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Effect of sprinkler irrigation on the properties of leached chernozem and the yield of *Bromopsis inermis* Leyss. in the Southern Cis-Ural

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Abstract: The paper examines the effect of the long-term (10 years) low-intensity sprinkler irrigation on the properties of leached chernozem soils covered with *Bromopsis inermis* Leyss. (BIL) stands in the Southern Cis-Ural forest-steppe. The study analysed changes in the soil's agrophysical and chemical properties. As a result of long-term irrigation, the humus horizon (A + AB) thickness increased by 16 ± 3 cm; the organic carbon (C_{org}) content and nutrients decreased in this rooting zone, in particular, C_{org} by 0.3%, available phosphorus by 24.8 mg/kg, exchangeable potassium by 18.4 mg/kg and the stock of C_{org} by 16 t/ha. The particle size distribution of irrigated soil did not significantly changed; some changes were observed for the soil's aggregate composition. The soil's hydrophysical properties, water and air regime worsened.

Keywords: harvests; natural moisture; perennial grass; drought; water regime; watering

Water reclamation practices are recommended in areas that experience insufficient and unstable supply of natural moisture. The practices should be encouraged to improve soil productivity and crop yield (Nikanorova et al. 2016). Irrigation has long been proven effective in increasing crop yields many-fold (Arampatzis et al. 2018). However, irrigation can lead to soil degradation, particularly when the recommended guidelines are not followed and the land is not adequately managed. In some cases, the adverse effects of irrigation systems may not be immediately noticeable but have an effect accumulated through the irrigation practices; in other cases, the negative effect is produced almost instantly, even after a single irrigation procedure (Sun et al. 2018, Safonov et al. 2019).

The Southern Cis-Ural forest-steppe is an important agricultural area and a zone of unstable natural moisture (the agricultural drought probability in this region is 42%). For the most area of agricultural lands, irrigation is used to obtain high and sustainable crop yields. For irrigation of land in the region, water is used from ponds and reservoirs, rivers, lakes, as well as diluted effluents from livestock complexes and sugar factories. The irrigated area corresponding to ponds and reservoirs is 56%, to rivers – 29%, to lakes – 13%, diluted wastewater – 2%. For irrigation in greenhouses, the groundwater is also used, which is collected in accumulation reservoirs before irrigation. In accordance with the soil-reclamation classification, the irrigation waters are mostly non-hazard (class 1) or low-hazard (class 2) and consist about 69%. The structure of crops on irrigated lands is as follows: perennial grasses 58%, cereals (wheat, barley) 17%, corn and sunflower for silage 8%, sunflower for oilseeds 2%, potatoes 3%, sugar beet 3%, soybeans 1%, annual grasses 2%, vegetables 6%. While the perennial grasses occupy a large part of irrigated lands, they enable significantly strengthen the fodder base of animal husbandry. The *Bromopsis inermis* Leyss. (BIL) as well as *Medicago sativa* L. and *Galega orientalis* L. are popular and demand forage crops in irrigated hayfields and pastures. The sprinkling dominates among the irrigation methods. Sprinkling irrigation allows getting 2–3 cuts of perennial grasses, while without it, it is usually only one cut.

This research aimed at studying the effect of long-term sprinkler irrigation (10 years) on the properties of leached chernozem covered by perennial grasses. The objectives were to study changes in the agrophysico-chemical properties and the effect of sprinkler irrigation on the productivity of BIL.

It is important to study the processes during irrigation to provide measures for the rational use of irrigated lands and to preserve soil fertility.

Objects and methods of the study. The study was conducted from 2000 to 2010 in the experimental field of the water-balance station "Bashmeliovodkhoz" (Ufa district, republic of Bashkortostan, Russia). In 2000, seeds of BIL were sown in the experimental plots. The experiment variants were: (1) the control (background) or unirrigated area (rainfed area) and (2) sprinkler-irrigated area. The grasslands were not fertilised. The source of water for irrigation was a groundwater from a 30–40 m deep borehole. The groundwater was supplied by an electric pump to a storage pool, air-warmed (1–2 days) and then used for irrigation. Irrigation rates varied from 900 to 3 900 m^3/ha over each vegetation period, depending on the lack of moisture and weather patterns. The average irrigation value was 1 320 m^3/ha. The irrigation unit KI-5 was used for sprinkling water (with an intensity of less than 1 mm/min). The salinity of irrigation water (groundwater) did not exceed 0.5 g/L (maximum allowable concentration = 1 g/L), and Stebler's irrigation coefficient was 19 (belongs to "very good" category). Thus, the soil cannot be salinised due to irrigation or the groundwater table's capillary rise. It is accepted that plants are optimally provided with moisture in the range from the field capacity (FC) to the trigger point (TP) (it equals 50% of available water capacity (AWC)). To avoid plant stress, irrigation was applied before the onset of TP, in particular when soil moisture at the layer of 0–50 cm approached 65% of FC. Field observations, drilling and sampling (every 10 cm layer to a 50 cm depth) for soil moisture determination were done every ten days during the growing season. The gravimetric method was used to determine soil moisture. The hydrothermal coefficient (HTC) as a climatic indicator of moisture availability of the territory (Selyaninov 1930) was calculated by applying the formula:

$$HTC = \Sigma p/\Sigma t \times 10$$

where: Σp and Σt – accordingly sum of precipitations and temperatures in the period when the temperature was not lower than 10 °C.

After ten years of BIL cultivation and irrigation (in August 2010), six soil pits were excavated: three on control and three on the irrigated area (Figure 1), and soil samples were taken by shovel from each soil

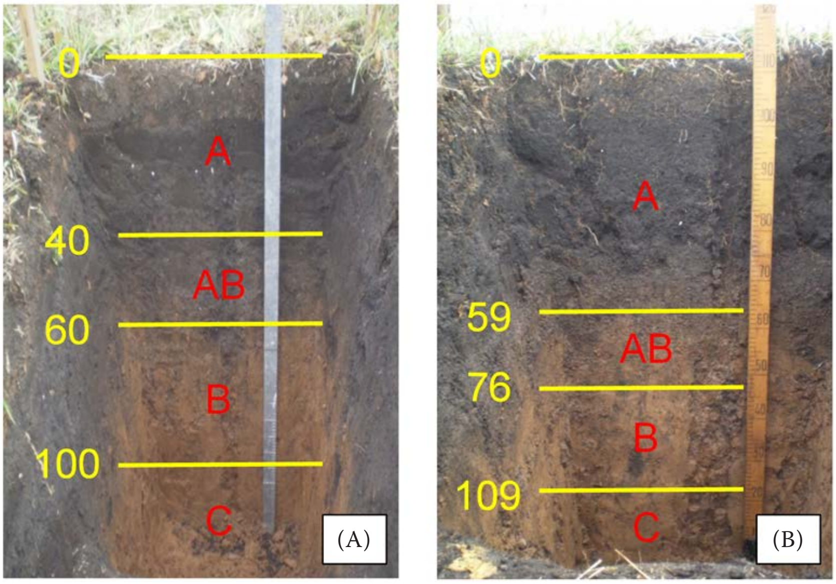

Figure 1. The view of soil cross-sections and depth distribution (cm) of soil genetic horizons at: (A) rainfed area, and (B) irrigated area

horizon. Additionally, undisturbed soil sampling was done at every 5–10 cm using metal core samplers (with 5 cm diameter). The standard methods were used to establish agrochemical and water-physical properties in soil samples (Arinushkina 1970, Sokolov 1976, Vadyunina and Korchagina 1986). In particular, the organic carbon (C_{org}) content was determined according to the Tyurin titrimetric (wet combustion) method; available phosphorus and exchangeable potassium were extracted at 0.5 mol/L CH_3COOH at a 1:2.5 soil/solution ratio by the Chirikov method; ammonium nitrogen content and nitrate nitrogen were extracted at 1 mol/L KCl (1:2.5 soil/solution) according to the Cornfield method; aggregate composition by dry and wet sieving. All analyses were made for the 0–40 cm soil layer. The particle size distribution was measured by the standard pipette (sedimentation) method for 0–5, 5–20, 20–40, 40–60, ~60–80, 80–100, ~100–120 cm soil layers. The bulk density (BD), capillary moisture capacity (CMC), field capacity (FC), saturation capacity (SC) of soil were measured in the laboratory using metal cylinders with undisturbed soil samples for each 5 cm soil layer (with 5 cm interval) until the depth of 70 cm. The soil cover formed at the experiment field is a leached chernozem with the medium thickness of the humus-accumulative horizon. The parent material (bedrock) is diluvial clay. The yield of BIL was analysed in 50 m^2 check plots, and the cut grass biomass was weighed from the whole area; the forage quality (the content of nutrients and energy) was determined according to the methods of the All-Russian Williams Fodder Research Institute. The soil sampling, grass cuttings and laboratory analyses were made in 3 repetitions. The data were averaged and reported in text, tables and graphs as means. The standard error (SE), the significance of the differences between means (*t*-test) and the least significant difference (*LSD*) were calculated using Microsoft Excel 2007 (Redmond, USA).

RESULTS AND DISCUSSION

Morphological properties of soils. Ten-year-long sprinkler irrigation of the soil changed the thickness and boundaries of soil horizons. The humus-accumulative horizon (A + AB) thickened by 16 ± 3 cm in the irrigated area, and the lower horizon boundary shifted downwards. The illuvial horizon (B) starts in the depth of 76 ± 3 cm. The change may not be crucial for BIL as its roots may reach 80 cm deep. However, the shift may cause a lack of nutrients for other crops. As the downward flow of irrigation water causes the leaching of humus and other nutrients into the deeper layers, thus plants/crops cannot uptake the nutrients. The long-term and improper irrigation may also cause thinning of the humus horizon due to soil erosion (Komissarov and Gabbasova 2017) and some soil loss during harvesting root crops or tillage operations.

Agrophysical properties of soils. The soil texture of the unirrigated chernozem is silt loam (Table 1). Down the soil profile, clay (< 0.001 mm) gradually increases its content, reaching the maximum in the illuvial horizon B (42.1 ± 1.7%). The silt and clay content declines slightly in the subsoil, typical of the particular soil type and horizon. The 10-year-long irrigation did not cause considerable changes in the particle size distribution of soil at all horizons. The percentage of very fine sand (0.05–0.01 mm) increased 1.5 fold on average across the soil profile. The topsoil (plough horizon of 0–20 cm) showed a 4.4% lower proportion of silt and clay, which indicated that fine fractions moved to the sub-plough horizon. Principally, the silt and clay content (total fractions sized < 0.01 mm) decreased by 11.8% in the topsoil due to the washing out of fine soil particles during irrigation. The correlations between sand and silt + clay are the basis for determining the main properties of soil. It is believed that the higher content of silt and clay fractions, the more nutrients are in the soil, the more slowly the soil moisture evaporates. Additionally, the differences in transpiration can also take place. These factors appropriately affect crop yields. In general, the soil texture of both irrigated and rainfed areas remained silt loam with silt and clay particles as the dominant fractions.

After the 10-year-long irrigation, soil structure tended to decline (Table 2). The amount of blocky and small aggregates increased by 5.8% and 2.4%, respectively, in the irrigated area. The number of "healthy" aggregates (soil particles of 0.25–10.0 mm) decreased by 3.4%, thus providing evidence for the soil structure's negative trend. The soil conservation technologies may minimise the risks described.

Water and physical properties of soils. Long-term irrigation did not significantly affect the critical soil moisture assessment values (Table 3). The irrigated area showed a slight increase in capillary moisture capacity across the soil profile (up to 50 cm). The most significant difference was found in the layer of 20–30 cm (1.5 fold). At a 50 cm depth, the CMC

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Table 1. The soil texture of chernozem on rainfed and irrigated areas

Horizon and depth (cm)	The size of soil fractions (mm), % and name						Total particles sized	
	1.00–0.25 (coarse sand)	0.25–0.05 (fine sand)	0.05–0.01 (very fine sand)	0.01–0.005 (medium silt)	0.005–0.001 (very fine silt)	< 0.001 (clay)	< 0.01 (silt + clay)	> 0.01 (sand)
Rainfed area (unirrigated)								
A0 0–5	2.8 ± 0.1	12.7 ± 0.5	16.3 ± 0.7	13.5 ± 0.5	26.2 ± 1.1	28.5 ± 1.1	68.1 ± 3.1	31.9 ± 1.2
A 5–20	3.3 ± 0.2	10.1 ± 0.3	17.4 ± 0.8	15.0 ± 0.6	27.0 ± 1.2	27.1 ± 1.2	69.2 ± 3.3	30.8 ± 1.2
A 20–40	0.9 ± 0.1	12.9 ± 0.4	22.1 ± 1.0	12.5 ± 0.4	22.6 ± 0.9	29.1 ± 1.3	64.1 ± 3.0	35.9 ± 1.4
AB 40–60	1.0 ± 0.1	14.8 ± 0.5	24.4 ± 1.0	9.8 ± 0.4	21.6 ± 0.8	28.4 ± 1.1	59.8 ± 2.5	40.2 ± 1.7
B 60–80	1.4 ± 0.1	12.1 ± 0.3	14.5 ± 0.6	9.7 ± 0.4	20.1 ± 0.8	42.1 ± 1.7	72.0 ± 3.0	28.0 ± 1.0
B 80–100	1.3 ± 0.1	14.8 ± 0.6	13.7 ± 0.5	8.8 ± 0.3	19.8 ± 0.7	41.7 ± 1.8	70.2 ± 3.1	29.8 ± 1.2
C 104–119	0.8 ± 0.0	11.2 ± 0.4	14.5 ± 0.5	15.2 ± 0.6	26.5 ± 1.0	32.0 ± 1.4	69.6 ± 2.9	30.4 ± 1.1
Irrigated area								
A0 0–5	6.4 ± 0.3	10.3 ± 0.4	21.6 ± 1.0	11.0 ± 0.4	24.9 ± 1.0	25.8 ± 1.1	61.7 ± 2.8	38.3 ± 1.8
A 5–20	3.0 ± 0.2	8.3 ± 0.1	24.9 ± 1.1	14.4 ± 0.5	24.1 ± 0.9	25.4 ± 1.0	63.8 ± 2.9	36.2 ± 1.6
A 20–40	1.5 ± 0.1	4.8 ± 0.2	26.6 ± 1.2	12.7 ± 0.5	27.0 ± 1.1	27.4 ± 1.1	67.1 ± 3.0	32.9 ± 1.4
A 40–60	1.4 ± 0.1	6.4 ± 0.3	30.7 ± 1.3	8.4 ± 0.3	17.7 ± 0.7	35.4 ± 1.3	61.5 ± 2.7	38.5 ± 1.5
AB 59–76	1.4 ± 0.1	6.0 ± 0.2	26.3 ± 0.9	8.4 ± 0.3	17.1 ± 0.8	40.9 ± 1.7	66.4 ± 3.0	33.7 ± 1.5
B 80–100	1.8 ± 0.1	13.1 ± 0.6	23.7 ± 0.9	7.5 ± 0.3	15.4 ± 0.6	38.6 ± 1.2	61.5 ± 2.6	38.6 ± 1.7
C 109–122	2.1 ± 0.1	13.0 ± 0.5	26.4 ± 1.1	10.8 ± 0.04	20.7 ± 0.8	27.0 ± 0.8	57.5 ± 2.4	42.5 ± 1.9

somewhat decreased compared to the rainfed area. The saturation capacity and field capacity indices were 5.5% and 2.7% lower almost at each horizon in the irrigated area. SC and FC express the capacity of soil to retain moisture. Consequently, prolonged sprinkler irrigation results in the worsening of the water and air regime of soil.

In contrast to the rainfed area, compacted soil was observed from a 50 cm depth in the sprinkler-irrigated area. Irrigation water appears to move fine fractions through macropores from the surface horizon to the deeper ones, so the soil is compacted and clogged in the deeper layers. As a result, the soil structure degrades, and the agronomic value of soil declines.

The content of C_{org} and nutrients. According to Kutova et al. (2020), high-quality farming, organic fertilisers, perennial grasses in the crop rotation, and appropriate irrigation regimes ensure stable and increased C_{org} content in the soil. However, at the same time, the humic substances can move across the soil profile during irrigation and reach subsoil and parent material (bedrock).

Our study confirmed the tendency described above. C_{org} declined in the layer of 0–40 cm by 7% due to the long-time irrigation practices (Table 4), i.e., the stock of C_{org} decrease from 197 to 181 t/ha in this topsoil layer. Also, and most likely, the reduced values of NPK are due to the increased removal of nutrients from the

Table 2. The effect of the long-term sprinkler irrigation on the structural and aggregate composition of chernozems (layer of 0–40 cm)

Experiment variant		The size of soil aggregates (mm, %)									Coefficient of soil structure	Soil aggregate stability (%)
		> 10	10–7	7–5	5–3	3–1	1–0.5	0.5–0.25	< 0.25	> 0.25		
Rainfed area	dry	1.0 ± 0.1	3.4 ± 0.1	7.9 ± 0.3	24.8 ± 1.0	30.1 ± 1.1	21.2 ± 0.9	7.4 ± 0.2	4.2 ± 0.1	95.8 ± 3.2	18.2 ± 0.7	85 ± 2
	wet	–	–	4.5 ± 0.2	21.8 ± 0.9	31.4 ± 1.1	14.5 ± 0.5	9.6 ± 0.4	18.3 ± 0.5	81.7 ± 3.5		
Irrigated area	dry	6.8 ± 0.2	7.8 ± 0.3	10.3 ± 0.4	23.7 ± 0.9	28.2 ± 1.1	17.0 ± 0.7	4.4 ± 0.1	1.8 ± 0.1	98.2 ± 2.1	9.4 ± 0.4	89 ± 2
	wet	–	5.3 ± 0.2	8.8 ± 0.3	27.0 ± 1.1	28.1 ± 1.2	12.0 ± 0.4	6.3 ± 0.2	12.5 ± 0.4	87.5 ± 2.0		

dry – dry sieving data; wet – wet sieving data

Table 3. Soil moisture assessment values and bulk density on irrigated and unirrigated plots

Layer (cm)	Area	Capillary moisture capacity	Field capacity	Saturation capacity	Available water capacity (mm)	Bulk density (g/cm^3)
			(%)			
0–5	irrigated	54.1 ± 2.6	54.5 ± 2.4	61.6 ± 2.9	9.5 ± 0.4	1.04 ± 0.04
	rainfed	53.9 ± 2.5	59.1 ± 2.4	69.9 ± 3.0	10.1 ± 0.5	1.02 ± 0.04
5–10	irrigated	54.2 ± 2.4	49.5 ± 2.2	61.6 ± 2.7	8.6 ± 0.4	1.02 ± 0.03
	rainfed	47.6 ± 2.1	52.1 ± 2.1	67.4 ± 3.0	9.3 ± 0.4	0.98 ± 0.03
10–15	irrigated	58.2 ± 2.5	51.4 ± 2.3	67.7 ± 3.1	9.2 ± 0.3	0.98 ± 0.03
	rainfed	49.2 ± 2.2	56.1 ± 2.3	70.4 ± 3.1	9.7 ± 0.4	1.01 ± 0.03
15–20	irrigated	54.1 ± 2.3	52.0 ± 2.3	58.4 ± 2.6	8.6 ± 0.3	1.06 ± 0.03
	rainfed	51.8 ± 2.3	51.8 ± 1.2	62.2 ± 2.7	8.1 ± 0.3	1.12 ± 0.04
20–30	irrigated	42.0 ± 2.0	41.7 ± 1.9	48.4 ± 2.0	14.2 ± 0.6	1.03 ± 0.03
	rainfed	28.2 ± 1.1	42.5 ± 1.7	50.7 ± 2.1	13.0 ± 0.6	1.14 ± 0.04
30–40	irrigated	39.8 ± 1.7	40.7 ± 1.7	47.6 ± 2.0	13.1 ± 0.5	1.09 ± 0.03
	rainfed	35.6 ± 1.3	46.2 ± 2.0	55.3 ± 2.4	15.4 ± 0.7	1.05 ± 0.03
40–50	irrigated	38.0 ± 1.6	43.9 ± 1.9	48.8 ± 2.1	13.9 ± 0.4	1.10 ± 0.04
	rainfed	29.3 ± 1.2	36.5 ± 1.4	44.5 ± 1.4	10.6 ± 0.5	1.21 ± 0.05
50–60	irrigated	32.9 ± 1.3	32.1 ± 1.1	38.6 ± 1.6	9.2 ± 0.3	1.22 ± 0.04
	rainfed	35.6 ± 1.5	35.9 ± 1.4	45.9 ± 1.7	10.7 ± 0.4	1.17 ± 0.04
60–70	irrigated	29.4 ± 1.2	28.6 ± 1.0	36.1 ± 1.4	7.5 ± 0.2	1.34 ± 0.05
	rainfed	36.4 ± 1.6	37.8 ± 1.1	52.1 ± 2.0	12.3 ± 0.5	1.08 ± 0.03

soil by high-yielding perennial grasses compared to the dry farming lands. Over 36 years of farming practices (from 1982 to 2016), the C_{org} content fell by 17.6% on the region's arable lands (Asylbaev et al. 2020).

BIL is one of the essential perennial grasses because it has high yields, provides a good hay quality (digestibility and intake) and longevity. This grass is fast-growing and provides several cuts in the vegetation season. Hayfields and pastures are planted with the grass alone or in combination with other grasses. BIL increases the organic matter in soils, caused by the decomposition of root mass (Novák et al. 2020). The dynamics of soil moisture are critical in optimising the soil regime of the land where perennial grasses are planted (Khafizov et al. 2019, Safonov et al. 2020). During the research years (2001–2010), the rainfed area had moisture below CR at the beginning of the regrowth period. On average, BIL lacked soil moisture for 38 days in the growing season. The shortest period (10 days) of the absence of readily available water in the soil was observed in the wet year of 2002, and the longest (90 days) period was in the very dry year of 2010 (Figure 2). Therefore, in Bashkortostan's southern forest-steppe zone, BIL should be irrigated yearly regardless of the precipitation level during the growing season. The 10-year studies of the root zone water balance established that for BIL, the irrigation rate was 900–3 900 m^3/ha. The grass should be irrigated once or twice before the first cutting in dry years. A higher frequency of irrigation (2–5 times) is required in the period between cuttings.

Assessment of BIL yields has shown that irrigation is one of the main factors for improving hayfield productivity. Over the ten years, in the irrigated area,

Table 4. Organic carbon (C_{org}) content and nutrients (0–40 cm layer)

Experiment variant	C_{org} (%)	Hydrolytic acidity	Total of absorbed bases	Ammonium nitrogen	Nitrate nitrogen	Available phosphorus	Exchangeable potassium
		(mmol$_+$/kg)		(mg/kg)			
Rainfed area	4.7 ± 0.1	12 ± 0.5	365 ± 11	2.9 ± 0.1	7.6 ± 0.3	61.9 ± 2.2	99.0 ± 3.1
Irrigated area	4.4 ± 0.1	7 ± 0.3	377 ± 9	2.2 ± 0.1	7.8 ± 0.1	37.1 ± 0.6	80.6 ± 2.5

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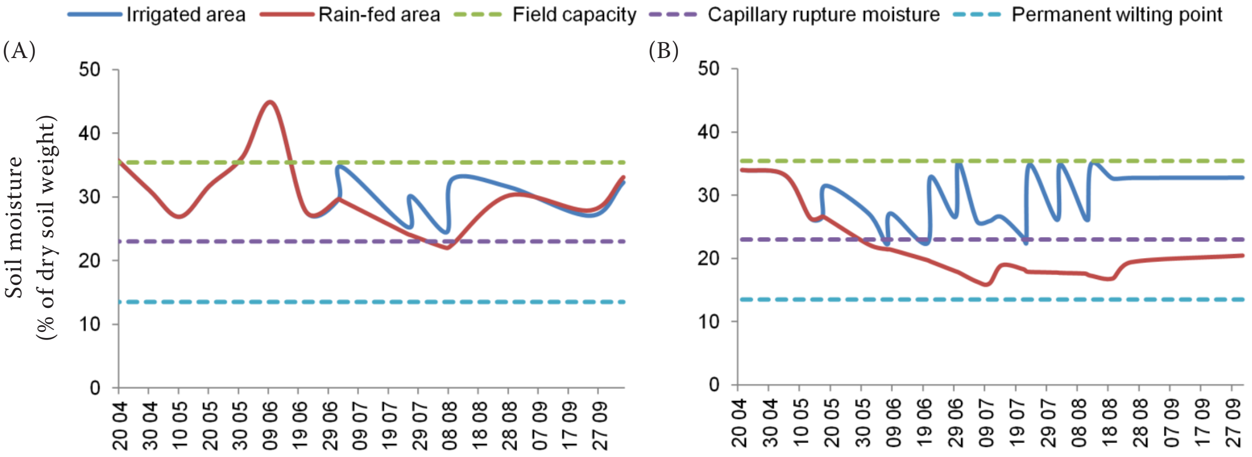

Figure 2. The moisture of soil (0–50 cm layer) covered with *Bromopsis inermis* Leyss. stands in a (A) wet year of 2002 (HTC = 1.56) and a (B) very dry year of 2010 (HTC = 0.44). HTC – hydrothermal coefficient

an increase averaged 1.09 t/ha, and the yield was 5.29 t/ha of hay (Table 5). In the research years, the yield of the first cut exceeded that of the second cutting and averaged 3.33 t/ha for the first cuts, 1.96 t/ha for the second cuts in the irrigated area; the values were 2.96 t/ha and 1.24 t/ha, respectively, in the rainfed area. The grass was harvested in the heading stage: the grass was cut for the first time in the last ten days of June, for the second time – in the last ten days of August. Irrigation was particularly useful for the second cutting when both air and soil experienced a lack of moisture. For example, the second cut in 2010 was characterised by an increase in yield (caused by irrigation) on 285%, and the second cut in 2004 only on 12%. At the same time, in 2004, on the plot without irrigation, the highest yield of the second cut was observed (among of all years of experiment). The periods between cuts (from ~ 20 June to ~ 20 August) of the corresponding years were characterised in 2010 as severely arid (HTC – 0.39; precipitation – 62 ± 2 mm), and 2004 as wet (HTC – 1.14; precipitation – 128 ± 2 mm).

In the first five years of growing BIL (2001–2005), a yield of 6.67 t/ha was obtained in the irrigated area; in fact, irrigation increased the production/yield by 22%. For the next five years (2006–2010), a decline

Table 5. The yield (t/ha) of *Bromopsis inermis* Leyss. on experimental plots

Year, year of hayfield use (sward age)	Rainfed area			Irrigated area/increment (%)			$LSD_{0.05}$
	1 cut	2 cut	total	1 cut	2 cut	total	
2001, 1	4.49	1.24	5.73	4.49/0	2.62/111	7.11/24	0.37
2002, 2	4.21	1.52	5.73	4.21/0	2.11/39	6.32/10	0.27
2003, 3	4.44	1.90	6.34	4.44/0	2.71/43	7.15/13	0.15
2004, 4	2.75	2.07	4.82	4.19/52	2.31/12	6.50/35	0.45
2005, 5	3.37	1.33	4.70	3.97/18	2.31/74	6.28/34	0.59
2006, 6	2.45	1.32	3.77	3.32/36	2.10/59	5.43/44	0.38
2007, 7	2.81	1.27	4.08	2.81/0	2.07/63	4.88/20	0.41
2008, 8	2.35	0.99	3.34	2.73/16	1.71/73	4.44/33	0.29
2009, 9	1.90	0.63	2.53	2.02/6	1.12/78	3.14/24	0.15
2010, 10	0.80	0.14	0.94	1.10/38	0.54/285	1.64/74	0.08
Average 2001–2005	3.85	1.61	5.46	4.26/11	2.41/50	6.67/22	
Average 2006–2010	2.06	0.87	2.93	2.39/16	1.52/75	3.91/33	
Average 2001–2010	2.96	1.24	4.20	3.33/13	1.96/58	5.29/26	

$LSD_{0.05}$ – least significant difference, given for yield in total for two cuttings

Table 6. The productivity of *Bromopsis inermis* Leyss. hayfields on experimental plots

Experiment variant	Output per hectare					
	dry matter (t)		metabolisable energy (GJ)		crude protein (t)	
	young herbage (1–5 y. u.)	old-growth herbage (6–10 y. u.)	young herbage (1–5 y. u.)	old-growth herbage (6–10 y. u.)	young herbage (1–5 y. u.)	old-growth herbage (6–10 y. u.)
Rainfed area	4.53 ± 0.18	2.43 ± 0.09	40.5 ± 1.7	20.0 ± 0.7	0.69 ± 0.02	0.29 ± 0.01
Irrigated area	5.54 ± 0.21	3.25 ± 0.12	50.8 ± 2.1	27.4 ± 0.5	0.92 ± 0.03	0.41 ± 0.02

y. u. – years of hayfield use (sward age)

in yields to 3.91 t/ha was observed; the irrigation effect was low – an increase in yield was 0.98 t/ha. Summarising, the highest yield of BIL was obtained in the third year of the hayfield and amounted to 6.34 t/ha in the rainfed area and 7.15 t/ha in the irrigated area. It should be noted that the temperature factor also significantly affected BIL yield formation. The productivity of irrigated hayfield in 2002 was lower than in 2001 and 2003, which is associated with a significant lack of sunshine during the 2002 growing season. The sum of active air temperatures (above 5 °C) in 2002 for the period from spring regrowth to the second cut was only 1 981 °C, while the mean annual value is 2 243 °C.

Cultivation of the grass for ten years resulted in its degradation. In the last year of study, on the rainfed area, the average grass stand density was 140 ± 5 stems/m^2 before the first cutting, 98 ± 3 stems/m^2 before the second cutting. The values were 4–5 times lower than in the first years of growing the grass. Similar dynamics were observed in the irrigated area, i.e., the grass stand density was 150 ± 5 stems/m^2 (first cut) and 105 ± 4 stems/m^2 (second cut) in the 10th year of herbage using, whereas in the third year it was 580 ± 17 and 510 ± 14 stems/m^2, respectively.

Irrigation leads to an increase in both the yield and qualitative characteristics of BIL. The irrigation had a strong effect on young hayfields, where its productivity was higher in all parameters than in the old-growth herbage (Table 6).

Irrigation of plot with a young grass stand (1–5 year-old swards) led to an increase in the output of dry matter (DM) to 1.01 t/ha (22%), metabolisable energy to 10.3 GJ/ha (25%), crude protein to 0.23 t/ha (33%). Irrigation of old hayfields (6–10 year-old swards) was less effective (in quantitative terms): the increase in DM was 0.82 t/ha (34%), 7.4 GJ/ha (37%) in metabolisable energy and 0.12 t/ha (41%) in crude protein. Irrigation also leads to some (up to 12%) increase in the hay quality (Table 7) for many parameters (except crude fiber) at young and old-growth herbage. However, over time, the forage quality (as well as yield of grass and its stand density) declined on both plots (irrigated and rainfed areas). It could be associated with herbage deterioration due to aging and/or with the absence of fertilising.

Table 7. The quality (content of nutrients and energy) of *Bromopsis inermis* Leyss. on irrigated and unirrigated plots

Indicator	Young herbage (1–5 year-old swards)		Old-growth herbage (6–10 year-old swards)	
	rainfed area	irrigated area	rainfed area	irrigated area
Crude protein (%)	15.2 ± 0.4	16.6 ± 0.6	11.8 ± 0.4	12.8 ± 0.5
Crude fat (%)	1.9 ± 0.1	1.9 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
Crude fiber (%)	30.8 ± 1.1	29.1 ± 1.2	35.3 ± 1.5	33.8 ± 1.4
Crude ash (%)	9.3 ± 0.3	9.5 ± 0.4	9.1 ± 0.4	9.6 ± 0.5
Nitrogen-free extract (%)	42.9 ± 1.1	43.0 ± 2.0	42.1 ± 1.2	42.2 ± 1.9
Gross energy in 1 kg of DM (MJ)	18.1 ± 0.4	18.1 ± 0.5	17.9 ± 0.7	17.9 ± 0.8
Metabolisable energy in 1 kg of DM (MJ)	8.9 ± 0.4	9.2 ± 0.5	8.2 ± 0.3	8.4 ± 0.3
Digestible protein in 1 kg of DM (g)	105 ± 4	117 ± 5	74 ± 3	83 ± 4

DM – dry matter

Irrigation of BIL on old hayfields in the Bashkortostan's forest-steppe zone produced an income of the whole production of only 0.9 thousand rubles/ha (~ 12 US dollars/ha). In comparison, irrigation of the BIL on young hayfields ensured an income of 8.5 thousand rubles/ha (~ 112 US dollars/ha). To accelerate the recoupment of costs for the construction and maintenance of stationary sprinkler systems, in irrigated crop rotations with perennial grasses, it is necessary to include a highly profitable row crops (sugar beets, potatoes), the cultivation of which brings a profit of 30–40 thousand rubles/ha (~400–530 US dollars/ha).

To sum up, our study revealed the following findings. Long practiced sprinkler-irrigation of leached chernozems stands covered with BIL in the Southern Cis-Ural forest-steppes as a zone of natural deficit moisture showed that irrigation is an effective way to increase yields (26%, average for 10 years) and improve hay quality. Growing BIL for more than 5–6 years results in lower yields and inadequate forage quality in irrigated and rainfed areas, thus economically (cost-effective) and practically better is to use the hayfields just for 5 years. The soil properties after irrigation were slightly changed but still remained in optimal values for chernozem. While similar studies in the region are absent or limited, further additional experiments with other crops, types of irrigation with/without fertilising are required.

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