	Extraction site lysimeter 1			
Date	28.06.2013			
Position	N52 04.012–E79 54.526			
Altitude	138 m			
Slope/exposition	<1			
Usage	Field/wheat			
Note	Amazone test field; Poluyamki/conventional tillage			
Soil type	Calcic Chernozem			
Horizon	Ah	AC	Ckc	C
Lower boundary (cm)	25	50	70	120+
Grain size fraction	SLSi (Uls)	SLSi (Uls)	SiL (Lu)	LS (Sl4)
Name/No.	Extraction site lysimeter 2			
Date	28.6.2013			
Position	N52 03.778–E79 55.868			
Altitude	142 m			
Slope/exposition	<1			
Usage	Natural steppe vegetation			
Note	No tillage for decades			
Soil type	Calcic Chernozem			
Horizon	Ah	AC	Ckc	C
Lower boundary (cm)	30	45	70	110+
Grain size fraction	SLSi (Uls)	SiL (Lu)	LS (Sl4)	LS (Sl4)

Environmental Research—UFZ was installed at a KULUNDA project test farm in Poluyamki, in the Mikhaylovskij region of Altai Krai, under Kulunda dry steppe conditions (Fig. 1). The location was chosen because the South–Western Kulunda steppe region is most affected by soil degradation processes compared to other parts of the administrative unit Altai Krai (Paramonov et al. 2003). In addition, severe effects of global climate change should be detected to a great extent in this vulnerable region. Other lysimeter stations in different climatic subzones are envisaged to get a reliable network regarding the exact measurement of water balance parameters and the calculation of ETa.

In cooperation with German and Russian project partners, the soil monoliths (surface area of 1 m^2, 2 m depth) were extracted from both an arable land site (lysimeter 1) and a fallow site which was plowed once in the 1950s but had since then been covered with natural, nearly pristine steppe vegetation (lysimeter 2) for the lysimeter-based investigations (Fig. 2). After the extraction of the soil column, a 20-cm-thick filter layer (geotextile over fine–coarse sand over gravel) was placed at the bottom of the lysimeter vessels to minimize disturbances to the natural flux. The depths of the soil columns are greater than the natural flux plane, which under the environmental and management conditions at the extraction sites lies between 0.9 and 1.3 m below the surface. Hence, it can be assumed that seepage flow in the

Fig. 1 Installation of the PE-HD lysimeter station at the Poluyamki test farm (*photo* E. Stephan)

lysimeters is not affected before it reaches the filter layer. The composition of the filter layer was chosen to allow free drainage of seepage water. The vessels were transported to Poluyamki and positioned in the lysimeter station on load cells using a three-legged steel frame.

The lysimeter station measures mass changes with sufficiently high precision (±20 g) to enable the calculation of water fractions input (dew, rime, and the water equivalent of snow) and the rates of ETa (Meissner et al. 2014). The total mass of each lysimeter vessel is approximately 4 t (the mass changes depending on the water content of the vessel). Both lysimeter vessels are equipped at different depths (0.30, 0.50, and 1.20 m) with time domain reflectrometry stick probes to measure the soil moisture content, with combined tensiometer and temperature probes to measure the matrix potential as well as the temperature changes in the soil and with suction cups to extract the soil solution (Fig. 3). The lysimeter is specifically adapted to the cold winter conditions in Siberia by adding a ring to cut the snow on the lysimeter surface from the adjacent snow.

The measured values are consolidated and stored in a data logger with a recording interval chosen by the user. This permits a very high temporal resolution (<1 min). The amount of seepage water is measured with a tipping bucket (values are stored by the data logger) and collected in a storage container, from which water

Fig. 2 Extraction sites: the arable land with young spring wheat (*left*) and the natural steppe vegetation (*right*) (*photo* E. Stephan)

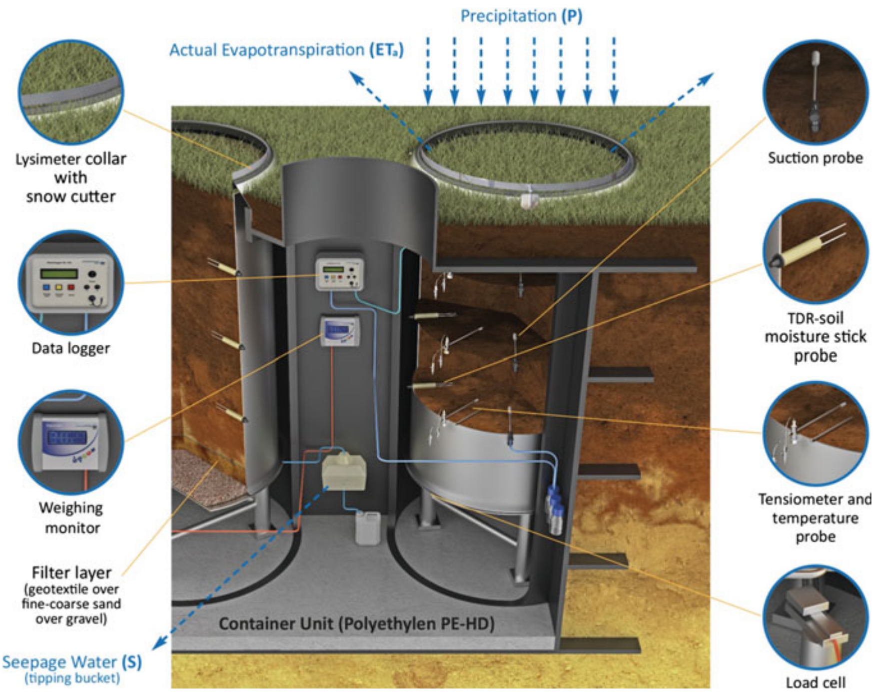

Fig. 3 Scheme of a weighable gravitation lysimeter installed at the Poluyamki site, Siberia

samples can be taken for chemical analysis. The installed computer software makes it possible to present all the parameters measured in different ways (e.g., average, minimum, maximum, or all values).

3 Results

Lysimeters are typically used to quantify rainfall, drainage, and ETa. According to the water balance equation, the changing masses (weights) represent the water storage within the soil monoliths. These changes can be displayed as positive or negative values. A mass gain in the soil monolith means precipitation; a mass reduction must be interpreted as seepage or as a release of gaseous water from plants and soil in the form of evaporation or transpiration, respectively. The rising and falling masses of the soil monoliths are thus the basis for calculating precipitation and ETa, which can be displayed as quantities in mm. The weighing precision of the presented lysimeter station allows small mass changes to be detected, even those generated by dew, fog, rime, or snow. To demonstrate the operational reliability of the lysimeter station, Fig. 4 shows the mass of the installed lysimeter recorded over a 3-day period in August 2013 based on a 1-hour measurement. There was no drainage from the lysimeters in the period mentioned. While the mass

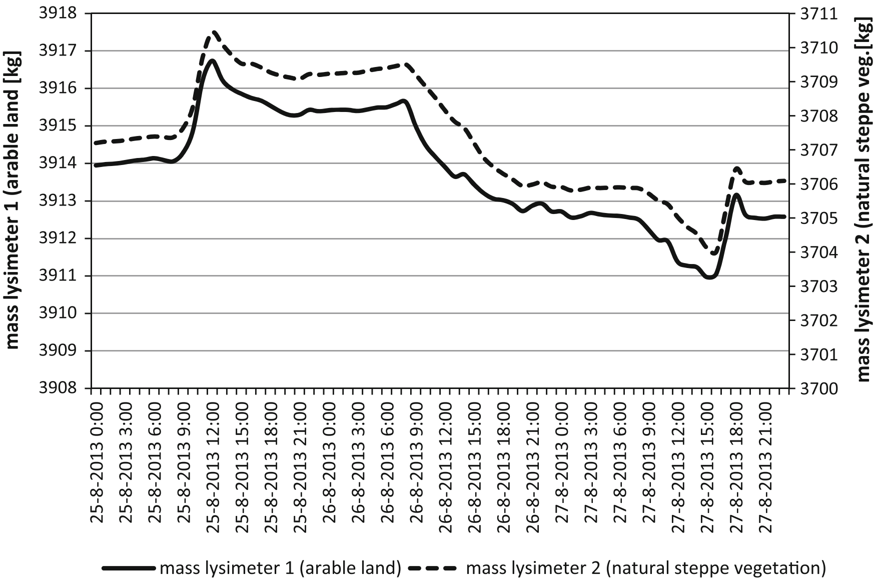

Fig. 4 Example of the diurnal mass changes of two gravitation lysimeters planted with spring wheat and a pristine plant cover

of lysimeter 1 (arable land, spring wheat) on August 25, 2013, 08:00 was 3914.1 kg, the lysimeter 2 mass (natural steppe vegetation) was 3707.4 kg.

Both soil monoliths registered a precipitation event on August 25, 2013, 08:00–12:00 resulting in mass increases about 2.7 kg (=2.7 mm; lysimeter 1) and 3.1 kg (=3.1 mm; lysimeter 2), respectively. The differences between the two monoliths are mainly based on the different vegetation covers and associated interception. Between 12:00 and 21:00, both monoliths registered a mass reduction of about 1.4 kg (=1.4 mm), which has to be interpreted as ETa. On the following day, the monolith mass decreased with the rising sun; between 08:00 and 12:00, ETas of 2.9 mm (lysimeter 1) to 3.6 mm, respectively were measured. Also on August 27, 2013, between 08:00 and 15:00 ETa values of 1.5 mm (lysimeter 1) and 1.7 mm (lysimeter 2) were determined. The precipitation event after 16:00 (lysimeter 1: 2.2 mm, lysimeter 2: 2.4 mm) stopped the ongoing ETa. From 18.00 until the end of the measuring period ETa occurred, causing small mass losses of 0.5 kg (=0.5 mm, lysimeter 1) and 0.4 kg (=0.4 mm, lysimeter 2). Considering the entire study period (August 25, 2013, 00:00–August 27, 2013, 23:00), it was seen that on lysimeter 1 ΔW was reduced by about −1.4 kg during a precipitation amount of 4.9 mm, leading to an ETa of 6.3 mm. In comparison, for lysimeter 2 a mass change in −1.6 kg and a precipitation amount of 5.5 mm were recorded, based on this data the calculated ETa was 7.1 mm (Fig. 4).

As already mentioned and demonstrated in the example earlier, the weighing precision of the lysimeter is very high. One item of interest is a detailed view for the time period between August 25, 2013, 20:00 and August 26, 2013, 08:00 for lysimeter 1 (see Fig. 4). During this time slot the mass increased by 340 g. Because no precipitation was measured and ETa stopped due to a lack of daylight (Xiao 2013), the formation of dew (amounting to 0.34 mm) must be the reason for the mass increase. This assumption is supported by measuring the relative humidity in a neighboring weather station, which increased in the late afternoon from 65 to 90 % at 23:00, remained at that level until 08:00 the next morning, and then decreased to 70 %. Regarding the amount and time-dependent occurrence of dew, this result fits well with our own measurements in Northern Germany (Meissner et al. 2007). A more detailed investigation of these phenomena will be the focus of future work. Information regarding the amount of precipitation caused by dew, fog, rime, or snow is especially important in dry areas that are prone to wind erosion because the establishment of a vegetation cover is a prerequisite for protecting the soil against further degradation.

4 Conclusions

The use of the unique weighable gravitation lysimeter station on the German–Russian KULUNDA project will enable us to carry out a thorough study of the water balance under dry steppe conditions, thus forming the basis for a highly accurate solute balance calculation and for modeling hydrological processes in the

Kulunda steppe of Altai Krai (Russia). In combination with meteorological data and soil hydrological field measuring stations, the lysimeter delivers reliable information regarding water balance input factors (precipitation, snow, etc.) and output factors (seepage water quantity and quality, changes in soil moisture at different depths, Eta, etc.). Sustainable land management practices for the Kulunda steppe will be developed to tackle the problems of soil degradation, carbon sequestration, and water scarcity.

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References

Bazilevich NI (1959) Soils of the Kastanozem Zone in the dry steppe. In: Soils of the Altai Krai. (Почвы каштановой зоны сухой степи in: Почвы Алтайского края). Academy of Sciences of the USSR, Moscow, pp 46–65 (in Russian)

BMBF (2011–2016). www.kulunda.eu. Accessed 2014/06/05

Chernikova MI (1971) Agroclimatic resources of the Altai Krai (Агроклиматические ресурсы Алтайского края) Leningrad, Gidrometeoizdat, 156 p (in Russian)

Ermakov N, Dring J, Rodwell J (2000) Classification of continental hemiboreal forests of North Asia. Braun-Blanquetia 28, Camerino 131 p

FAO (2006) World reference base for soil resources. Food And Agriculture Organization of the United Nations, Rome, pp 76–84

Gee GW, Newman BD, Green SR, Meissner R, Rupp H, Zhang ZF, Keller JM, Waugh WJ, van der Velde M, Salazar J (2009) Passive wick fluxmeters: design considerations and field applications. Water Resour Res 45:1–18

Haerdle B (2013) New life for the steppe. Science Portrait 8 (Kulunda): http://modul-a.nachhaltiges-landmanagement.de/fileadmin/user_upload/DOCUMENTS/RPs/KULUNDA/KULUNDA_SciencePortrait_2013-11-19.pdf. Accessed 2015/03/05

Lavrenko EM (2000) Steppes of the USSR. In: Selected papers (Степи СССР. In: Избранные труды) St. Petersburg, pp 11–223 (in Russian)

Meissner R, Seeger J, Rupp H, Seyfarth M, Borg H (2007) Measurement of dew, fog, and rime with a high-precision gravitation lysimeter. J Plant Nutr Soil Sci 170:335–344

Meissner R, Rupp H, Seyfarth M (2014) Advanced technologies in lysimetry. In: Mueller L, Saparov A, Lischeid G (eds) Novel measurement and assessment tools for monitoring and management of land and water resources in agricultural landscapes of Central Asia. Springer international, environmental science and engineering 2014, pp 159–173. http://link.springer.com/chapter/10.1007/978-3-319-01017-5_8. Accessed 2015/03/05

Morkovkin G, Litvinenko Y, Maksimova N (2013) Dynamics of soil cover state and degradation processes intensity in natural soil zones of the Altai Region. EURASIAN SOIL WORKSHOP 2013, "The biophysical attributes of soil quality". 29–31 May 2013, Ondokuz Mayis University, Samsun, Turkey, pp 25–29

Nendel C (2014) MONICA: a simulation model for nitrogen and carbon dynamics in agro-ecosystems. In: Mueller L, Saparov A, Lischeid G (eds) Novel measurement and assessment tools for monitoring and management of land and water resources in agricultural landscapes of Central Asia. Springer international, environmental science and engineering 2014, pp 389–405. http://link.springer.com/chapter/10.1007/978-3-319-01017-5_23. Accessed 2015/03/05

Nimis PL, Malyshev LI, Bolognini G (1994) A phytogeographic analysis of birch woodlands in the southern part of West Siberia. Plant Ecol 113(1):25–39

Paramonov E G, Ischutin JN, Simonenko A P (2003) The Kulunda Steppe. Problems of desertification (Кулундинская Степ': Проблемы опустынивания. Алтайский государственный университет). Altai State University, Barnaul, 137 p

Rudaya N, Nazarova L, Nourgaliev D, Palagushkina O, Papin D, Frolova L (2012) Mid-late Holocene environmental history of Kulunda, southern West Siberia: vegetation, climate and humans. Quatern Sci Rev 48:32–42

Safonov G, Safonova Y (2013) Economic Analysis of the impact of climate change in agriculture in Russia. http://www.oxfam.org/sites/www.oxfam.org/files/rr-economic-impacts-climate-change-agriculture-russia-010413-en.pdf. Accessed 2015/03/05

UGT (2014) Novel Lysimeter-Techniques. http://www.ugt-online.de/en/produkte/lysimetertechnik/lysimeter.html. Accessed 2015/03/05

Xiao H, Meissner R, Seeger J, Rupp H, Borg H, Zhang Y (2013) Analysis of the effect of meteorological factors on dewfall. Sci Total Environ 452–453:384–393