Sustainable Agriculture Research; Vol. 6, No. 2; 2017
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Greenhouse Gas Emissions from Livestock Manure Management in Southwestern Siberia, Russia

Maria Störrle[1], Hans-Jörg Brauckmann[1] & Gabriele Broll[1]

[1]Institute of Geography, University of Osnabrück, Osnabrück, Germany

Correspondence: Maria Störrle, Institute of Geography, University of Osnabrück, Seminarstraße 19 a/b, 49074 Osnabrück, Germany. Tel: 49-541-969-4073. E-mail: maria.stoerrle@uni-osnabrueck.de

Received: December 13, 2016 Accepted: January 14, 2017 Online Published: March 3, 2017

doi:10.5539/sar.v6n2p66 URL: https://doi.org/10.5539/sar.v6n2p66

Abstract

This study investigates the amounts of greenhouse gas (GHG) emissions due to manure handling within different livestock production systems in Tyumen oblast of Western Siberia. Tyumen oblast occupies approx. 160 000 km² of Asian taiga and forest steppe. The amount of GHGs from manure was calculated as a function of the handling according to current IPCC guidelines for ecozones and livestock production systems. The entire Tyumen oblast has annual 7 400 t methane emissions and 440 t nitrous oxide emissions from manure. Three livestock production systems are prevalent in Tyumen oblast: Mega farms, small farms and peasant farms. The share of mega farms is 81 % (171 kt CO_2 eq). Additionally, the slurry system in mega farms causes environmental pollution. GHG emissions and environmental pollution could be reduced by implementing solid manure systems or pasturing, by installing storage facilities for slurry outside the stables and through application of the manure as fertiliser at mega farms. In small farms solid manure systems and a small stocking density of livestock lead to smallest GHG emissions (1 %, 3 kt CO_2 eq) from manure. In peasant farming 18 % (38 kt CO_2 eq) of GHGs are emitted due to pasturing.

Keywords: GHG emissions from manure, livestock production system, manure management

1. Introduction

The Tyumen oblast in southwestern Siberia is an administrative area with approx. 160 000 km². The region is of global importance for carbon storage, biodiversity, and food production due to the extensive prevalence of organic soils and fertile soils such as Chernozems and Phaeozems (Störrle, Hagedorn, Yurtaev, Brauckmann, & Broll, 2016). The livestock sector is characterized by different production systems. Large producers with modern equipment produce livestock products for local and national market. About 50 % of the livestock products are being produced by peasants for the local market (Russian Federal State Statistics Service [ROSSTAT], 2013; Störrle, Brauckmann, & Broll, 2015).

The interdisciplinary joint project SASCHA “Sustainable land management and adaptation strategies to climate change for the Western Siberian Grain Belt” investigates the impacts of agricultural land-use change on ecosystem services and biodiversity in Tyumen oblast (Václavík et al., 2016). A sub-project investigates the residual potential for the agricultural by-products as well as their environmental and climate impact, especially greenhouse gas (GHG) emissions from livestock manure in Tyumen oblast (Störrle et al., 2015).

An increase in agricultural production is expected in Tyumen oblast. Climate change in northern regions, programmes of local agriculture policy, growing population and re-cultivation of abandonment land in Tyumen oblast are drivers for agricultural expansion or intensification in Tyumen oblast (Frey, & Smith, 2003; Shulgina, Genina, & Gordov, 2011; Degefie et al., 2014; Kühling, Griewald, Broll, & Trautz, 2015; Stupak, 2017). An increase in agricultural production needs a holistic view for sustainable development. Until now, climate change issues in agriculture are barely effectively addressed by the state regulation and governmental programmes in Tyumen oblast (Stupak, 2017).

Globally, GHG emissions from agriculture, forestry and other land use account for 24 % (Food and Agriculture Organization of the United Nations [FAO], 2016). According Tubiello et al. (2015), the GHG emissions from crop and livestock production make up about 11 %, while O’Mara (2011) calculated for the livestock sector 8 % to 10.8 % of total global GHG emissions. Manure left on pastures and manure management account for 11 %

and 7 %, respectively of GHG emissions from agriculture in Asia (FAO, 2016). O'Mara (2011) calculated 12 million tonnes of CH_4 and 28 million tonnes of N_2O emissions from manure for post-Soviet states.

In addition to the GHG emissions, manure can lead to several other environmental impacts if improperly handled, such as over-fertilisation, water pollution, and air pollution due to NH_3 (Sharpley et al., 1997; Beckwith, Cooper, Smith, & Shepherd, 1998; Otabbong, Arkhipchenko, Orlova, Barbolina, & Shubaeva, 2007; McGinn, & Sommer, 2007; Leet et al., 2012). A lack of manure storage facilities is the main cause of environmental pollution due to livestock in Russia (Bondarenko, Miroshnikov, & Miroshnikov, 2010).

Cropland is primarily farmed by mega farms in the Tyumen oblast (ROSSTAT, 2013; Kühling, Broll, & Trautz, 2016). These agricultural fields show a constant decrease in soil organic carbon (SOC) content and a deterioration of the soil structure (Eremin, 2012; Federal Service for State Registration, Cadastre and Cartography [ROSREESTR], 2012; Abramov, 2013; Störrle et al., 2016). The percentage of cropland that is organically fertilised is very low (2%) (ROSSTAT, 2013; Störrle et al., 2015). The nutrients in the livestock manure from the mega farms in the Tyumen oblast could supply 23 % of the cropland from the mega farms sufficiently with nutrients (Störrle et al., 2015).

This fertiliser potential is not utilised, because transporting the manure is considered unprofitable by the farmers. The manure is spread upon the bare fallows in great amounts, up to 300 t per hectare and year. Moreover, illegal disposal of the manure in agriculture is prevalent (Störrle et al., 2015). These practices squander the potential of the livestock manure as fertiliser and pollute the environment.

The amount of GHG emissions from manure is dependent upon livestock production system (Jungbluth, Hartung, & Brose, 2001; Monteny, Groenestein, & Hilhorst, 2001; Sneath, Beline, Hilhorst, & Peu, 2006; van der Meer, 2008; O`Mara, 2011; Fukumoto, Suzuki, Waki, & Yasuda, 2015; Owen, & Silver, 2015). The manure handling system influences the water and oxygen budget in the manure. Whereas slurry systems primarily produce CH_4, solid manure systems produce both CH_4 and N_2O (Intergovernmental Panel on Climate Change [IPCC], 2006).

The results of this study on GHG emissions and the environmental impact of manure handling systems serve as the basis for recommendations for the business and politics, to decrease GHG emissions from agriculture as well as to reduce the environmental impact due to incorrect manure handling systems. Moreover, the results can combat the ongoing soil degradation through rational use of manure as an organic fertiliser.

The following objectives were formulated from these goals:

1. What is the amount of GHGs produced by manure management in agroecosystems in Tyumen oblast?

2. Which portion of the GHG emissions is produced by the manure management of different livestock production systems?

3. How can the GHG emissions be reduced by sustainable livestock manure management?

2. Study Area

2.1 Ecozones and Land Use

The Tyumen oblast is located in the Western Siberian Grain Belt of the Russian Federation (Figure 1). Continental climate, flat relief, and high occurrence of peatland and also fertile mineral soils are typical for this region. The area of the Tyumen oblast occupies approximately 160 000 km^2 of the Western Siberian plain. Its administrative centre is the city of Tyumen (Figure 1). There are twenty-two districts in the Tyumen oblast (ROSREESTR, 2012).

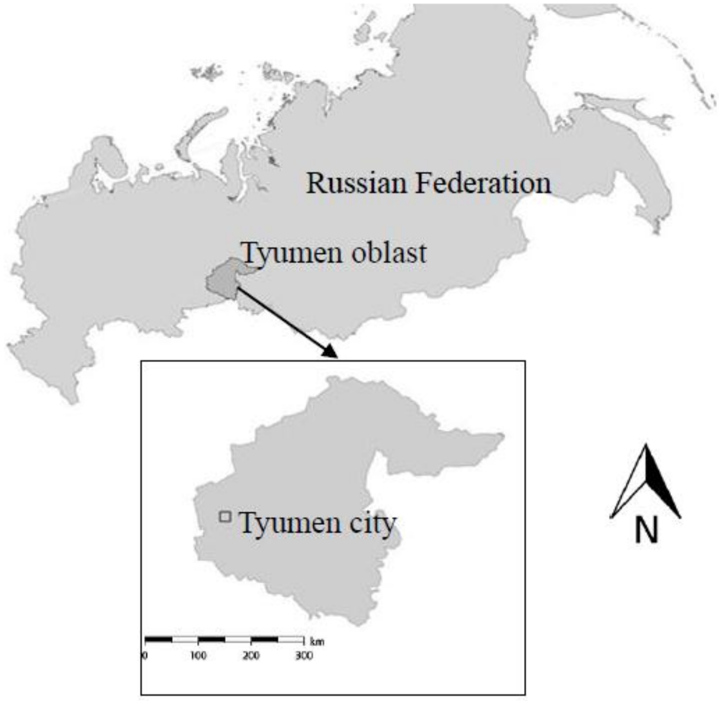

Figure 1. Map of Russian Federation and location of the Tyumen oblast

The land-use intensity is strongly influenced by the climate and soil conditions. There is a clear north-south-gradient recognizable in the land-use intensity in the Tyumen oblast (Kühling et al., 2016). The vegetation period is 106 days in the northernmost districts and 130 days in the southernmost one. The northern region of the oblast has a mean annual precipitation of 454 mm. In the south, it is lower - 330 mm (Agro-climatic Resources in the Tyumen oblast, 1972, cited in Karetin, 1990).

The Tyumen oblast has two vegetation zones: taiga and forest steppe. The taiga is further divided into the southern taiga and the sub-taiga. The forest steppe is also divided into the northern and southern forest steppe (Figure 2).

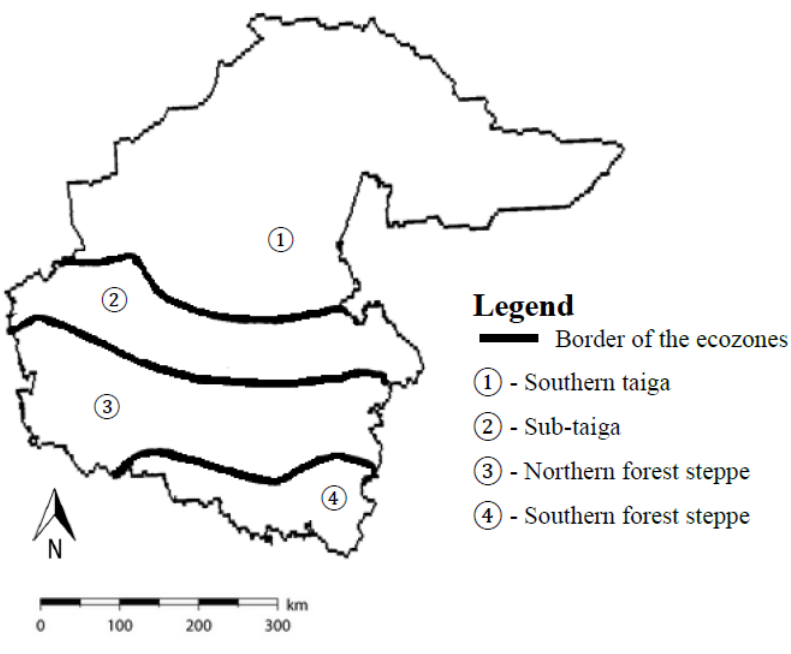

Figure 2. Ecozones of the Tyumen oblast (Karetin, 1990)

The southern taiga also covers part of the northern half of the Tyumen oblast and covers 57 % of the oblast (9.1 million ha). Due to the widespread distribution of Histosols in conjunction with poor agro-climatic conditions, arable farming only plays a minor role: about 16 000 ha arable land. The livestock density is low: 0.05 livestock units (LSU) per ha^{-1} (Table 1).

Along the southern border of the southern taiga, the sub-taiga follows with a width of 60-80 km. The area of the sub-taiga in the Tyumen oblast is 15 % (2.4 million ha). Forests cover 52 % of the sub-taiga. The livestock density is 0.08 LSU ha^{-1} and cropland covers to approx. 138 000 ha.

The area of the wetlands is approx. 11 % in the northern forest steppe. There are large stands of *Betula* or *Betula-Populus* forests that grow on Albic Luvisols. *Pinus* forests grow mainly on Podzols. Towards the south there are copses and groves and there are farms on fertile soils, such as Chernozems and Luvisols (Karetin, 1990). The highest livestock density (0.20 LSU ha^{-1}) of the entire Tyumen oblast (Table 1) is found here. Moreover, grassland and arable land have the highest land-use intensity in this area (Kühling et al., 2016).

The southern forest steppe is in the south of the Tyumen oblast and has an area of 1.3 million ha, which is 8 % of the oblast. The landscape is characterised by grassland vegetation with scattered groves. Hydromorphic soils cover 15 % of the area. Salt influenced soils such as Solonchaks and Solonetz occur (Karetin, 1990). The livestock density is 0.06 LSU ha^{-1} and the area of arable land is approx. 152 000 ha (Table 1).

Table 1**.** Livestock units per hectare agricultural area[1], agricultural area and arable land within livestock production systems and ecozones of Tyumen oblast

			Arable land (ha)		
Ecozones	LSU ha^{-1}	Agricultural area[1)] (ha)	Peasant farms	Small farms	Mega farms
Southern taiga	0.05	290 700	2 681	2 682	11 179
Sub-taiga	0.08	786 200	8 367	20 610	109 087
Northern forest steppe	0.20	1 598 400	11 055	64 530	351 525
Southern forest-steppe	0.06	708 000	3 332	30 351	118 317
Total		*3 383 300*	*25 435*	*118 173*	*590 108*

Source: European Commission, 2009; ROSREESTR, 2012; ROSSTAT, 2013

Note. LSU=Livestock units.

[1]orchards area, arable land, abandoned land and grassland

2.2 Characterisation of Livestock Production Systems and Stocks

Three types of livestock production systems are prevalent in the Tyumen oblast: Peasant farms, small farms and mega farms.

1. The smallest kind of livestock production systems is peasant farming. Peasant farms have on average 20 animals and 5 ha arable land.

2. Small farms include individual companies and farmer associations. The small farms keep approx. 100 animals and have on an average 100 ha of arable land.

3. Mega farms are characterised through large stocks of animals: On average there are 1 000 cattle and/or pigs or up to 3 million poultry at one production site. The main part of arable land (75 %) belongs to mega farms in the Tyumen oblast (Table 1). One third of the mega farms operate as mixed farms with crop and livestock production (ROSSTAT, 2013).

Livestock population in ecozones increases with the climate gradient towards the south in peasant farms as well as in mega farms (Table 2). Moreover, the livestock units per hectare and the extent of arable land are higher in the forest steppe than in the taiga (Table 1). Another factor for the regional concentration of livestock producers in the northern forest steppe is the geographical proximity to the sales market in Tyumen city, where 49 % of the population of Tyumen oblast live (ROSSTAT, 2016).

Table 2. Livestock population within livestock production systems and ecozones of Tyumen oblast in the year 2011

Ecozones	Livestock species (head) Cattle	Swine	Horses	Sheep & goats	Poultry
			Peasant farms		
Southern taiga	11 761	6 441	1 961	11 524	24 235
Sub-taiga	20 412	33 879	2 942	28 447	114 317
Northern forest steppe	56 979	89 528	6 841	57 203	266 088
Southern forest steppe	20 790	25 107	2 352	22 724	108 743
			Small farms		
Southern taiga	544	55	67	135	106
Sub-taiga	5 320	1 140	322	337	503
Northern forest steppe	4 442	2 255	179	1 920	3 237
Southern forest steppe	956	16	0	20	15
			Mega farms		
Southern taiga	4 680	1 013	240	1 939	0
Sub-taiga	27 798	2 200	724	2 667	0
Northern forest steppe	83 645	163 550	1 696	771	7 597 393
Southern forest steppe	19 064	282	546	290	0
Total	*256 391*	*325 466*	*17 870*	*127 977*	*8 114 637*

Source: ROSSTAT, 2013

The highest portion of livestock products is produced in mega farms (Figure 3). The second largest livestock production system is peasant farming. The larger part of the livestock is kept by the peasants, with the exception of poultry. The majority of poultry farming (94 %) in the entire oblast is concentrated in five mega farms. Three factory poultry producers are located in the vicinity of Tyumen city in the northern forest steppe (Störrle et al., 2015).

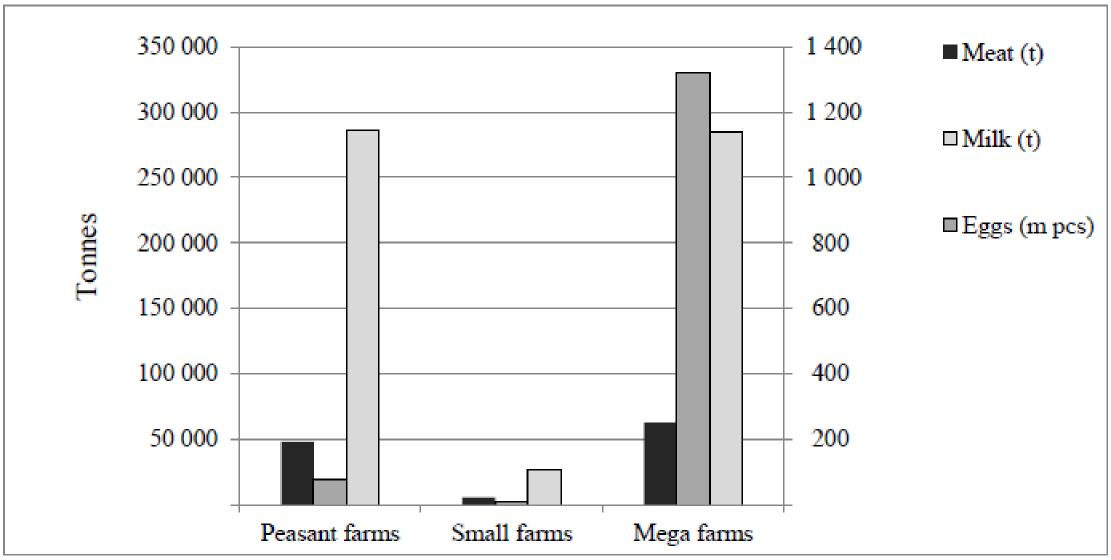

Figure 3. Output of livestock products in the three types of livestock production systems in Tyumen oblast in 2011 (ROSSTAT, 2013)

3. Methods

3.1 Manure Handling Assessment

Information about the manure handling was obtained from farm visits and interviews of eight mega farm managers. All major mega farms were surveyed across the Tyumen oblast in 2012 and 2013. Three poultry mega farms, three cattle mega farms, and two swine mega farms, as well as five small farms and twenty peasant farms were visited and interviewed in five districts of the Tyumen oblast. Information about environmental damage due to manure handling on mega farms was obtained from the state environmental reports from 2011 (Administration of Tyumen oblast, 2012; ROSREESTR, 2012).

3.2 Calculation of the GHG Emissions from Manure

3.2.1 Methods and Data Selection

The calculations were carried out in accordance to the guidelines published by the Intergovernmental Panel on Climate Change in "Guidelines for National Greenhouse Gas Inventories" chapter 10 – "Emissions from Livestock and Manure Management". The methane and nitrous oxide emissions from manure were calculated with the Tier 2 method (IPCC, 2006).

The calculation of the GHG emissions from manure is based on the livestock numbers from the Tyumen oblast at the district level from the Russian Federal State Statistics Service from 2011 (ROSSTAT, 2013). The following livestock categories were taken into consideration in the calculations: dairy cows, other cattle, sheep / goats, swine, horses, and poultry. For poultry, a distinction is made according to production-specific manure types. Data on the husbandry systems and manure handling systems of the large poultry producers were collected during the visits at the farms.

The calculations were differentiated according to the three different livestock production systems: (1) Peasant farms (2) Small farms and (3) Mega farms. The emission factors for slurry storage were used in the calculations for the mega farms. It was assumed that the small farms use solid manure system. The calculation factors for pasturing were used in the calculation for the livestock on the peasant farms.

3.2.2 Methane Emissions

The methane emission factors were calculated according the Tier 2 method. The calculated emission factors (EF) take the different storage systems in the three production system types into account (Table 3).

The calculation factors are based on information from North America, because no well-fitting calculation factors are provided for Siberian climate conditions (IPCC, 2006). The suggested EF for dairy cows in the Tier 1 method from IPCC (2006) for Asia under cold climate is 9 kg CH_4 head^{-1} year^{-1}. The suggested EF for dairy cows in the Tier 1 method from IPCC (2006) for North America is 48 kg CH_4 head^{-1} year^{-1}. To validate the North American values, regional data from the dairy cow feeding experiment by Bulatov and Kurdoglyan (2006) were used. The share of the organic volatile solids (VS) in the manure was calculated with local values for the dairy cows. The share of volatile solids for dairy cows in the Tyumen oblast is 4.9 kg head^{-1} day^{-1}. The IPCC (2006) guidelines list a VS value of 5.4 kg head^{-1} day^{-1} for North America. Using Russian data, the calculated EF for dairy cows in mega farms is 48.89 kg CH_4 head^{-1} year^{-1}.

Table 3**.** Methane emission factors calculated according to the Tier 2 method for different production systems in the Tyumen oblast

Livestock category	Peasant farms	Small farms	Mega farms
Dairy cow	2.87	5.75	48.89
Other cattle	1.11	2.23	18.95
Swine	0.59	1.17	9.97
Sheep	0.1	0.19	0.19
Layer (dry)	-	-	0.03
Layer (wet)	-	-	1.12
Broiler	0.01	0.02	0.02

Source: IPCC, 2006, - Data not available

3.2.3 Nitrous Oxide Emissions

The N_2O emission factors from manure for each livestock category and production system were calculated with the Tier 2 Method from the IPCC (2006). The values for nitrogen contents from the manure, which were necessary for the calculations, were obtained from the study on nutrient supply from manure in the Tyumen oblast (Störrle et al., 2015), where the nutrient contents were calculated according to the guidelines of the Lower Saxony Chamber of Agriculture, Germany [LWK] (2009). Additionally, an adaption of nutrient contents in cattle manure due to low milk yields was carried out. Validation of calculated nutrient contents was carried out with data from lab analysis.

The N_2O emission factors for pasturing for the peasant farms were taken from the IPCC Guidelines for National Greenhouse Gas Inventories, chapter 11 "N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application" (IPCC, 2006). The emission factors for N_2O are listed in Table 4.

Table 4**.** Nitrous oxide emission factors for the Tier 2 method for different production systems in the Tyumen oblast

Livestock category	Peasant farms	Small farms	Mega farms
Dairy cows	0.02	0.005	0.005
Other cattle	0.02	0.005	0.005
Swine	0.02	0.005	0.005
Sheep	0.01	0.005	0.005
Layer (dry)	-	-	0.005
Layer (wet)	-	-	0.001
Broiler	0.02	0.001	0.001
Horses	0.01	0.005	0.005

Source: IPCC, 2006; LWK, 2009, - Data not available

3.2.4 CO_2 – Equivalents

To determine the CO_2 equivalents, the values for the global warming potential (GWP) and global temperature change potential (GTP) were multiplied with CH_4 and N_2O emissions and are listed in Table 5.

Table 5. Global warming potential and global temperature change potential values for a 100 year time horizon

Greenhouse gas	GWP_{100}	GTP_{100}
CH_4	34	11
N_2O	298	297

Source: IPCC, 2013

Note. GWP=global warming potential, GTP=global temperature change potential.

4. Results

4.1 Manure Handling Systems

On peasant farms, cattle, horses, sheep and goats graze with low intensity on pastures or abandoned fields during the growing season. During winter, solid manure is stored in piles. Later, it is distributed on their own arable fields or it is given away to garden owners. Most of the small farmers use solid manure systems. This manure is spread on their own arable fields too. On mega farms, solid manure is produced in broilers, in horse farms, in sheep and goat farms. Two poultry mega farms process poultry manure into dry chicken manure. Moreover on mega farms, slurry is produced in cattle farms, in swine farms and partly in poultry farms. Slurry is stored in open lagoons without sealing the ground. It is applied only after it has been thickened due to evaporation and percolation and only on fields near the farms. Nowadays, a transport of solid manure and slurry even within short distances of a few kilometres is considered unprofitable. The most important limiting factor is the high diesel price (Störrle et al., 2015).

Spring or fall fertilisation with manure is not possible due to the short growing season. Therefore, it is common to apply the manure on the bare fallows of the mega farms. The application rates are very high – up to 300 t ha^{-1} $year^{-1}$. Illegal disposal of manure in the landscape is also common (Störrle et al., 2015).

4.2 GHG Emissions

Slurry management in the mega farms annually produces ca. 7 000 t methane, which is 95 % of the entire methane emissions from manure in the Tyumen oblast. The peasant farms produce 320 t and the small farms 47 t methane annually. 74 % of the methane emissions occur in the northern forest steppe (Table 6).

Table 6. Annual methane emissions from manure in ecozones and livestock production systems in the Tyumen oblast

Ecozones	Peasant farms	Small farms	Mega farms
		CH_4 (%)	
Southern taiga	0.39	0.03	2.13
Sub-taiga	0.86	0.29	11.66
Northern forest steppe	2.30	0.27	73.69
Southern forest steppe	0.78	0.05	7.83
Total	*4.35*	*0.35*	*95.31*
		CH_4 ($t\ a^{-1}$)	
Southern taiga	29.3	2.2	156.9
Sub-Taiga	63.7	21.4	860.8
Northern forest steppe	169.8	19.6	5,439.6
Southern forest steppe	57.9	3.5	577.9
Total	*320.8*	*46.7*	*7 035.2*

Source: IPCC, 2006; LWK, 2009; ROSSTAT, 2013

In comparison to the mega farms, pasturing by the animals from the peasant farms leads to high N_2O emissions (Table 7), an annual N_2O emission of 316 t, which is 72 % of the nitrous oxide emissions from manure. The mega farms produce 118 t N_2O (27 %). Through spreading the dry manure on the fields, the small farms annually produce 7 t N_2O.

Table 7. Annual nitrous oxide emissions from manure in ecozones and livestock production systems in the Tyumen oblast

Ecozones	Peasant farms	Small farms	Mega farms
		N_2O (%)	
Southern taiga	6.82	0.07	0.62
Sub-taiga	14.34	0.71	3.51
Northern forest steppe	37.31	0.67	20.12
Southern forest steppe	13.24	0.11	2.49
Total	*71.71*	*1.56*	*26.73*
		N_2O ($t\ a^{-1}$)	
Southern Taiga	30.01	0.29	2.73
Sub-taiga	63.13	3.14	15.41
Northern forest steppe	164.22	2.96	88.53
Southern forest steppe	58.27	0.48	10.97
Total	*315.63*	*6.86*	*117.65*

Source: IPCC, 2006; LWK, 2009; ROSSTAT, 2013

Note. N_2O= nitrous oxide.

In 2011, approx. 7 400 t methane and 440 t nitrous oxide from manure were emitted in the Tyumen oblast. Methane emissions occurred mainly due to mega farms, whereas N_2O occurred mainly from the peasant farms. Annual CO_2 equivalents for a global temperature change potential (GTP) for a 100 year time horizon from manure are 211 kt for the entire oblast. CO_2 equivalents for the global warming potential (GWP), also for a 100 year time horizon, are 382 kt for the entire Tyumen oblast (Table 8).

Table 8. Annual emissions of CH_4, N_2O and CO_2 equivalents for global temperature change potential and global warming potential values for a time horizon of 100 years from livestock manure in ecozones in the Tyumen oblast

Ecozones	CH_4 (t a^{-1})	N_2O (t a^{-1})	CO_2 eq GTP_{100} (kt a^{-1})	CO_2 eq GWP_{100} (kt a^{-1})
Southern taiga	188	31	12	15
Sub-taiga	946	82	34	57
Northern forest steppe	5 629	255	138	267
Southern forest steppe	639	70	27	43
Total	*7 403*	*440*	*211*	*382*

Source: IPCC, 2006; IPCC, 2013; LWK, 2009; ROSSTAT, 2013

Note. GWP=global warming potential, GTP=global temperature change potential.

The share from mega farms is 81 % of the GHG emissions (CO_2 eq GTP and GWP) from manure (Table 9). The smallest amount of CO_2 eq is produced by the small farms. Their share is only 1 %. The peasant farms produce 18 % of the GHG emissions from manure (CO_2 eq GTP and GWP) due to pasturing.

Three largest poultry producers of Russia are located in the Tyumen oblast. The share of GHG emissions from manure handling systems caused by the poultry producers is about 10 %. The largest share of GHG emissions from manure is caused by the cattle farms and is 60 % in Tyumen oblast.

Table 9. Annual CO_2 equivalents for global temperature change potential and global warming potential values for a 100 year time horizon from manure in ecozones and livestock production systems in the Tyumen oblast

Ecozones	Peasant farms	Small farms	Mega farms
	CO_2 eq GTP_{100} (kt a^{-1})		
Southern taiga	1.13	0.11	10.64
Sub-taiga	5.28	1.17	28.22
Northern forest steppe	28.15	1.09	108.52
Southern forest steppe	3.90	0.18	23.66
Total	*38.45*	*2.55*	*171.04*
	CO_2 eq GWP_{100} (kt a^{-1})		
Southern taiga	1.81	0.16	14.28
Sub-taiga	6.76	1.66	48.08
Northern forest steppe	32.10	1.55	233.62
Southern forest steppe	5.24	0.26	37.01
Total	*45.91*	*3.63*	*332.99*

Source: IPCC, 2006; IPCC, 2013; LWK, 2009; ROSSTAT, 2013

Note. GWP=global warming potential, GTP=global temperature change potential.

Average CO_2 equivalents per head for GTP and GWP can be used to compare the different production systems (Table 10). The dairy cows from the peasant farms produce higher CO_2 eq for GTP than from the mega farms: 1 022 and 790 kg CO_2 eq (GTP), respectively. Clearly lower GHG emissions are produced in the small farms with 240 kg CO_2 eq (GTP) per dairy cow. With respect to CO_2 eq for GWP, dairy cows from peasant farms have lower emissions with a value of 1092 kg CO_2 eq in comparison to mega farms, in which a dairy cow contributes up to 1915 kg CO_2 eq to the total balance of the GHG emissions from manure. With respect to GWP, dairy cows from small farms also have the lowest CO_2 eq per head: 373 kg CO_2 eq. The category “other cattle” does not have significantly different GTP values for CO_2 eq per head: The peasant farms have 266 kg CO_2 eq and the mega farms have 295 kg CO_2 eq. The values for CO_2 eq for the small farms are clearly less with 119 kg CO_2 eq (GTP). With respect to the GWP values, the category “other cattle” from the mega farms has the highest emissions with 732 kg CO_2 eq.

In swine farming the CO_2 eq from peasant farms is 137 for GTP, and from mega farms it is 134 kg CO_2 eq per head. Due to the solid manure system used in the small farms, 45 kg CO_2 eq (GTP) are produced per swine. With respect to the GWP values in swine farming, the mega farms have highest values with 363 kg CO_2 eq per swine. The small farms have smallest GHG emissions from manure with 72 CO_2 eq per swine.

The higher N_2O emissions from the sheep and goat pasturing from the peasant farms cause the higher CO_2 eq for

GTP with 70 and GWP with 73 CO_2 eq per head. In small farms and mega farms 37 (GTP) and 41 (GWP) CO_2 eq per head are produced respectively.

A comparison of the three manure types: solid manure, slurry and dry manure from poultry farming shows that the accumulation of naturally wet solid manure in broiler production in small, and mega farms is the climate friendly variant with 0.4 kg CO_2 eq (GTP) and 0.8 kg CO_2 eq (GWP) per stable place, whereas 13 kg (GTP) and 39 (GWP) kg CO_2 eq are produced annually per stable place in slurry lagoons in mega farms. Battery-cages, in which the chicken dung is dried on the belts, are also more climate friendly than slurry lagoons in mega farms (2.2 kg GTP and 2.9 kg GWP CO_2 eq).

Horse pasturing in peasant farms produces the highest CO_2 eq per head in the GTP (365 kg CO_2 eq) and GWP values (392 kg CO_2 eq). In small farms the GHG emissions are lower with 189 kg CO_2 eq (GTP) and 225 kg CO_2 eq (GWP). Horse farming in mega farms leads to lowest annually CO_2 equivalents per horse: 137 kg CO_2 eq (GTP) and 173 kg CO_2 eq (GWP).

Table 10. Annual average CO_2 equivalents per head for GTP and GWP in the different production systems in the Tyumen oblast

Livestock category	Peasant farms	Small farms	Mega farms
	CO_2 eq GTP_{100} (kg head^{-1} a^{-1})		
Dairy cow	1 022	240	790
Other cattle	266	119	295
Swine	137	45	134
Sheep / Goat	70	37	37
Layer (dry)	-	-	2.2
Layer (wet)	-	-	13
Broiler	3.1	0.4	0.4
Horse	365	189	137
	CO_2 eq GWP_{100} (kg head^{-1} a^{-1})		
Dairy cow	1 092	373	1 915
Other cattle	292	171	732
Swine	151	72	363
Sheep / Goat	73	41	41
Layer (dry)	-	-	2.9
Layer (wet)	-	-	39
Broiler	3.4	0.8	0.8
Horse	392	225	173

Source: IPCC, 2006; IPCC, 2013; LWK, 2009; ROSSTAT; 2013

Note. GWP=global warming potential, GTP=global temperature change potential, - Data not available.

5. Discussion

5.1 Influence of Livestock Production Systems on GHG Emissions and Environment

In the Tyumen oblast a clear difference can be seen in the amount of GHG emissions due to the manure handling systems in the three production systems: mega farms, small farms and peasant farms. The number of livestock and the manure handling system in the respective production system have an influence upon the amount of GHG emissions. The differences in CO_2 eq per head are not significantly different in peasants and mega farms (Table 10). The difference of higher GHG emissions from mega farms can be explained through the difference in livestock populations in comparison to peasants. Mega farms have higher cattle stocks and swine's stocks than peasants. The peasants have higher numbers of horses and sheep / goats (Table 2). Responsible for the higher GHG emissions at mega farms is the category "dairy cow" with significantly higher CO_2 eq emissions than horses and sheep / goats (Table 10). Additionally, higher GHG emissions in mega farms are caused by the three large poultry producers, which kept 95 % of poultry stock in Tyumen Oblast (Table 2).

It is a known problem that in mega farms, the use of livestock manure without targeted management leads to environmental pollution and waste of the fertilization potential (Moore, Daniel, Sharpley, & Wood, 1995; DeLuca, & DeLuca, 1997; Jongbloed, & Lenis, 1998; Otabbong et al., 2007). Also in Tyumen oblast manure handling at mega farms leads to environmental pollution. Highest environmental pollution is reported for the three large poultry producers in Tyumen oblast. Increased levels of nitrite, bromine, barium, lead and sodium in groundwater have been measured by state investigations on agricultural areas of the poultry producers in Tyumen oblast (Administration of Tyumen Oblast, 2012).

In large-scale livestock farming, cattle and swine year-round indoor stabling requires manure storage capacities that are usually not available in Russia or in the Tyumen oblast (Bondarenko et al., 2010; Störrle et al., 2015). Slurry lagoons, which in practice represent large earth holes, lead to pollutant emissions. Manure disposal onto bare fallows or forests, in which several tonnes of manure are applied at single points, or pumping slurry into a hole in the ground near the stable lead to negative environmental impacts in the Tyumen oblast (Administration of Tyumen Oblast, 2012; Störrle et al., 2015). At the same time, these methods can lead to a reduction in the methane emissions under Siberian climate. Methane emissions sink under cold outside temperatures (Husted, 1994; Sommer, Petersen, & Møller, 2004).

The environment is not polluted in small farms and peasants and the farmyard manure is used appropriately (Jarvis, 1993; Devendra, & Thomas, 2002; Rufino et al., 2007). Inadequate manure handling cannot be detected on peasant farms and small farms in Tyumen oblast.

5.2 Recommendations for the Reduction of GHG Emissions

The production systems have a clear impact upon the amount of GHGs emitted from manure. Solid manure system on the small farms leads to lowest GHG emissions from manure handling systems (Table 10). Converting the mega farm manure handling system from slurry to solid manure would reduce the annual GHG emissions by two thirds.

Since neither mega nor small farms have closed storage facilities for manure in the Tyumen oblast, the manure is also taken outside in winter. Some mega farms spread the manure on bare fallow the entire year. In other cases, manure is illegally disposed of on open unused areas. Mega farms also have widespread open slurry lagoons. These practices lead to a natural reduction of the methane emissions. Since methanogenesis is dependent upon the temperature, cooling slurry is an option for reducing methane emissions (Husted, 1994; Sommer et al., 2004). However, this procedure leads to negative environmental impacts due to nitrate leaching and ammonia emissions (De Bode, 1991; Otabbong et al., 2007). Furthermore, this also squanders the fertilisation potential that livestock manure provides. Setting up closed storage facilities for manure or slurry of the stable would avoid the negative environmental impacts. An additional utilisation of such storage would also be biogas production.

Kühling et al. (2015) recommends for Western Siberian regions low intensity land-based cattle farming by mega farms with obligatory summer grazing and hay production. This measure would reduce slurry amounts and enhance biodiversity. Because ancient and ex-arable grasslands are important for biodiversity conservation in this region (Mathar et al., 2015; Kämpf, Mathar, Kuzmin, Hölzel, & Kiehl, 2016; Weking, Kämpf, Mathar, & Hölzel, 2016). Furthermore, nutrients in manure could be applied back to soil without transportation costs for the manure. On pastures that are used at low intensity, livestock excrements contribute to SOC enrichment and improvement of aggregate stability (Franzluebbers, Stuedemann, Schomberg, & Wilkonson, 2000; Whitehead, 2000; Wortmann, & Shiparo, 2008).

There are several technical methods that are recommended by FAO (Hristov et al., 2013), to reduce GHG emissions from manure. Examples of these methods are dietary manipulation and nutrient balance: reduced dietary protein, high fibre diets and reduced grazing intensity. There are also methods for direct manure treatment that can be applied. Among these are anaerobic digestion, solids separation, aeration and manure acidification, nitrification inhibitor and urease inhibitor. Furthermore, various manure storage methods also reduce GHG: decreased storage time, storage cover with straw, natural or induced crust, aeration during slurry storage, composting, litter stacking and storage temperature regulation (Hristov et al., 2013, Hothan, Brauckmann, & Broll, 2013).

Presently none of these methods are being applied in the Tyumen oblast, excepting isolated cases of solids separation. Nor is any research being carried out on this topic. These methods should be investigated in scientific tests to determine the local suitability. Moreover, possible interactions when applying these methods need to be scientifically investigated, to determine, e.g., if the methods have a negative impact on the productivity of the livestock or if they possibly influence the soil micro-organisms.

6. Conclusions

In Tyumen oblast, 7 400 t methane and 440 t nitrous oxide are emitted annually from manure handling. That equates to about 211 kt CO_2 eq for global temperature change potential (GTP) for a 100 year time horizon. In the taiga 46 kt CO_2 eq (GTP) are emitted annually and in the forest steppe 165 kt CO_2 eq (GTP).

With 81 %, mega farms have the highest share of GHG emissions from manure handling with 171 kt CO_2 eq (GTP) annually in Tyumen oblast. Additionally, the slurry system in mega farms causes environmental pollution. GHG emissions from small farms account for annually 1 % (2.6 kt CO_2 eq) of total GHG emissions from manure handling. The share of peasant farms in GHG emissions from manure handling is 18 % with 38 kt CO_2 eq annually.

GHG emissions and environmental pollution could be reduced by implementing solid manure systems or low-intensity pasturing, by installing storage facilities outside the stables and through application of the manure as fertiliser. GHG emissions at small farms are lower due to solid manure system. Manure usage in small farming cycles would enhance SOC sequestration and biodiversity.

Acknowledgements

This work was conducted as part of the project SASCHA ('Sustainable land management and Adaptation strategies to climate change for the Western Siberian Grain Belt'). We are grateful for funding by the German Government, Federal Ministry of Education and Research within their Sustainable Land Management funding framework (funding reference 01LL0906G). We acknowledge support by Deutsche Forschungsgemeinschaft (DFG) and Open Access Publishing Fund of Osnabrück University. Also, we thank Insa Kühling for helpful comments.

References

Abramov, N. V. (2013). *Production in agroecosystems and condition of soil fertility in Western Siberia*. State Agricultural University of Northern Transural, Tyumen. (Russian).

Administration of Tyumen Oblast. (2012). *Report on the environmental situation in the Tyumen oblast in 2011*. Retrieved March 3, 2013, from http://admtyumen.ru/ogv_ru/about/ecology/eco_monitoring/more.htm?id=10922884@cmsArticle.

Beckwith, C. P., Cooper, J., Smith, K. A., & Shepherd, M. A. (1998). Nitrate leaching loss following application of organic manures to sandy soils in arable cropping. *Soil Use and Manage, 14*(3), 123-130. https://doi.org/10.1111/j.1475-2743.1998.tb00135.x

Bondarenko, A.M., Miroshnikov, & M.A., Miroshnikov, V.V. (2010). Study of processing semiliquid manure in high-quality organic fertiliser. *Vestnik Agricultural Science of Don, 3,* 15-19. (Russian).

Bulatov, A. P., & Kurdoglyan, A. A. (2006). *The milking of cows: theory and practice.* Kurgan. (Russian).

De Bode, M. J. C. (1991). *Odour and ammonia emissions from manure storage*. Odour and ammonia emissions from livestock farming, 5, 59.

Degefie, T. D., Fleischer, E., Klemm, O., Soromotin, A. V., Soromotina, O. V., Tolstikov, A. V., & Abramov, N.V. (2014). Climate extremes in South Western Siberia: past and future. *Stochastic Environmental Research and Risk Assessment, 28,* 2161-2173. https://doi.org/10.1007/s00477-014-0872-9

DeLuca, T. H., & DeLuca, D. K. (1997). Composting for feedlot manure management and soil quality. *Journal of Production Agriculture, 10*(2), 235-241. https://doi.org/10.2134/jpa1997.0235

Devendra, C., & Thomas, D. (2002). Crop–animal interactions in mixed farming systems in Asia. *Agricultural Systems, 71*(1), 27-40. https://doi.org/10.1016/S0308-521X(01)00034-8

Eremin, D. I. (2012). *Transformation of Luvic Chernozems due to agricultural land use in the northern Transural* (PhD thesis). Agricultural Academy of the province of Tyumen, Russia. (Russian).

European Comission. (2009). Commission Regulation (EC) No 1200/2009 of 30 November 2009 implementing Regulation (EC) No 1166/2008 of the European Parliament and of the Council on farm structure surveys and the survey on agricultural production methods, as regards livestock unit coefficients and definitions of the characteristics. Official Journal of the European Union. Luxemburg.

FAO (2016). FAO's work on Climate Change: Greenhouse Gas Emissions from Agriculture, Forestry and Other Land Use. Retrieved November 24, 2016, from http://www.fao.org/3/a-i6340e.pdf

Franzluebbers, A. J., Stuedemann, J. A., Schomberg, H. H., & Wilkonson, S. R. (2000). Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA. *Soil Biology and Biochemistry, 32*(4), 469-478. https://doi.org/10.1016/s0038-0717(99)00176-5

Frey, K. E., & Smith, L .C. (2003). Recent temperature and precipitation increases in West Siberia and their association with the Arctic Oscillation. *Polar Research, 22*(2), 287-300. https://doi.org/10.3402/polar.v22i2.6461

Fukumoto, Y., Suzuki, K., Waki, M., & Yasuda, T. (2015). Mitigation option ofgreenhouse gas emissions from livestock manure composting. *JARQ-Japan Agricultural Research Quarterly, 49*(4), 307-312. https://doi.org/10.6090/jarq.49.307

Hothan, A., Brauckmann, H. J., & Broll, G. (2013). Influence of storage on methane yields of separated pig slurry solids. *Biomass and Bioenergy, 52*, 166-172. https://doi.org/10.1016/j.biombioe.2013.03.013

Hristov, A.N., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., … Oosting, S. (2013). Mitigation of greenhouse gas emissions in livestock production – A review of technical options for non-CO2 emissions. In P. J. Gerber, B. Henderson & H. P.S. Makkar (Eds.), *FAO Animal Production and Health Paper,* No. 177. Rome, Italy: FAO.

Husted, S. (1994). Seasonal variation in methane emission from stored slurry and solid manures. *Journal of Environmental Quality, 23*(3), 585-592. https://doi.org/10.2134/jeq1994.00472425002300030026x

IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories*. Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds). Institute for Global Environmental Strategies, Hayama, Japan: IPCC.

IPCC. (2013). *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental. Panel on Climate Change.* In Climate Change 2013. Stocker, T.F., D. Qin, G.-K., Plattner, M., Tignor, S.K., Allen, J., Boschung, A., Nauels, Y., Xia, V., Bex, & P.M. Midgley (Eds.). Cambridge University Press, Cambridge, United Kingdom und New York, NY, USA: IPCC.

Jarvis, S. C. (1993). Nitrogen cycling and losses from dairy farms. *Soil Use and Management*, *9*(3), 99-104. https://doi.org/10.1111/j.1475-2743.1993.tb00937.x

Jongbloed, A. W., & Lenis, N. P. (1998). Environmental concerns about animal manure. *Journal of Animal Science, 76*(10), 2641-2648. https://doi.org/10.2527/1998.76102641x

Jungbluth, T., Hartung, E., & Brose, G. (2001). Greenhouse gas emissions from animal houses and manure stores. *Nutrient Cycling in Agroecosystems, 60*(1-3), 133-145. https://doi.org/10.1023/A:1012621627268

Karetin, L. N. (1990). *Soils in Tyumen oblast*. Nauka, Novosibirsk. (Russian).

Kämpf, I., Mathar, W., Kuzmin, I., Hölzel, N., & Kiehl, K. (2016). Post-Soviet recovery of grassland vegetation on abandoned fields in the forest steppe zone of Western Siberia. *Biodiversity and Conservation, 25*(12), 2563-2580. https://doi.org/10.1007/s10531-016-1078-x

Kühling, I., Broll, G., & Trautz, D. (2016). Spatio-temporal analysis of agricultural land-use intensity across the Western Siberian grain belt. *Science of the Total Environment, 544*, 271-280. https://doi.org/10.1016/j.scitotenv.2015.11.129

Kühling, I., Griewald, Y., Broll, G., & Trautz, D. (2015). Potential of land-use intensity analysis for sustainable land management scenarios in Southern West Siberia. *Geo-Öko, 36*(3-4), 112-132.

Leet, J. K., Lee, L. S., Gall, H. E., Goforth, R. R., Sassman, S., Gordon, D. A., … Sepúlveda, M. S. (2012). Assessing impacts of land-applied manure from concentrated animal feeding operations on fish populations and communities. *Environmental Science & Technology, 46*(24), 13440-13447. https://doi.org/10.1021/es302599t

LWK. (2009, July 10). Lower Saxony Chamber of Agriculture, Germany. *Nährstoffausscheidungen landwirtschaftlicher Nutztiere je Stallplatz und Jahr (Nutrient excretion rates of farm animals per stable space and year)*. Retrieved June 11, 2013, from http://www.lwk-niedersachsen.de/download.cfm/file/196,78663bd7-237d-eebf5e6f095916f0ca16 ~pdf.html

Mathar, W. P., Kämpf, I., Kleinebecker, T., Kuzmin, I., Tolstikov, A., Tupitsin, S., & Hölzel, N. (2015). Floristic diversity of meadow steppes in the Western Siberian Plain: effects of abiotic site conditions, management and landscape structure. *Biodiversity and Conservation, 25*(12), 2361-2379. https://doi.org/10.1007/s10531-015-1023-4

McGinn, S. M., & Sommer, S. G. (2007). Ammonia emissions from land-applied beef cattle manure. *Canadian Journal of Soil Science, 87*(3), 345-352. https://doi.org/10.4141/s06-053

Monteny, G. J., Groenestein, C. M., & Hilhorst, M. A. (2001). Interactions and coupling between emissions of methane and nitrous oxide from animal husbandry. *Nutrient Cycling in Agroecosystems*, *60*(1-3), 123-132.

https://doi.org/10.1023/a:101260 2911339

Moore, P. A., Daniel, T. C., Sharpley, A. N. & Wood, C. W. (1995). Poultry manure management: Environmentally sound options. *Journal of soil and water conservation 50*(3), 321-327.

O'Mara, F. P. (2011). The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. *Animal Feed Science and Technology, 166*, 7-15. https://doi.org/10.1016/j.anifeedsci.2011.04.074

Otabbong, E., Arkhipchenko, I., Orlova, O., Barbolina, I., & Shubaeva, M. (2007). Impact of piggery slurry lagoon on the environment: A study of groundwater and river Igolinka at the Vostochnii Pig Farm, St. Petersburg, Russia. *Acta Agriculturae Scandinavia, Section B — Soil & Plant Science 57*(1), 74-81. https://doi.org/10.1080/09064710600933228

Owen, J. J., & Silver, W. L. (2015). Greenhouse gas emissions from dairy manure management: review of field-based studies. *Global Change Biology, 21*(2), 550-565. https://doi.org/10.1111/gcb.12687

ROSREESTR. (2012). Report on the state of property and the land use in the Tyumen oblast in the 2011. Federal Service of State Registration, Cadastre and Cartography of the Tyumen oblast. Retrieved July 20, 2013, from http://www.to72.rosreestr.ru/. (Russian).

ROSSTAT. (2013). *Agricultural indicators of Tyumen oblast*. Russian Federal State Statistics Service. Retrieved, April 14, 2013, from http//www.gks.ru

ROSSTAT. (2016). *Population indicators of Tyumen oblast*. Russian Federal State Statistics Service. Retrieved, October 14, 2016, from http//www.gks.ru

Rufino, M. C., Tittonell, P., Van Wijk, M. T., Castellanos-Navarrete, A., Delve, R. J., De Ridder, N., & Giller, K. E. (2007). Manure as a key resource within smallholder farming systems: analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. *Livestock Science, 112*(3), 273-287. https://doi.org/10.1016/j.livsci.2007.09.011

Sharpley, A., Meisinger, J. J., Breeuwsma, A., Sims, J. T., Daniel, T. C., & Schepers, J. S. (1997). *Impacts of animal manure management on ground and surface water quality*. Animal waste utilization: effective use of manure as a soil resource, 173-242. https://doi.org/10.1201/9781439822630.ch8

Shulgina, T. M., Genina, E. Yu., & Gordov, E. P. (2011). Dynamics of climatic characteristics influencing vegetation in Siberia. *Environmental Research Letters, 6*, 1-7. https://doi.org/10.1088/1748-9326/6/4/045210

Sneath, R. W., Beline, F., Hilhorst, M. A., & Peu, P. (2006). Monitoring GHG from manure stores on organic and conventional dairy farms. *Agriculture, Ecosystems & Environment, 112*(2), 122-128. https://doi.org/10.1016/j.agee.2005.08.020

Sommer, S. G., Petersen, S. O., & Møller, H. B. (2004). Algorithms for calculating methane and nitrous oxide emissions from manure management. *Nutrient Cycling in Agroecosystems, 69*, 143-154. https://doi.org/10.1023/b:fres.0000029678.25083.fa

Störrle, M., Brauckmann, H. J., & Broll, G. (2015). Livestock manure management in agroecosystems of southwestern Siberia, Russia. *Geo-Öko. 36*(3-4), 133-154.

Störrle, M., Hagedorn, L., Yurtaev, A., Brauckmann, H. J., & Broll, G. (2016). Soil structure of arable and non-arable land in the Western Siberian Grain Belt in Russia - Application of the soil fingerprint code for topsoil characterization. *Journal of Plant Nutrition and Soil Science, 179*(4), 510-519. https://doi.org/10.1002/jpln.201500450

Stupak, N. (2017). Adaptation of Russian agriculture to climatic variability: the role of federal and provincial policies. *Environmental Science & Policy 68*, 10-19. https://doi.org/10.1016/j.envsci.2016.10.003

Tubiello, F. N., Salvatore, M., Ferrara, A. F., House, J., Federici, S., Rossi, S., … Prosperi, P. (2015). The contribution of agriculture, forestry and other land use activities to global warming, 1990–2012. *Global Change Biology, 21*(7), 2655-2660. https://doi.org/10. 1111/gcb.12865

van der Meer, H. G. (2008). Optimising manure management for GHG outcomes. *Animal Production Science, 48*(2), 38-45. https://doi.org/10.1071/EA07214

Václavík, T., Langerwisch, F., Cotter, M., Fick, J., Häuser, I., Hotes, S., … Seppelt, R. (2016). Investigating potential transferability of place-based research in land system science. *Environmental Research Letters, 11*(9), 095002. https://doi.org/10.1088/1748-9326/11/9/095002

Weking, S., Kämpf, I., Mathar, W., & Hölzel, N. (2016). Effects of land use and landscape on Orthoptera communities in the Western Siberian forest steppe. *Biodiversity and Conservation*, *25*(12), 2341-2359. https://doi.org/10.1007/s10531-016-1107-9

Whitehead, D. C. (2000). Nutrient elements in grassland: soil-plant-animal relationships. Oxon, UK: Cabi. https://doi.org/10.1079/9780851994376.0000

Wortmann, C. S., & Shiparo, C. A. (2008). The effects of manure application on soil aggregation. *Nutrient Cycling in Agroecosystems, 80*(2), 173-180. https://doi.org/10.1007/s10705-007-9130-6