With support from

Federal Ministry
of Food
and Agriculture

by decision of the
German Bundestag

GERMAN-MONGOLIAN
COOPERATION PROJECT
"SUSTAINABLE AGRICULTURE"

STUDY

ON SUSTAINABLE AND CLIMATE CHANGE ADAPTED LAND USE IN THE MONGOLIAN CROP SECTOR

ULAANBAATAR
2020

GFA CONSULTING GROUP
General Agent BMEL
Berlin Office

STUDY

ON SUSTAINABLE AND CLIMATE CHANGE ADAPTED LAND USE IN THE MONGOLIAN CROP SECTOR

Implemented by

IAK AGRAR CONSULTING

AFC AGRICULTURE & FINANCE CONSULTANTS

DLG International

Disclaimer

This study is published under the responsibility of German-Mongolian Cooperation Project Sustainable Agriculture (MNG 19-01) and Subproject Expert dialogue on agriculture for climate change adaptation of the Mongolian crop sector (MNG 19-02), which are funded by the German Federal Ministry of Food and Agriculture (BMEL). All views and results, conclusions, proposals or recommendations stated therein are the property of the authors and do not necessarily reflect the opinion of the BMEL.

Edited by:

***Prof. Dr.* G.Gantulga**

***Dr.* B.Erdenebolor**

CONTENTS

FOREWORD

The German-Mongolian cooperation project "Sustainable Agriculture", implemented through a collaboration agreement between the Federal Ministry of Food and Agriculture of Germany and the Ministry of Food, Agriculture and Light Industry of Mongolia, entered its 3rd phase in 2019. The project focuses on development of a sound seed and variety system, dissemination of good agricultural practices and introduction of risk management approaches in the crop sector of Mongolia. The project activities can be structured in:

- Delivery of policy advice for enhancing the legal frameworks in the agricultural sector of Mongolia towards international standards;
- Provision of support and advice to key governmental and non-governmental actors in the sector, incl. farmer associations, research institutes and extension service providers for strengthening the institutional frameworks of the crop sector;
- Advanced and follow-up training of decision-makers, specialists and farmers for building the human resource capacity of the crop sector;
- Provision of information and research for the specific needs of project partners and target groups.

Supplementary climate funds approved by the Federal Ministry of Food and Agriculture in 2019 enabled us to initiate and implement the subproject "Expert dialogue on agriculture for climate change adaptation of the Mongolian crop sector". A major achievement of this subproject is the completion of a comprehensive study on the effects of climate change on the Mongolian crop sector and options for climate change adaptation, which is presented hereby.

Climate change is increasingly affecting agriculture. In Mongolia, the annual average temperature has risen by more than 2°C since 1940, and the crop sector is exposed to threats resulting from increasing frequencies and impacts of weather extremes, dryness and extraordinary heat, and a dramatic change in the seasonal distribution of precipitation. Elaboration and implementation of a long-term strategy for climate change adaptation is thus becoming inevitable, especially for countries with harsh climate such as Mongolia.

The Government of Mongolia has set goals for the reduction of greenhouse gas emission and the adaptation of the agricultural sector to climate change. For informed decision-making and turning decisions into actions at policy and production levels, reliable information and knowledge on sustainable cropping methods and approaches for adaptation of crop production to climate change are essential. This study therefore presents an important contribution to the development of a climate change adapted crop sector in Mongolia. It was conducted by a team of international and domestic researchers specializing in agricultural meteorology, soil science, agronomy and agricultural engineering. Based on research findings and using successful practical examples, the study provides insights into currently applied approaches and solutions for the adaptation of crop production to climate change, and discusses potential adaptation approaches for the future. Part of the study also assesses the embedment of climate change adaptation goals and related measures in the policy and legal frameworks of the agricultural sector.

The negative impacts of climate change are leading to yield losses, price increases of staple foods, and food shortages, thus threatening agricultural productivity and compromising the access of the vulnerable and low-income population segments to food. On behalf of the German-Mongolian cooperation project "Sustainable Agriculture", I am pleased to present this study as a contribution to the sustainable development of the food and agriculture sector, poverty reduction and food security in Mongolia.

***Dr.* Kather A.**
Team Leader

GERMAN-MONGOLIAN COOPERATION PROJECT
"SUSTAINABLE AGRICULTURE"

FOREWORD

The world population has already surpassed 7.5 billion and is projected to reach 10 billion in 2050 and 12 billion by 2100. Along with the rapid population growth, the importance of securing the availability of and access to food is continuously increasing. With future food security, far from being ensured, mankind is facing the additional threat of climate change and global warming.

In our country, where the intensity of warming has been three times the global average, resulting in a 2.4° C increase of air temperature during the last 80 years, this issue requires particular attention. Having joined numerous international conventions and treaties on mitigation of the negative impacts of climate change and adaptation to climate change, the parliament and the government of Mongolia have initiated national policies and programs and are working towards their successful implementation. The “National Program on Climate Change” was first approved by the parliament in 2000, and in a renewed version in 2011. The “Intended Nationally Determined Contribution of Mongolia” for the Paris Agreement was submitted in 2015 and 2019 to the UNFCCC Secretariat. Furthermore, climate change adaptation goals and related measures have been defined in the “Mongolia Sustainable Development Vision 2030” and the “Green Development Policy of Mongolia (2014-2030)”, both of which are currently being implemented.

The government of Mongolia is planning a new program for the crop sector development. The “Atar 4 – Sustainable Crop Sector Development” program will start in 2020, and we are already preparing the action plan of this program which defines the adaptation to climate change as a priority. The program aims at supporting the sustainable development of crop production through the adaptation to climate change, stabilizing crop yields, protecting the soil, improving soil fertility, facilitating breeding of new drought tolerant varieties and experimentation with and introduction of new crops, increasing the domestic seed production and the availability and use of fertilizers and pesticides as well as introducing the application of smart (digital) technologies in crop production.

The cooperation project “Sustainable Agriculture” of the Ministry of Food, Agriculture and Light Industry of Mongolia and the Federal Ministry of Food and Agriculture of Germany implemented a subproject on climate change adaptation in the crop sector in 2019. An important outcome of this subproject is the study presented hereby. It was conducted by a team of acknowledged international and national researchers, and the results were presented and discussed at the international conference “Sustainable and Climate Change Adapted Land Use in the Mongolian Crop Sector” that took place in Ulaanbaatar in December 2019. I am pleased that the study is now also available in print so that it is accessible to a wider circle of policy and decision makers, scientists, students and farmers.

I would like to use this occasion to express my sincere gratitude to the team of the German-Mongolian cooperation project “Sustainable Agriculture”. I wish every success in your future endeavors!

Bolorchuluun Ts.
Director General of the Department of Policy and
Coordination of Crop Sector Development

MINISTRY OF FOOD, AGRICULTURE AND LIGHT INDUSTRY

FOREWORD

The efforts of the government of Mongolia in accelerating the development of crop production, increasing the sector's performance, and enhancing domestic supply of healthy and safe organic foods have resulted in remarkable achievements during the recent years. However, due to limitations arising from the unique geographic location and harsh climate of Mongolia, which are further exacerbated by global warming and other effects of climate change, as well as shortcomings in the currently applied cropping methods and technologies, problems such as deterioration of soil fertility, drop in productivity and frequent yield losses are still persisting. At a warming intensity that is three times the global average, the annual temperature in Mongolia has increased by 2.40° C. In addition, a declining trend in the amount of precipitation during the vegetation period has been confirmed. Under these conditions, the need to modernize crop production through development and introduction of climate-smart, environmentally sound and labor and energy saving technologies must be urgently recognized, and decisive actions are required.

In response to this challenge, the German-Mongolian cooperation project "Sustainable Agriculture", which has been successfully implemented with the support by the Federal Ministry of Food and Agriculture of Germany since 2013, organized the international conference "Sustainable and Climate Change Adapted Land Use in the Mongolian Crop Sector" in Ulaanbaatar from 3 to 4 December 2019. The conference was attended by representatives from the Ministry of Food, Agriculture and Light Industry of Mongolia, MULS, the Institute of Hydrology, Meteorology and Environmental Monitoring, and professional and farmer associations of the Mongolian crop sector, besides delegates from German organizations such as the Institute of Soil Science of the University of Hanover, the Leibniz Institute of Agricultural Development in Transition Economies (IAMO) and the agricultural machinery manufacturer Amazone. During the two-day conference, research findings on current and future impacts of climate change on crop production in Mongolia were presented, and ideas and experiences were exchanged with the aim of identifying the sector's adaptation needs and, drawing on international experiences, possible adaptation strategies and solutions. The conference concluded with the formulation of policy recommendations for climate change adaptation in the crop sector. As a co-editor of the proceedings, I am very glad to present the research findings, which were introduced at this important event, to a wider audience.

The information and recommendations compiled in this brochure could make a significant contribution to the modernization of crop production in Mongolia through the introduction of cropping systems that are adapted to climate change. The recommendations also address the need to increase crop productivity and the profitability of cropping, and include strategies for reducing the risks of cropping and mitigating deterioration of soil fertility.
I am confident that crop farmers are aware that the prerequisite for the sustainable use of the relatively vulnerable natural resources in Mongolia and the establishment of cropping systems adapted to climate change is to modernize crop production towards the application of environmentally friendly, resource-saving green technologies. I am also confident that the farmers will have the courage and determination to make sustainable changes in the crop production system for the good of our country, our globe and our future generations.

On behalf of myself and my colleagues from the Academic Council of the Mongolian University of Life Sciences I would like to profoundly thank the team leader Dr. Alfred Kather and the staff of the "Sustainable Agriculture" project for organizing the international conference as well as the senior and other MOFALI officials and researchers for their support.

Let us show love for our beautiful homeland for all it gives to us!

Prof. Dr. **Gantulga G.**
Vice Rector for Research and Innovation

MONGOLIAN UNIVERSITY OF LIFE SCIENCES

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BAU	Business as usual
BMBF	German Federal Ministry of Education and Research
CARP	China Agricultural Reinsurance Pool
ce	centner
CIRC	China Insurance Regulatory Commission
CPI	Standardized Precipitation Index
CRMG	Commodity Risk Management Group
CRS	Crop Rotation System
CSA	Climate-Smart Agriculture
DFID	Department for International Development
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FSCF	Fund on Supporting Crop Farming
FSF	Farming Support Fund
GASI	General Agency of Specialized Inspection
GDD	Growing Degree Days
GHG	Greenhouse Gas
GIZ	German Corporation for International Cooperation GmbH
GMF	Green Manure Fallow
ha	Hectare
HTC	Hydrothermal Coefficient
IAEA	International Atomic Energy Agency
IBLI	Index-based Livestock Insurance
IFAD	International Fund for Agricultural Development
IFC	International Finance Corporation
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
MEGD	Ministry of Environment and Green Development of Mongolia
MET	Ministry of Environment and Tourism of Mongolia
MoFALI	Ministry of Food, Agriculture and Light Industry of Mongolia
MPCI	Multi-peril crop insurance
MSIS	Mongolian Statistical Information Service
MULS	Mongolian University of Life Sciences
NDC	Nationally Determined Contribution
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental organization
NSOM	National Statistics Office of Mongolia
OECD	Organisation for Economic Co-operation and Development
OSR	Oilseed Rape
PSARI	Plant Science and Agricultural Research Institute
RCP	Representative Concentration Pathway
SFCF	Support Fund for Crop Farmers
SMI	Soil Moisture Index
SP	State Parliament
SPEI	Standardized Precipitation Evapotranspiration Index
SST	State Seed Test
SSTU	State Seed Testing Unit
TFP	Total Factor Productivity
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations International Children's Emergency Fund
USSR	Union of Soviet Socialist Republics
WFP	World Food Programme
WHO	World Health Organization
WMO	World Meteorological Organization
WPR	World Policy Review
WRMS	Weather Risk Management Services

THE EFFECTS OF CLIMATE CHANGE ON THE CROP FARMING SECTOR OF MONGOLIA

Authored by:

***Doctor of Geography (PhD)* Natsagdorj L.**
Honored worker of Environment

***Doctor of Agricultural Sciences (PhD)* Erdenetsetseg B.**
Research Institute of Meteorology, Hydrology and Environment of Mongolia

CONTENTS

INTRODUCTION

One of the most important natural conditions for the sustainable development of agriculture, particularly crop production, is climate. As a result of the “Green Revolution” that happened in the agricultural sector during a period of scientific and technological innovations, agricultural production has become less dependent on natural factors. However, its efficiency and sustainability continue to rely heavily on climatic conditions, and in some ways have become even more dependent.

According to a recent climate change assessment, Mongolia’s socio-economic development has become more susceptible to changes in the climate due to factors such as the vulnerable ecosystem of the country, dependence on pastoral livestock and non-irrigated farming, rise in urban population, and increased migration. Based on assessments of current and future impacts of climate change, Mongolia’s surface water, forest resources, rangeland, soil and socio-economic sectors, such as livestock and crop production, health and natural disaster management, are areas that may be the most affected ones *(Ministry of Environment and Green Development (MEGD), 2014; Ministry of Environment and Tourism (MET), 2018)*.

Although Mongolia’s conventional agricultural sectors, livestock and crop farming, have adapted to climate change and the associated risks in the long run, substantial efforts from the government are required. These should particularly focus on increasing the crop diversity and implementing innovative technologies to mitigate the challenges posed by the effects of rapid climate change in recent years. Pasture availability and crop production will be affected by changes in rangeland capacity, and although crop yields may improve in some regions, most agricultural producers will require a substantial amount of investment to adapt to climate change, at some risk to suffer losses *(MEGD, 2014)*.

Permanent monitoring of changes in agro-climatic resources leads to improvements in the selection of crops adapted to the current weather and climatic conditions, in decision making on which new crops should be introduced or eliminated from crop rotation, as well as in selection of agricultural machinery, equipment and techniques, and the development of methods to determine the conditions for emergence and prevalence of pests and diseases. A constant detailed monitoring of the agro-climatic resources, especially with regard to the current drastic changes in global climate, may bring benefits in adaptation of crop production that further secures sustainable food production for an increasing demand of a rising population.

1. MONGOLIA’S AGRO-CLIMATIC RESOURCES AND THEIR CHANGES

1.1. DEPENDENCE OF WHEAT YIELDS ON WEATHER CONDITIONS

The effects of global warming on Mongolia have been significant as the annual average air temperature rose by 2.4 °C between the years 1940 and 2018, which is about three times higher than the global average of 0.85 °C. The fact that the amount of precipitation did not rise during that time span but decreased slightly over the vegetation period, creates an additional challenge to agricultural production. This brings negative natural and socio-economic consequences such as an increase in the frequency of droughts, dzuds (severe winter conditions), floods, arterial winds and heatwaves, an increased evaporation potential as well as a soil moisture imbalance; all of which lead to scarcity of water resources, rangeland desertification, increase in fluctuations in crop yields, and pest and disease outbreaks *(MET, 2018)*.

Due to the harsh, drastic climatic conditions, rainfed agriculture in Mongolia is extremely risky, resulting in crop losses in more than 2 out of every 10 years. According to various estimates of the bio-potential of the climate, the current grain production areas are located within medium-low or low bio-potential zones, and are not located within **medium** or **high bio-potential zones** *(Natsagdorj et al., 2019)*.

In general terms, climate is the cumulative average of the atmospheric parameters and has established itself in an area over many years. In the current state of rapid climate change, the World Meteorological Organization defined the climatological standard normals (or the normal ranges of the climate) as averages of the parameters computed for the last 30 years. As such, the normal range (normal) is considered to be the long-term average in the period from 1981 to 2010.

Crop yields are heavily dependent on each year’s weather conditions since Mongolia’s climate is risky for crop production and is an area with low bio-potential. The dependence of wheat yields on the main meteorological parameters during the vegetation period each year is depicted in **Table 1.1**.

Region	Vegetation stages	Climate parameters			
		T	P	HTC	S_i
Orkhon-Selenge	IV-VII	-0,33	0,62	0,63	-0.59
	V-VI	-0,17	0,65	0,65	-0.55
	V-VII	-0,50	0,64	0,65	-0.64
	VI-VII	-0,68	0,69	0,71	-0.75
	V-VIII	-0,02	0,61	0,59	-0.42
Bulgan-Khuvsgul	IV-VII	-0,57	0,47	0,54	-0.58
	V-VI	-0,47	0,49	0,54	-0.57
	V-VII	-0,47	0,48	0,48	-0.50
	VI-VII	-0,62	0,52	0,59	-0.62
	V-VIII	-0,38	0,40	0,44	-0.46

Arkhangai, Uvurkhangai	IV-VII	-0,33	0,34	0,41	-0.43
	V-VI	-0,33	0,31	0,54	-0.52
	V-VII	-0,59	0,34	0,43	-0.55
	VI-VII	-0,59	0,36	0,45	-0.54
	V-VIII	-0,54	0,38	0,44	-0.51
Onon-Kherlen	IV-VII	-0,33	0,77	0,81	-0.77
	V-VI	-0,39	0,67	0,65	-0.72
	V-VII	-0,14	0,77	0,79	-0.65
	VI-VII	-0,65	0,80	0,83	-0.85
	V-VIII	-0,42	0,55	0,63	-0.73

Table 1.1: Major climatic conditions of crop farming regions.
Where: T - average monthly temperature, **P** - monthly sum of precipitation, **HTC** - Selyaninov's hydrothermal coefficient, S_i - Ped index of drought and dzud *(Source: D.Dagvadorj 1988, D.Dagvadorj, 2011).*

Based on the table above, during the vegetation period between April and August, the wheat yields correlate negatively with the average monthly temperatures and the Ped index of drought and dzud, whereas precipitation and hydrothermal coefficients cause a positive correlation. Moreover, the monthly temperatures and precipitation are the most influential factors during the months June and July.

1.2. HEAT ACCUMULATION DURING THE VEGETATION PERIOD

Heat required for plant growth is generally considered as sufficient in most areas of Mongolia. Heat supply for plant growth is calculated using the following parameters: mean daily temperatures constantly above 5 °C which is considered as the base temperature for the beginning of plant growth; length of periods with the mean daily temperatures dropping constantly below 5 °C; sum of mean daily temperatures above the 5 °C threshold; length of periods with mean daily temperatures fluctuating constantly above or below 10 °C which is considered as the base temperature for active plant growth; and sum of accumulated mean daily temperatures above the 10 °C threshold. Heat accumulation is expressed through either the sum of mean daily temperatures above each threshold and is considered as the Sum of Effective Temperature or the sum of mean daily temperatures above the threshold minus the biological base temperature, i.e. the biological minimum (also considered as Growing Degree Days - GDD in western countries).

The main parameters of heat supply recorded by selected meteorological stations representing the cropping regions are shown in **Table 1.2**.

Name of stations	Duration over 5°C (month, day)		Length (days)	Sum of Active Temperature ∑t>5° C	Duration over 10°C (month, day)		Length (days)	Sum of Active Temperature ∑t>10° C	Sum of Effective Temperature	
	Start	End			Start	End			∑t>5° C	∑t>10° C
Central Region										
Sukhbaatar	IV.24	X.9	168	2486	V.16	IX.19	126	2157	1641	887
Yuruu	IV.28	IX.30	155	2260	V.18	IX.17	122	2003	1480	772
Tarialan	IV.24	X.3	163	2110	V.18	IX.14	119	1785	1292	582
Murun	IV.23	X.4	164	2188	V.16	IX.16	122	1895	1364	653
Darkhan	IV.24	X.6	165	2472	V.14	IX.22	130	2201	1643	888
Hutag-Undur	IV.22	X.6	170	2333	V.12	IX.18	129	2050	1476	744
Orkhon	IV.23	X.6	163	2403	V.15	IX.20	128	2126	1581	839
Erdenet	IV.29	X.4	158	2034	V.20	IX.16	116	1713	1240	542
Baruunkharaa	IV.25	X.7	164	2439	V.14	IX.24	131	2182	1611	859
Bulgan	V.1	IX.30	151	1965	V.20	IX.11	114	1691	1205	538
Erdenemandal	IV.29	IX.30	154	1892	V.24	IX.11	110	1546	1117	437
Ugtaal	V.1	X.4	156	2180	V.21	IX.21	124	1919	1395	673
Erdenesant	IV.30	X.7	161	2234	V.18	IX.24	129	1979	1424	681
Eastern region										
Dadal	IV.28	X.1	156	2114	V.19	IX.16	120	1843	1329	629
Binder	IV.27	X.2	158	2155	V.18	IX.14	120	1864	1361	658
Undurkhaan	IV.24	X.5	164	2413	V.15	IX.22	130	2160	1589	846
Dashbalbar	IV.29	X.4	158	2330	V.17	IX.22	128	2109	1535	816
Khalkhgol sum or Sumber	IV.24	X.7	166	2521	V.15	IX.22	130	2256	1689	944
Choibalsan	IV.24	X.9	168	2635	V.12	IX.25	136	2386	1788	1015
Matad	IV.24	X.10	169	2562	V.16	IX.26	133	2290	1712	954
Erdenetsagaan	IV.26	X.11	168	2465	V.17	IX.25	131	2178	1620	859
Western Region										
Baruunturuun	IV.27	X.7	164	2271	V.12	IX.18	129	2020	1448	722
Bayantes	V.4	IX.26	145	1834	V.27	IX.7	103	1521	1103	477
Ulaangom	IV.24	X.8	166	2464	V.9	IX.19	133	2213	1626	876

Table 1.2: Main parameters of heat supply in crop farming regions (by yearly averages between 1981 and 2010).

Where: **∑t**-sum of mean daily temperatures, minus the base value (5 °C, 10 °C). *(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019).*

It can be seen from the table that the average air temperature in crop farming regions rises steadily above the 5 °C threshold during the last 10 days of April and decreases steadily below the said threshold in the first 10 days of October, accumulating approximately 1,900-2,400 degrees of effective temperature. The average air temperature rises steadily above the 10 °C threshold during the 10 days in mid-May and decreases steadily below the threshold during the 10 days in mid-September, whilst accumulating approximately 1,700-2,200 degrees of active temperature.

Based on time-series data from meteorological stations in the cropping regions, the trends and changes in heat accumulation during the vegetation period are shown in (**Table 1.3**).

Name of stations	Time series	Duration of 10°C base temperature		Length (days)	Sum of Active Temperature	
		Spring	Fall		Above 5°C	Above 10°C
Central region						
Sukhbaatar	1966-2016	-0,27	0.62	0.33	8.05	8.79
Yuruu	1961-2016	-0.17	0.19	0.36	8.29	8.61
Tarialan	1963-2016	-0.17	0.32	0.50	8.18	9.75
Darkhan	1984-2016	-0.35	0.09	0.44	19.81	16.87
Khutag-Undur	1962-2016	-0.31	0.09	0.40	7.66	8.58
Orkhon	1969-2016	-0.17	0.21	0.38	10.49	9.87
Erdenet	1974-2016	-0.38	0.35	0.73	11.18	13.82
Baruunkharaa	1961-2016	-0.13	0.23	0.36	9.15	9.53
Bulgan	1961-2016	-0.16	0.18	0.35	6.20	7.25
Erdenemandal	1964-2016	-0.19	0.22	0.42	9.39	8.78
Ugtaal	1980-2016	-0.06	0.15	0.21	12.14	10.11
Erdenesant	1962-2016	-0.30	0.35	0.65	8.98	12.05
Eastern region						
Dashbalbar	1976-2016	-0.35	0.13	0.48	10.35	12.08
Dadal	1961-2016	-0.24	0.32	0.56	8.56	10.52
Binder	1961-2016	-0.24	0.22	0.46	8.75	9.15
Khalkhgol	1961-2016	-0.21	0.09	0.30	6.19	6.89
Undurkhaan	1961-2016	-0.14	0.12	0.26	7.36	7.50
Western region						
Baruunturuun	1961-2016	-0.27	0.19	0.47	9.36	9.99

Table 1.3: Trends and changes in the heat accumulation during the vegetation period in crop farming region (linear regression coefficients).
Where: The linear equation coefficient is high in places with shorter time series. *(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019).*

The table above shows the angular coefficient of the linear trend equation (coefficient - a) of changes in the date when average daily temperature crosses the 10 °C threshold in spring and fall, and sum of the effective temperatures above 5 °C and 10 °C over a period of 50 years. For example, in Khutag-Undur soum of Bulgan aimag, the date when average air temperature rises above 10 °C has shifted backwards by three days in spring (negative angular coefficient indicates a shift back in the period), forwards by one day in fall (positive angular coefficient indicates a shift forward in the period), which results in an extension of the duration of effective plant growth by four days every 10 years. In other words, the average date when temperature rises above 10 °C was on April 27, and when it falls below 10 °C on October 5 in Khutag-Undur between 1962 and 1990. The average dates have changed to April 18 and October 7, respectively, between 1991 and 2016, thus extending the duration by 11 days from 161 to 172 days of effective plant growth. Across all regions over the period between 1961 and 2016, the average date when air temperatures rose above 10 °C shifted backwards by 12 days in spring and was extended by 13 days in fall when the temperature fell below 10 °C.

According to time-series data of multiple years from weather stations, the sum of effective temperatures above 10 °C has risen at a rate of 80-90 °C every 10 years across all regions, and the duration of effective temperature that is above 5 °C and 10 °C has been extended by about three weeks from the 1960s to 2016. Although this provides an opportunity to expand crop farming regions in Mongolia (possibly to high altitude areas or further to the north), moisture supply and frost damage will remain as the main factors limiting crop yields.

Frost

Although the heat accumulation required for vegetation periods in Mongolia is considered as sufficient, occurrence of frost damage risk in Khangai regions is high. Based on years of observation, the last frost is between June 10 and 20 in high mountains at an elevation of 1,500-2,000 m above sea level, June 1 and 10 in medium-range mountains at an elevation of 1,000-1,500 m above sea level, May 20 and June 20 in the Great Lakes Depression area and the river basins of Orkhon-Selenge, Onon, Ulz, Khalh and Nomrog rivers, and May 10 and 20 in the steppe region. Frost damage in mountainous areas usually starts to occur in Mongolia in early fall. As it begins between August 20 and September 1 in areas situated 1,000 m above sea level, the period without frost is shorter than 70 days and is as short as 30 to 40 days in some years. Whereas in Orkhon-Selenge basin and forest-steppe regions it happens between September 1 and 10, it is between September 10 and 20 in steppe regions. On average, the period without frost damage is between 70-90 days in high mountainous regions situated 1,300-2,000 m above sea level, 90-110 days in Orkhon-Selenge basin, forest steppe regions and mountainous regions situated up to 1,300 m above sea level, and 110-130 days in steppe regions *(Jambaajamts, 1989).*

Table 1.4 shows the observed mean dates of the last frost in spring and the first frost in fall for the period between 1981 and 2010. If we compare the average duration of the periods without cold weather from the table below with the dates from "Mongolia's agricultural climate reserves guidebook - 1996", it has increased by 7-19 days for crop farming regions. However, selecting crops with longer vegetation periods in farming practice would still not be recommended due to the persistent risk of frost damage.

Areas	Frost on the earth surface			Frost in air (altitude of 2m)			
	Late spring	Beginning of fall	Warm period shown by number of days	Late spring	Beginning of Fall	Length of warm period, in days	
						Average	Change
Sukhbaatar	5/26	9/14	111	5/19	9/18	122	
Yuruu	5/31	9/9	102	5/30	9/11	104	+19
Baruunturuun	6/3	9/10	99	5/25	9/15	113	+14
Tarialan	6/3	9/12	101	5/26	9/14	112	+16
Darkhan	5/29	9/11	105	5/23	9/19	119	
Khutag-Undur	5/31	9/10	102	5/14	9/14	113	+16
Orkhon	5/29	9/9	102	5/25	9/12	110	
Dadal	6/5	9/9	96	5/30	9/11	104	
Baruunkharaa	5/26	9/12	109	5/24	9/14	114	+15
Erdenet	6/7	9/6	91	5/27	9/15	111	
Bulgan	6/7	9/3	88	6/3	9/6	95	+12
Binder	6/2	9/8	98	5/26	9/11	108	+17
Ugtaal	6/6	9/6	92	5/29	9/12	105	
Choibalsan	5/19	9/18	122	5/12	9/22	133	+10
Gurvanbulag	5/25	9/15	114	5/18	9/17	122	
Sumber sum	5/20	9/16	119	5/19	9/17	120	+10
Undurkhaan	5/31	9/9	101	5/25	9/13	111	+7
Matad	5/26	9/17	114	5/18	9/17	122	
Erdenesant	6/2	9/9	99	5/23	9/14	114	+18
Khujirt	6/11	8/31	81	6/5	9/4	91	

Table 1.4: The dates of frost at the end of spring and beginning of fall, and the duration without frost (based on 1981-2010 averages).
Where: The last column of the table shows how the average length without frost between the years 1981-2010 has changed compared with that between 1961-1990. Periods without frosts are indicated with a "+". *(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019)*.

1.3. MOISTURE SUPPLY

The moisture supply of plants is determined by the following parameters: amount of precipitation, moisture reserves in soil, evaporation (evaporation capacity of surface levels or potential evaporation) and parameters of the dry-moist state of the climate.

Precipitation is considered as low in general due to Mongolia's location in arid and semi-arid climate zones. Therefore, 85 % of all precipitation occurs within the warm seasons (April to September), whilst 50-60 % of it coming down within the months of July and August alone. **Table 1.5** shows the monthly and yearly average amount of precipitation measured by weather stations in crop farming regions.

The amount of snowfall in winter is significantly low. Thus, the amount of precipitation during cold seasons does not exceed 30 mm in mountainous areas and 10 mm in Gobi areas. The only regions that experience more than 30 mm of snowfall in the cold seasons of the year (October to March) are Khangai, Khentii Mountains and Lake Khovsgol areas. Due to global warming, the total amount of snowfall in the winter has risen and the amount of rainfall in warmer seasons has decreased in general. *(MEGD, 2014; MET, 2018)*.

We estimated the change in the amount of rainfall with an average air temperature above 0 °C or during warm weather using the trendline based on data from 1961-2016, which resulted in a decrease of 23 mm. This could be an indication that the climate change might affect natural evolution.

Weather stations	Month												Sum of the year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Central region													
Sukhbaatar	3.1	2.3	2.9	8.2	24.6	52	67.7	69.9	33.8	9.2	6.1	3.9	283.8
Yuruu	2.8	1.5	2.3	4.5	15.6	54.3	70.2	77.1	29.1	8.6	3.7	3.5	273.2
Orkhontuul	2.8	2.4	4.5	8.6	25.2	48.2	69.0	83.1	31.4	12.2	6.0	5.6	299.3
Tarialan	2.4	1.4	2.8	6.5	17.4	56.5	102.5	82.6	24.6	6.4	2.6	2.6	308.4
Murun	1.5	1.1	1.3	6.9	18.3	47.8	73.2	57.7	19.8	5.6	2.3	3.0	238.4
Darkhan /1984-2010/	4.1	3.3	4.6	12.0	27.4	57.8	70.0	84.9	35.4	14.4	7.4	6.0	327.2
Khutag-Undur	2.5	1.1	3.2	9.3	19.7	51.1	97.6	77.2	27.1	8.0	4.3	2.8	303.9
Selenge /1993-2010/	2.1	2.0	4.7	8.6	23.6	61.0	99.9	74.2	31.8	10.5	4.2	3.8	326.3
Orkhon	2.7	2.4	2.8	6.4	20.4	55.4	72.0	72.7	32.3	8.7	5.2	4.0	284.9
Erdenet	2.8	2.3	6.4	13.4	22.1	71.1	94.7	83.8	35.1	12.8	6.6	4.6	355,7
Baruunkharaa	3.1	2.2	3.4	8.0	23.2	56.2	70.7	73.9	34.7	8.7	7.2	4.1	295.4
Bulgan	2.0	1.5	4.7	9.0	20.4	62.2	108.1	79.3	29.7	10.2	3.9	2.4	333.3
Erdenemandal	1.6	1.4	2.1	6.4	19	58.8	88.8	71.1	19.4	5.7	2.1	1.5	277.9
Tuvshruulekh /1997-2010/	1.9	2.2	6.0	9.2	27.2	52.4	76	57.8	20.5	10.4	5.4	2.4	271.4
Ugtaal	1.8	1.8	4.1	7.1	20.8	54.3	71.3	68	28.2	8.7	5.8	3.3	275.1
Erdenesant	2.3	2.0	4.3	6.8	18.8	48.1	68.4	63.4	22.4	8.0	4.7	3.2	252.4

Bayanchand-mani /1989-2010/	1.5	1.6	3.4	7.5	22.7	49.7	67.7	73.8	28.7	6.6	4.0	3.3	270.4
Jargalant /1991-2010/	2.9	2.5	5.3	8.7	28.2	49.5	69.3	81.0	36.1	12.4	7.6	5.3	308.6
Khujirt	1.5	1.8	4.3	7.7	22.8	56	82.1	66.5	21.4	7.6	3.3	2.1	277
Eastern region													
Dadal	2.4	2.3	5.6	13.5	24.6	74.2	106.7	98.8	42.6	17.2	5.6	2.8	396.2
Binder	1.9	2.1	4.4	9.7	16.6	59.7	98.8	77.3	36.1	12.5	4.3	2.4	325.9
Undurkhaan	2.0	2.6	3.7	6.3	16.5	39.7	66.5	62.4	22.7	7.1	3.4	2.7	235.5
Dashbalbar	2.1	1.6	2.4	6.3	16.9	39.4	91.1	78.1	29.9	7.9	3.4	3.2	282.3
Khalkhgol	2.7	2.6	5.2	10.1	18.6	47.7	98.9	62.5	26.4	10.8	4.9	5.4	295.8
Bayan Uul /1993-2010/	2.9	2.8	4.6	7.5	17.9	45.6	104.1	76.9	34.5	14.0	5.0	4.3	320.2
Choibalsan	2.2	2.0	3.8	5.6	16.3	37.2	65.5	55.9	28.7	8.7	3.0	3.2	232
Matad	2.1	2.1	4.9	7.4	16	43.9	69.5	47.9	18.3	6.6	4.2	3.1	226
Erdenetsagaan	2.1	2.8	6.0	8.0	18.8	54.7	76.7	60	19.8	8.7	5.7	4.3	267.5
Western region													
Baruunturuun	3.5	3.8	6.7	13.5	22.3	34.5	57.9	48.9	24.5	13.3	10.8	6.5	246.2
Bayantes	3.4	3.1	2.8	5.2	13.1	29.6	51.7	41.5	20.1	7.5	6.8	6.1	190.9
Ulaangom	2.4	2.5	3.2	3.6	7.1	30.1	43.1	29.2	11.2	6.0	9.5	6.6	154.6

Table 1.5: Amount of precipitation in mm *(averages from 1981-2010).*
Where: Average is noted by soums that have established weather stations since 1981. W
(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019).

A special characteristic of precipitation in Mongolia is that its seasonal and yearly variability is high. Thus, there is a higher chance of crop yield fluctuation. **Table 1.6** shows the value of the precipitation variability coefficient in warm seasons measured by weather stations across crop farming regions over two periods: 1961-1990 and 1991-2016.

Areas	Coefficient of variability	
	1961-1990	1991-2016
Baruunturuun	28	34
Murun	30	25
Tarialan	24	22
Khutag-Undur	22	26
Bulgan Khot	24	24
Erdenemandal	22	29
Tsetserleg	17	23
Sukhbaatar	28	22
Baruunkharaa	28	32
Yuruu	28	23
Erdenesant	21	33
Khujirt	18	33
Arvaikheer	25	32
Undurkhaan	24	22
Bayan Ovoo	25	34
Dadal	22	28
Binder	24	36
Choibalsan	28	49
Khalkhgol	29	47

Table 1.6: Precipitation variability coefficient *(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019).*

Based on the table above, not only did the precipitation variability coefficient increase in most regions during warm weathers, but some regions where less than 30 % was observed had an increase above the usual threshold. This is an indication that the stability of local ecosystems in some regions is deteriorating.

However, the amount of precipitation and its seasonal distribution cannot show the full picture of the dry-moist state of the climate. This can be done through either the difference between the inflow (precipitation) and outflow (required evaporation or aggregate evaporation which equals to soil evaporation + plant transpiration) of crop moisture supply, or the dry-moist state indicator of the climate, which is Shashko's index of moisture or Selyaninov's hydrothermal coefficient (HTC):

Shashko's index of moisture:

$$M_d = \frac{\sum P}{\sum(E-e)} = \frac{\sum P}{\sum d} \qquad (1.1)$$

Selyaninov's hydrothermal coefficient (HTC):

$$\text{ЧДИ} = \frac{\sum P_{V-VIII\ \text{cap}}}{0.1 \sum t_{>10^0\text{C}}} \qquad (1.2)$$

Where: P - amount of precipitation, which is the total sum over the vegetation period of May-August; (**E-e**) - subtraction of water vapor pressure from saturated vapor pressure which determines amount of moisture (water vapor) needed for the air saturation and denoted as **d**. It is summed as the average moisture deficit over the months May-August and denoted as **∑d**. The higher the moisture deficit, the higher the chances of plant perspiration and soil evaporation.

The daily average moisture deficit in Mongolia during the summer is estimated to be around 9-12 hPa (hectopascals). The geographical distribution of these parameters illustrates the dry-moist state of the country.

Figure 1.1 shows the geographical distribution of the standard value of Shashko's moisture coefficient between 1981 and 2010. Regional moisture supply is determined by the following ranges of Shashko's moisture coefficient values:

<0.15 - very arid,
0.10-0.25 - arid,
0.25-0.35 - less arid,
0.35-0.45 - less humid,
0.45-0.60 - humid,
>0.60 - excess humidity.

The moisture supply for plants is deemed at an appropriate level and moisture when the moisture index M_d is **0.5**, sometimes around **0.45**.

Based on information from weather stations, the regions containing the highest value of Shashko's moisture index were Terelj with 0.42, Bulgan with 0.37, Tsagaan uurt of Khovsgol with 0.36, while the crop farming regions did not have any value exceeding 0.26. In other words, cropping regions mostly fit into the dry and less dry categories. **Figure 1.2** shows how the dry-moist state of the climate changed over the years 1975 - 2017, differentiated by crop farming regions.

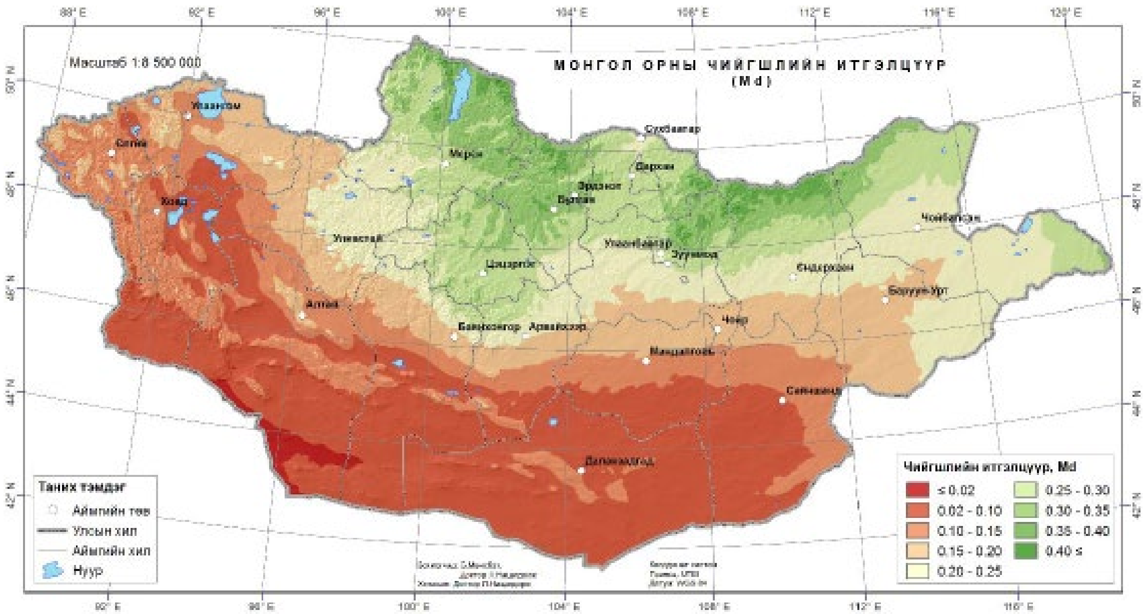


Figure 1.1: Geographical distribution of Shashko's moisture index *(by 1981-2010 averages).*

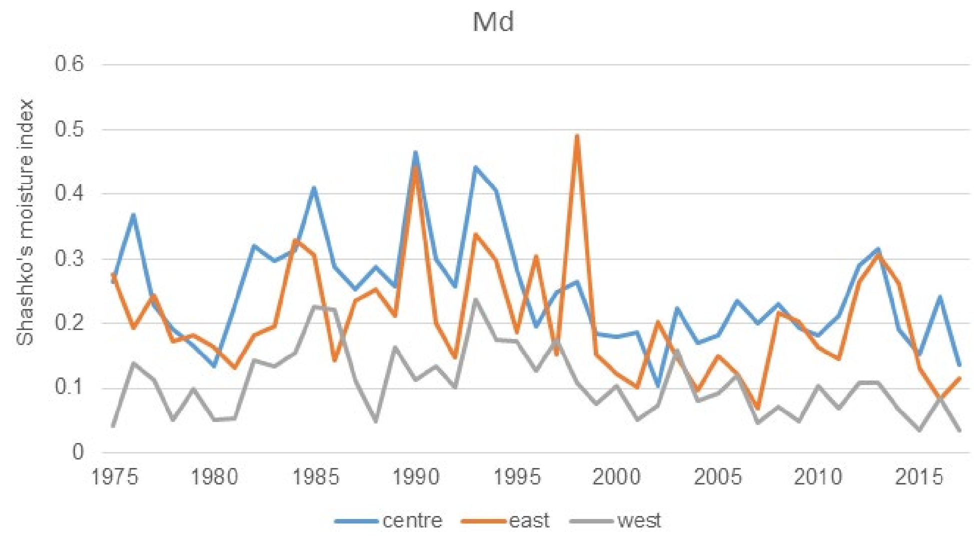


Figure 1.2: Shashko's moisture index over the years
by crop farming zones (Source: Own illustration)

The figure above shows that Shashko's index for moisture and heat in the climate is decreasing through all crop farming regions in our country with an increased intensity in central zones in our country. Moreover, it can be seen from the figure that central zones are humid and western zones are dry.

One of the main reasons of aridification and desertification facing Mongolia currently is that the rise in air temperatures during plant vegetation periods has resulted in an increased evaporation potential or total evaporation that is higher than the amount of precipitation which is insufficient to keep the moisture balance and even decreasing slightly over time. **Figure 1.3** shows the evaporation and precipitation amount in the central crop farming zone over multiple years.

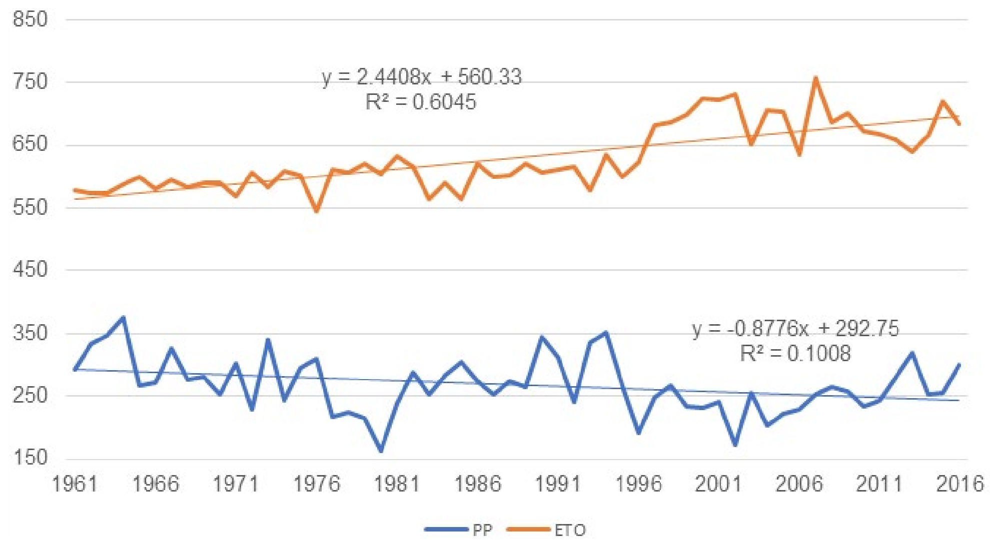


Figure 1.3: The cumulative evaporation rates (E_0) and precipitation in the central crop farming zone over multiple years *(red is cumulative evaporation, blue is precipitation in mm) (Source: Own illustration).*

There are some other multi-year indices for the dry-moist state which show the process of aridification in Mongolia. We estimated Selyaninov's hydrothermal coefficient (HTC) from 1961-2016, and **Table 1.7** shows how the average value changed during this period, cutting it off at 1990.

Weather stations	HTC		Difference
	I	II	
Murun	1.11	0.86	-0.25
Tarialan	1.49	1.22	-0.27
Tsertserleg	1.78	1.32	-0.46
Sukhbaatar	1.09	0.95	-0.14
Baruunkharaa	1.38	1.12	-0.26
Baruunturuun	0.82	0.77	-0.05
Bulgan	1.61	1.41	-0.20
Khutag	1.45	1.24	-0.21
Yuruu	1.21	0.92	-0.29
Erdenesant	1.19	0.84	-0.35
Khujirt	1.70	1.30	-0.40
Undurkhaan	1.07	0.78	-0.29
Bayan-Ovoo	1.09	0.95	-0.14
Dadal	1.70	1.31	-0.39
Binder	1.48	1.14	-0.34
Choibalsan	1.02	0.79	-0.23
Khalkhgol	1.15	1.14	-0.01*

Table 1.7: The change in Selyaninov's hydrothermal coefficient (HTC) *(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019).*
Where: I - average of 1961-1990, II - average of 1991-2016, * - the difference was insignificant because Khalkh-river station moved to Sumber from the soum center in 1975 *(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019)*.

Another thing to note here is that the dry-moist state of the climate has shifted toward aridification at certain stations over the last 26 years when compared with the averages of the 30 years before.

Winter precipitation and snow covers

Out of the total amount of precipitation over a year in Mongolia, 5-15 % falls in the form of snow in the cold season with a thin layer of snow cover (average thickness does not exceed 10 cm), and therefore, it fails to protect the soil from deep freezing and limits the conditions for winter crop cultivation.

It snows on 30-45 days of the year across crop farming regions. It is rare that a firm snow cover forms immediately after the first snowfall, and it takes about 20 days to a month for a stable snow cover to form after the Winitiation. **Table 1.8** illustrates the date of forming a stable snow cover and the thawing start date, and the number of days with stable snow covers across crop production regions.

Station	S.C. days	S.S.C. days	Stable snow cover			Dates when snow cover starts to thaw		
			Aver-age	Early	Late	Aver-age	Early	Late
Ulaangom	145	141	XI.12	X18	XII.6	IV.2	III.13	IV.28
Baruunturuun	202	155	XI.1	X.23	XI.23	IV.5	IV.3	IV.8
Bayan-Uul	176	161	XI.3	XI.10	II.4	IV.13	III.28	V.19
Murun	98	71	XI.29	X.19	II.6	II.10	XII.23	III.21
Bulgan	175	103	XI.19	II.10	XII.27	III.2	I.8	XII.16
Erdenet	152	114	XI.15	X.18	II.26	III.9	I.31	IV.15
Arvaikheer	126	95	XII.11	X.14	II.20	II.27	XII.31	IV.4
Khujirt	172	78	XII.7	XI.1	I.19	II.22	II.12	III.9
Baruunkharaa	142	121	XI.14	X.21	I.4	III.25	XII.18	IV.9
Orkhon	139	121	XI.14	X.10	I.18	III.17	II.22	IV.12
Sukhbaatar	129	101	XI.23	X.11	XII.19	III.4	XII.31	III.22
Darkhan	153	113	XI.13	X.22	XII.13	III.8	II.19	III.26
Ugtaal	212	123	XI.11	X.28	XII.3	III.14	II.16	IV.14
Undurkhaan	135	104	XI.24	X.27	I.3	III.10	I.26	IV.12
Binder	123	96	XI.20	X.10	I.13	III.25	XII.23	IV.7
Dadal	153	122	XI.17	X.6	II.1	III.15	I.28	IV.17
Choibalsan	108	68	XII.3	XI.5	XII.31	II.9	I.5	II.1
Dashbalbar	168	108	XI.14	X.15	XII.26	III.2	II.3	IV.3
Khalkh gol	142	107	XI.26	X.31	XII.27	III.13	I.31	IV.5
Erdenetsagaan	158	116	XI.24	I.4	XII.13	III.20	I.2	IV.16

Table 1.8: Dates of forming stable snow covers and thawing start, and number of days with snow covers (1975-2010) *(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019).*

It snows on 30-45 days of the year across crop farming regions. It is rare that a firm snow cover forms immediately after the first snowfall, and it takes about 20 days to a month for a stable snow cover to form after the Winitiation. **Table 1.8** illustrates the date of forming a stable snow cover and the thawing start date, and the number of days with stable snow covers across crop production regions.

The dates of formation of stable snow covers and thawing start have a trend of shifting forward during this time period, resulting in a reduction of the number of days with snow covers.

Snow covers are generally not thick and do not exceed 10 cm according to field snow measurements. However, they might exceed 20 cm in years with dzud or heavy snowfall.

As such, water reserves across crop farming regions do not exceed the amount of 10-15 mm because snow covers are not thick. Water melting from the snow is not absorbed into the frozen soil and therefore does not increase the moisture content of soil, because the date when the snow thaws has shifted backward by approximately one month compared with the 1960s.

Change in soil moisture index

The Soil Moisture Index (SMI) is the ratio of total evaporation and evaporation capacity (potential evaporation). Since the multi-year average of total evaporation in Mongolia is close to the amount of precipitation *(Natsagdorj, 2004)*, it is referred to as the soil moisture index which shows the amount of precipitation absorbed by the soil and used for plant growth. **Figure 1.4** illustrates the soil moisture index, classified by crop farming regions.

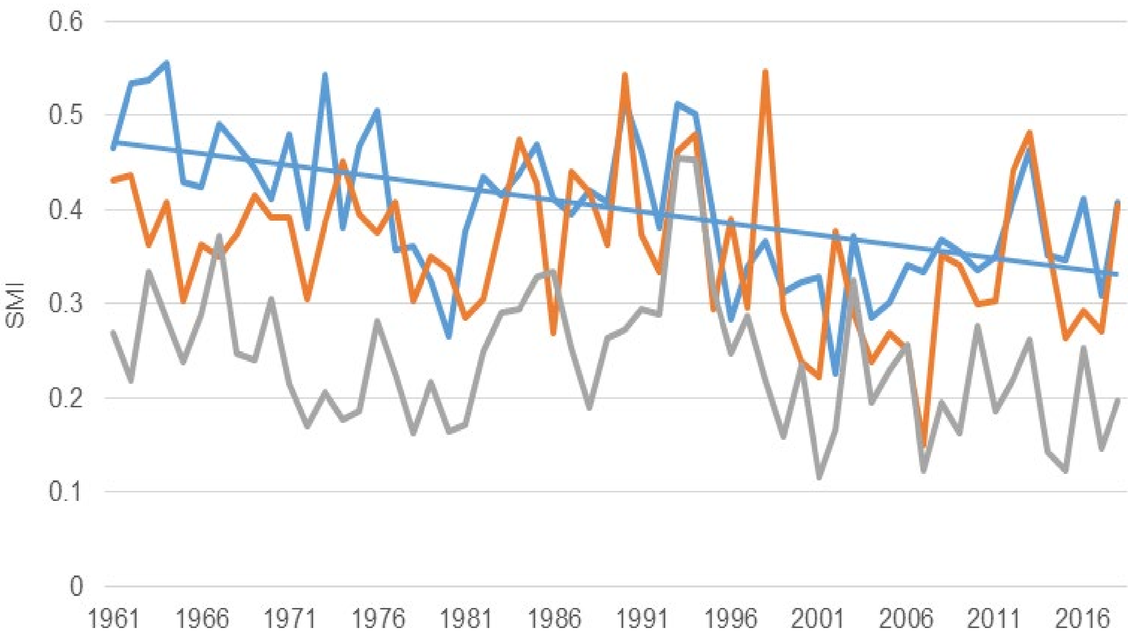


Figure 1.4: Multi-year soil moisture index *by crop farming zones (Source: Own illustration).*

Based on the figure above, the soil moisture index has decreased through all crop farming zones over the last 50 years, with the most intensity in central zones and the least intensity in western zones.

1.4. FACTORS THAT LIMIT CROP YIELDS

Droughts and aridity

There are many factors that limit crop yields in Mongolia, with droughts and dryness being among the main factors. Several measures determine droughts, with **Figure 1.5** showing the results by means of Selyaninov's hydrothermal coefficient (HTC) *(Gomboluudev et al., 2018).*

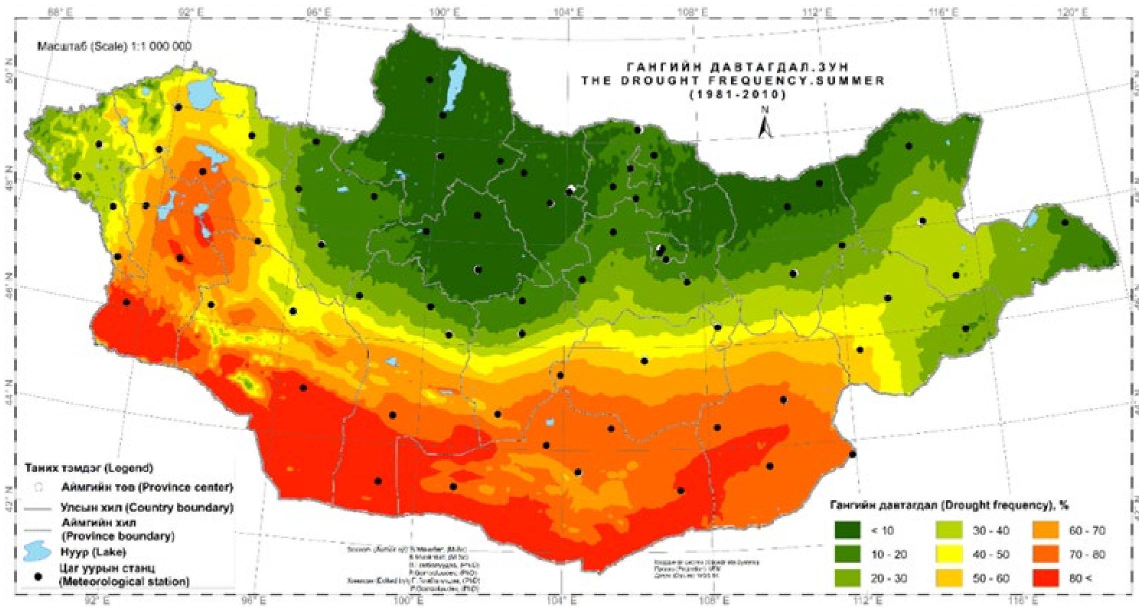


Figure 1.5: Drought frequency assessment in the summer *(Source: Gomboduulev et al., 2018).*

This assessment shows that drought frequency is low across crop production regions in central zones of Mongolia, which corresponds to the results obtained through B. Jambaajamts's dryness degree method. However, in reality, the frequency results are as high as 20 %, based on results assessing the drought-dryness for the growth of pastoral plants *(Natsagdorj et al., 2002).*

Since most indicators that determine the drought-dryness state of a region (Selyaninov's hydrothermal coefficient, Shashko's moisture index, Jambaajamts's dryness degree, etc.) also illustrate the dry-moist condition of the climate, it is inappropriate to conduct a comparative analysis on regions across different geographical conditions. For example, according to Jambaajamts's dryness degree, between the years 1940-1970, Bulgan experienced stages from heavy droughts to dry conditions in four out of the 30 years and had reliable summer conditions for the rest, while Dalanzadgad, which is situated in a desert-steppe zone, experienced 19 years of drought, 8 years of dry conditions and only one year of reliable summer conditions over a period of 28 years. *(Natsagdorj et al., 2002).*

The intensity of droughts is increasing in Mongolia during the process of climate change. **Figure 1.6** shows a comparison between average wheat yields in Mongolia and Ped's drought index (proposed by D. A. Pedey in 1975) for drought-dryness between May and July. The Ped index is calculated as follows:

$$S_i(\tau) = \frac{\Delta T}{\sigma_T} - \frac{\Delta P}{\sigma_P} \qquad (1.3)$$

Where: ΔT – average air temperature (10 days, monthly, seasonal); **ΔP** – precipitation sum; σ_T, σ_P – the standard deviation of air temperature and precipitation of the time-series data.

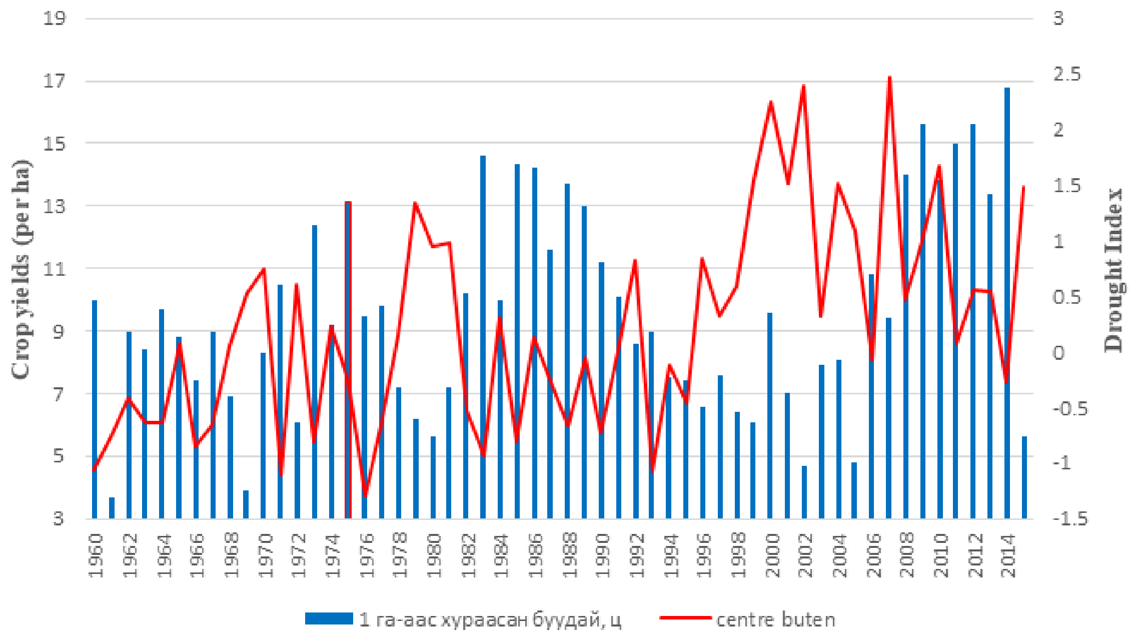


Figure 1.6: Drought-dryness index and wheat yields across the central crop production zone (■ crop yields per ha in dt).
Where: The negative part of the index illustrates reliable summer conditions, and the positive part reflects state of droughts *(Source: Own illustration).*

The Ped index does not depend on the dry-moist state of the climate and only shows the frequency of dry or moist conditions (in the 10 days, months, seasons of estimation) in a selected area. A negative value of the Ped index indicates reliable summer conditions, whereas a positive value indicates dry conditions, and a value greater than 1 expresses moderate droughts (dry) and a value greater than 2 shows severe drought. Due to the index being based on standard deviations of average air temperature and precipitation of a certain period (multi-year norm or normal amount), one of the drawbacks of this indicator is that it is unsuitable in the current state where climate change is rapid.

The total evaporation and the Standardized Precipitation Evapotranspiration Index (SPEI) use the distribution functions of total evaporation and air temperature. Indicators such as the Standardized Precipitation Index (CPI), Standardized Precipitation Evapotranspiration Index (SPEI) and other indicators also show that drought and dryness in Mongolia is increasing due to climate change. **Figure 1.7** illustrates the multi-year Standardized Precipitation Evapotranspiration Index (SPEI) of Khutag-Undur and Baruunkharaa stations between the years 1961-2015.

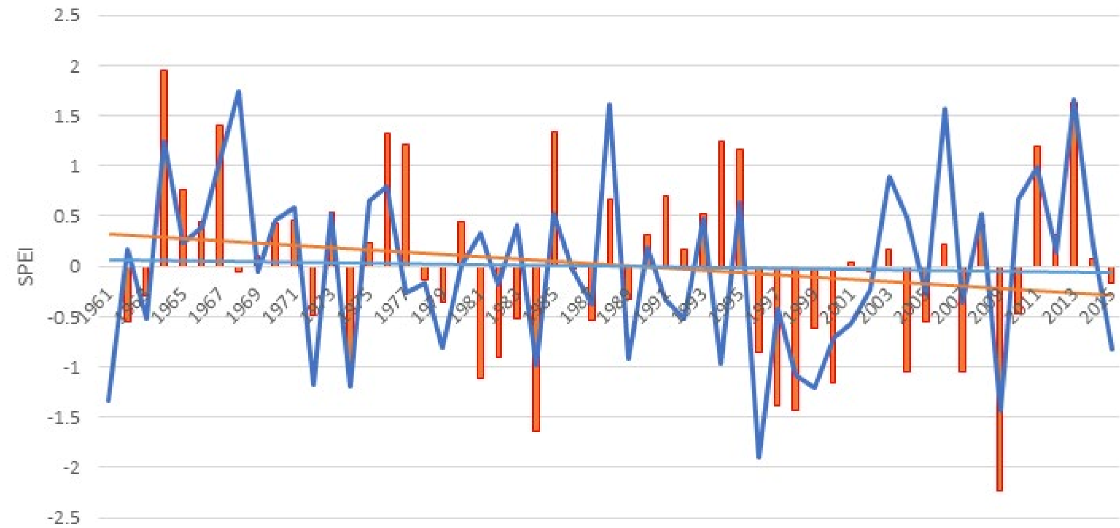


Figure 1.7: Standardized Precipitation Evapotranspiration Index (SPEI) over multiple years (■ Khutag, ■ Baruunkharaa) *(Source: Own illustration).*

A negative value of SPEI indicates drought, a positive value indicates reliable summer conditions and is classified as follows: a value less than 0 (< 0) indicates an arid state; between -1 and -1.5 a moderate drought; between -1.5 and -2 a strong drought; and more than -2 severe droughts *(Beguería S. et al., 2014)*. The figure above shows that the state of dryness has been increasing since the sixties from the last century and is most likely going to continue to increase based on future climate trends *(MET, 2018).*

Overheating

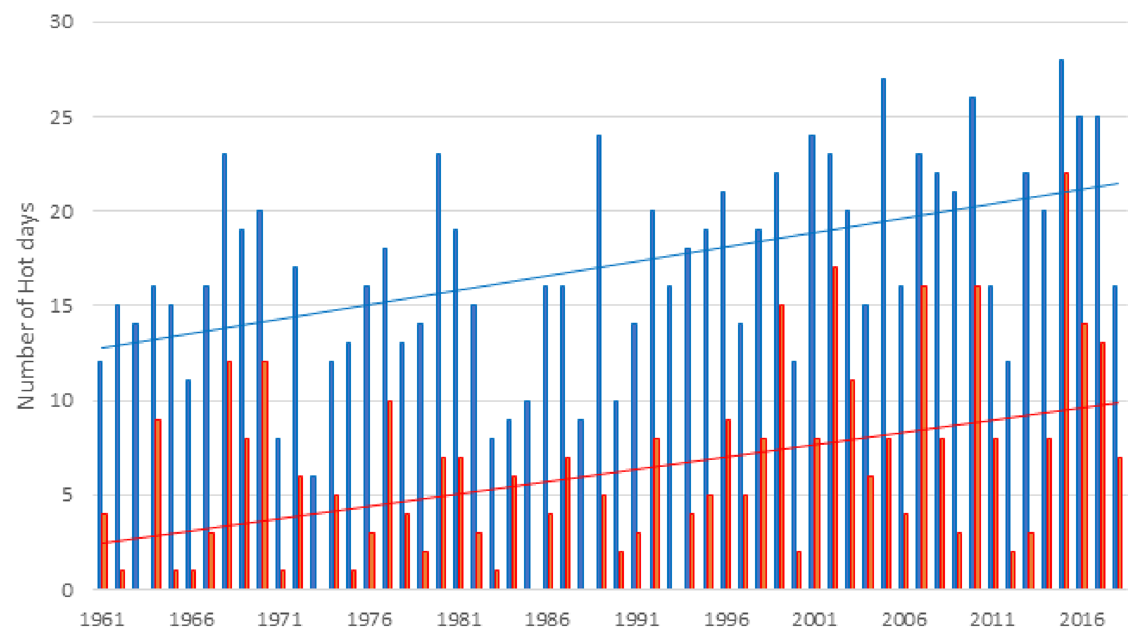


Figure 1.8: The number of days in Yuruu that had temperatures exceeding 26 °C and 30 °C *(Source: Own illustration).*

The number of days that are extremely hot is increasing in Mongolia due to climate change. It was stated in the 3rd Lecture of the Intergovernmental Panel on Climate Change (IPCC) that every **1 °C** rise from the 26 °C threshold during the flowering and pollination stages of grains leads to a 10 % decrease in yields.

As such, on average, the number of days that had temperatures exceeding 26 °C in July was 14 between the years 1961-1990 and had changed to 20 days on average during the years from 1991-2018 in the Yuruu soum (**Figure 1.8**).

We find that such a trend has occurred in all crop farming regions in Mongolia. The following table, based on data from weather stations in Mongolia, shows the number of days when temperatures have exceeded 26 °C and 30 °C in July since 1961, split into two periods: 1961-1990 and 1991-2018.

Weather stations	Days (by yearly intervals)			
	1961-1990		1991-2018	
	≥26° C	≥30° C	≥26° C	≥30° C
Yuruu	14.6	4.2	19.9	8.3
Buyant-Ukhaa	7.3	1.8	14.8	6.6
Bulgan	5.6	0.7	10.8	4.0
Baruunkharaa	14.1	4.2	19.6	8.8
Orkhon (1969-2018)	15.9	4.4	19.2	7.9
Khutag-Undur	11.7	2.3	17.2	6.6
Murun	8.4	1.4	14.0	4.3
Tarialan (1963-1990)	4.9	0.6	10.7	9.2
Sukhbaatar	14.6	4.4	20.4	8.5
Erdenesant	7.2	1.5	12.9	4.8
Choibalsan	18.3	6.4	19.7	9.1
Sumber sum (from 1975)	17.7	5.7	19.6	7.6
Baruunturuun	9.6	1.5	16.4	5.7

Table 1.9: Average number of hot days in July. (1961-1990 and 1991-2018) *(Source: Information and Research Institute of Meteorology, Hydrology and Environment, 2019).*

Observing the table above, the number of hot days has risen considerably, and the number of very hot days has increased at a fast pace. Since 1975, the number of days that heated up more than 30 °C in Mongolia has been rising *(Natsagdorj, 2008)*. This shows that one of the factors that will limit crop yields in the near future is going to be overheating.

2. CLIMATE TRENDS OF THE NEAR FUTURE

The Intergovernmental Panel on Climate Change (IPCC) has identified the Representative Concentration Pathway or Scenario (RCP) based on socio-economic prospects and developed the Fifth Assessment Report (Climate Change) (IPCC, AR5).

Past climate change was calculated for the period 1860-2005, and future climate change was calculated for 2006-2100, utilizing data from about 40 models of 28 major scientific centers that develop climate models and future prospects of greenhouse gas (GHG) emissions *(Taylor, K. E. et al., 2012)*.

We calculated the future climate based on the four GHG emission scenarios and classified the atmospheric radiation burden into the following four incremented categories of 2.6, 4.5, 6.0 and 8.5 W/m² by 2100. We used the first ten of the climate models on a global scale for our research, conducting a multi-criteria analysis on the basic climate calculations of Mongolia between 1986 and 2006, and ordered them.

Future trends of air temperature and precipitation in winter and summer seasons were calculated until 2100 based on yearly averages of radiation from the RCP categorized into large, medium and small (**Table 2.1**).

GHG Emission scenario	Season	Short-run future, 2016-2035		Long-run future, 2081-2100	
		Temperature,°C	Precipitation, %	Temperature,°C	Precipitation, %
RCP2.6	Winter	2.3	10.1	2.5	15.5
	Spring	2.3	9.2	2.4	11.7
	Summer	2.2	6.2	2.5	5.1
	Fall	2.1	7.6	2.4	7.6
RCP4.5	Winter	2.1	12.3	3.7	28.7
	Spring	2.0	7.8	3.4	17.4
	Summer	2.1	1.1	3.5	7.8
	Fall	2.0	8.1	3.4	11.7
RCP8.5	Winter	2.2	14.0	6.3	50.2
	Spring	2.2	9.8	5.6	28.6
	Summer	2.2	2.4	6.0	8.7
	Fall	2.2	6.4	6.1	24.1

Table 2.1: Seasonal climate change in Mongolia, based on different scenarios of GHG emissions. (by averages from ten global-scale climate models) *(Source: Ministry of Environment and Tourism, 2018).*

We incorporated the results from previously mentioned assessments that determine and truly reflect the climate of Mongolian regions, such as Germany's Max Planck Institute's ECHAM5 (hereafter RegCM4-ECHAM5) and United Kingdom's global climate research Hadley center's HadGEM2 (hereafter RegCM4-HadGEM2), into the initial and peripheral conditions of the RegCM4 model of regional climate and obtained results with a relatively high accuracy. We determined that by having regional climate models with an estimated threshold of 30 km the regional microlevel atmospheric processes can be accurately illustrated. The model was estimated by RCP 8.5 of GHG emissions or the scenario with the most emissions and categorized into the following time periods: the base climate period of 1986-2005 and the future periods of 2016-2035, 2046-2065 and 2081-2100. The results are illustrated in **Table 2.2** and **Figures 2.1** to **2.4**.

a/ RegCM4-ECHAM5 model

Season	RegCM4-ECHAM5					
	Temperature, °C			Precipitation, %		
	2016-2035	2046-2065	2081-2100	2016-2035	2046-2065	2080-2099
Winter	1.3 [±0.3]	2.5 [±0.3]	4.4 [±0.4]	12.9 [±17.7]	30.8 [±20.3]	74.7 [±50.3]
Spring	1.4 [±0.2]	2.3 [±0.2]	3.8 [±0.4]	14.1 [±6.1]	23.9 [±11.1]	47.6 [±27.3]
Summer	0.9 [±0.2]	1.9 [±0.2]	4.1 [±0.3]	0.1 [±7.4]	6.5 [±10.2]	10.7 [±16.2]
Fall	0.8 [±0.1]	2.0 [±0.3]	3.9 [±0.4]	9.5 [±10.3]	24.4 [±18.8]	35.1 [±26.1]
Year	1.1 [±0.1]	2.2 [±0.2]	4.0 [±0.3]	5.6 [±5.9]	14.5 [±7.2]	25.8 [±18.1]

b/ RegCM4-HadGEM2 model

Season	RegCM4-HadGEM2					
	Temperature, °C			Precipitation, %		
	2016-2035	2046-2065	2081-2100	2016-2035	2046-2065	2080-2099
Winter	1.6 [±0.1]	3.7 [±0.3]	6.1 [±0.3]	27.3 [±22.5]	38.2 [±32.8]	101.0 [±96.5]
Spring	1.5 [±0.2]	3.2 [±0.3]	5.3 [±0.4]	7.7 [±9.9]	20.4 [±12.5]	43.3 [±22.4]
Summer	1.4 [±0.2]	3.4 [±0.6]	5.7 [±0.7]	3.7 [±11.1]	9.5 [±16.7]	21.4 [±29.3]
Fall	1.4 [±0.1]	3.2 [±0.2]	5.8 [±0.3]	8.9 [±14.9]	18.9 [±20.1]	47.9 [±40.3]
Year	1.5 [±0.1]	3.4 [±0.3]	5.7 [±0.3]	5.3 [±6.9]	13.7 [±10.9]	32.1 [±21.2]

Table 2.2: Future trends in air temperature and precipitation, based on regional climatic models. *(Source: Ministry of Environment and Tourism, 2018).*

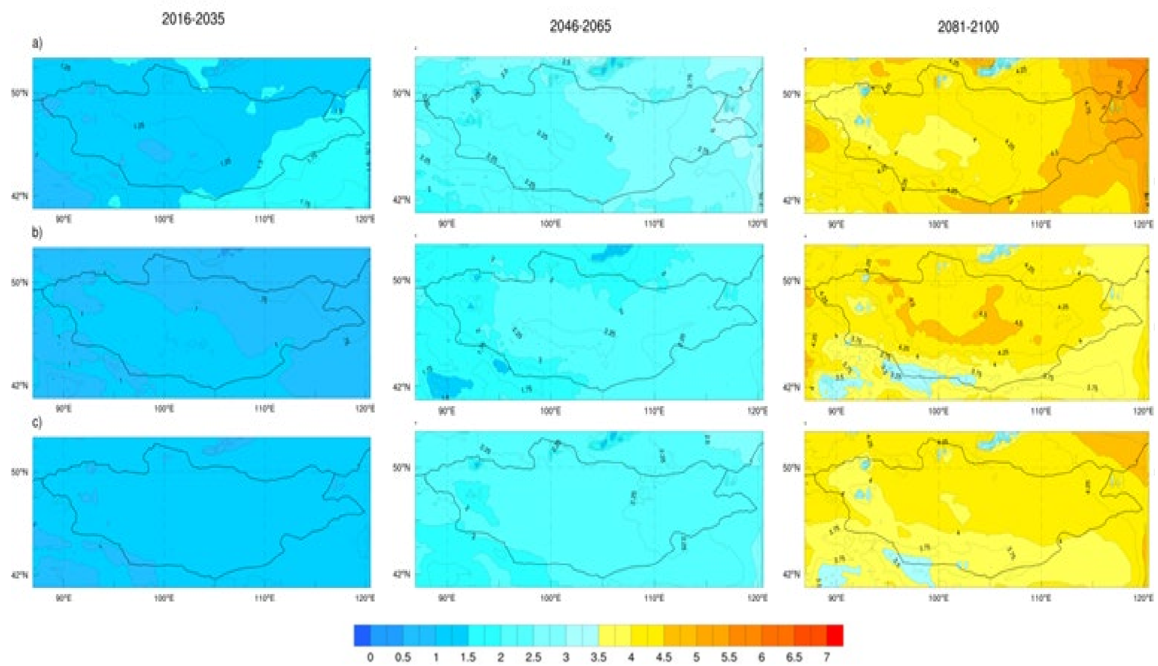


Figure 2.1: Change in air temperature (in °C), based on calculations from RegCM4-ECHAM5 model. (a - winter, b - summer, c - yearly average) *(Source: Ministry of Environment and Tourism, 2018).*

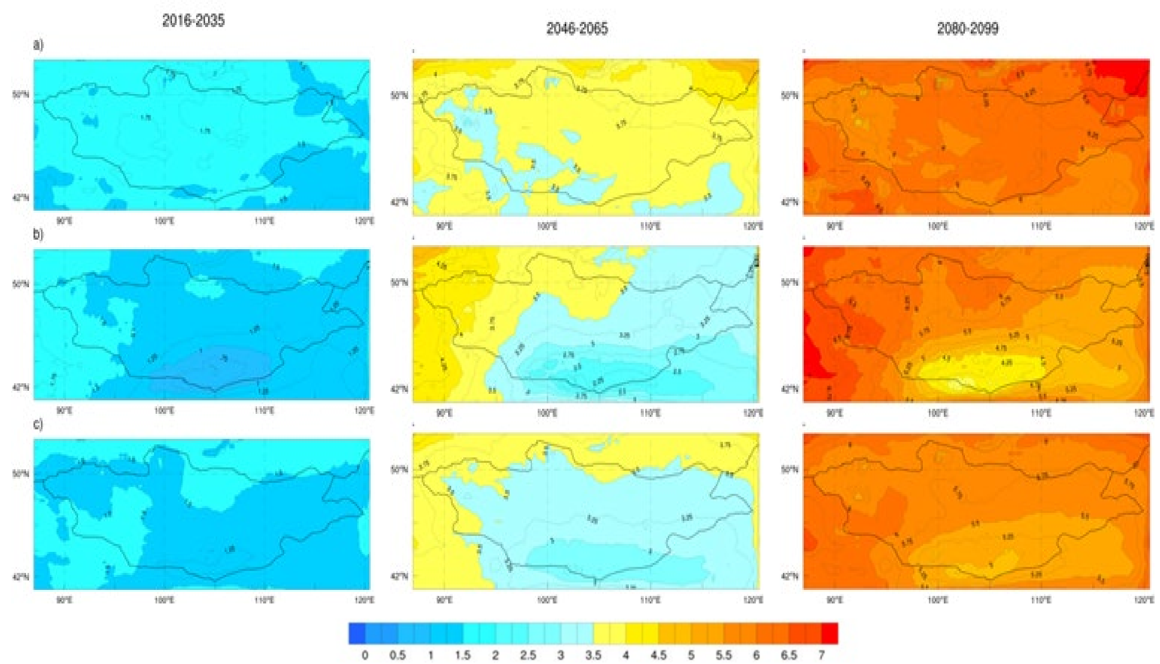


Figure 2.2: Change in air temperature (in °C), based on calculations from RegCM4-HadGEM2 model. (a - winter, b - summer, c - yearly average) *(Source: Ministry of Environment and Tourism, 2018).*

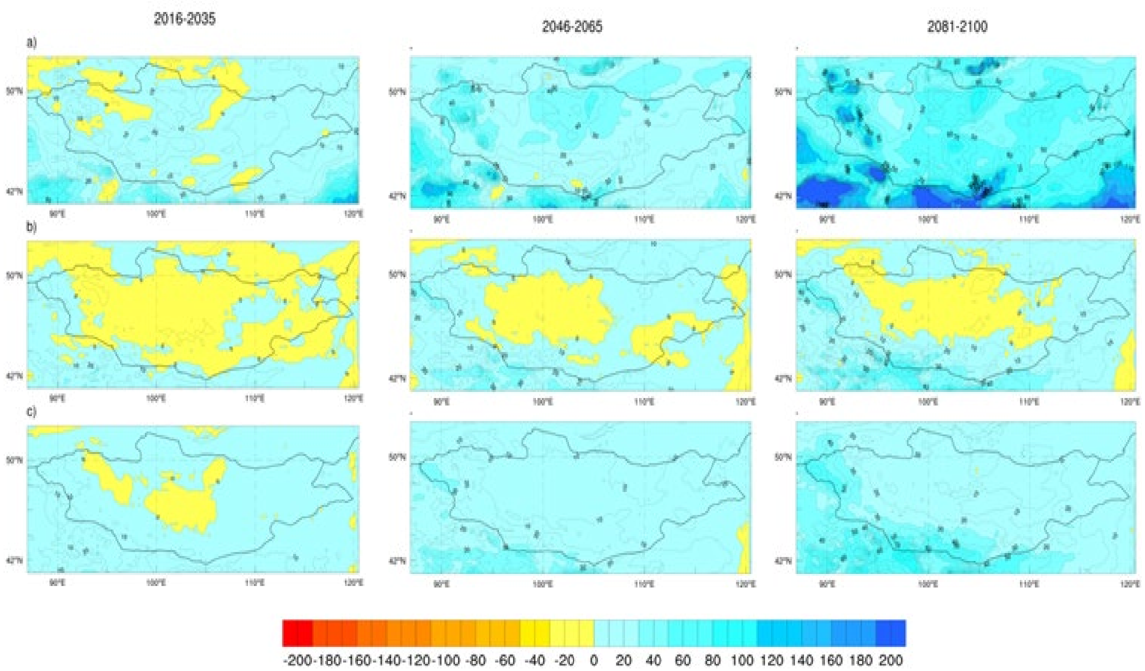


Figure 2.3: Change in precipitation (in %), based on calculations from RegCM4-ECHAM5 model. (a - winter, b - summer, c - yearly average) *(Source: Ministry of Environment and Tourism, 2018).*

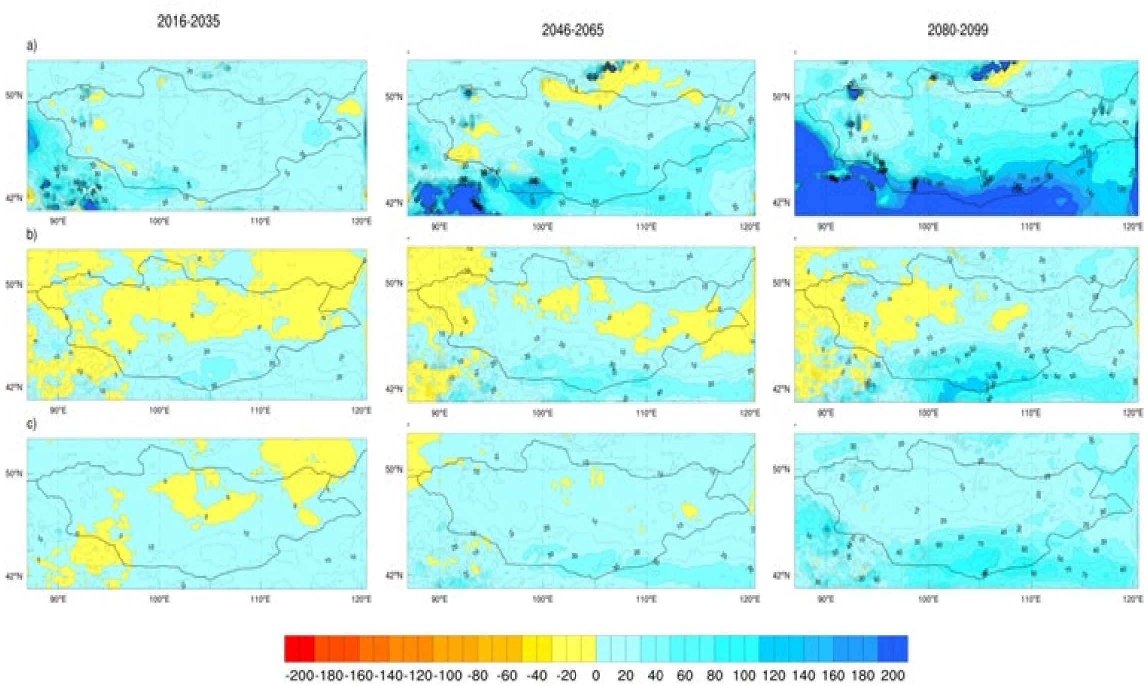


Figure 2.4: Change in precipitation (in %), based on calculations from RegCM4-HadGEM2 model. (a - winter, b - summer, c - yearly average) *(Source: Ministry of Environment and Tourism, 2018).*

Since the rate of climate change in the beginning of the 21st century will not differ much from the RCP estimations and depends on the differences of future projections, we can assume that the estimates for 2016-2035 and 2046-2065 will not vary in a significant way.

3. THE TREND OF THE EFFECT OF CLIMATE CHANGE ON CROP PRODUCTION

We used a dynamic model of yield estimation (DSSAT v4.6) to calculate how wheat yields have changed from the baseline year's average determined by the RCP8.5 emission scenario, which is based on future climate change estimates such as the United Kingdom's Hadley center's model (RegCM4-HadGEM2) and Germany's Max Planck Institute's model (RegCM4-ECHAM5), and compared them with data from 2020 (2011-2030), 2050 (2046-2065), 2080 (2080-2099) (**Table 3.1**).

№	Station name	RegCM4-ECHAM5			RegCM4-HadGEM2		
		2020	2050	2080	2020	2050	2080
1	Darkhan	-5	-22	-43	-20	-31	-44
2	Baruunkharaa	-21	-20	-49	-10	-30	-47
3	Baruunturuun	-5	-9	-22	-4	-30	-39
4	Erdenesant	-3	-15	-31	-2	-17	-35
5	Yuruu	-10	-2	-44	-5	-29	-47
6	Khalkhgol	-11	-10	-21	-15	-5	-29
7	Orkhon	-9	-20	-39	0	-23	-44
8	Tarialan	-6	-14	-42	-11	-20	-35
9	Tsagaannuur	-19	-3	-32	14	-11	-31
10	Ugtaal	-5	-7	-32	-6	-19	-34
11	Khutag	-9	-23	-30	-17	-32	-46
12	Orkhontuul	-7	-23	-50	-24	-35	-56
13	Binder	-5	-10	-36	-18	-23	-36
14	Dadal	-12	-10	-24	3	-14	-28

Table 3.1: Trends and change in future wheat yields in percent. *(Source: Ministry of Environment and Tourism, 2018).*

It can be seen from the table above that if we estimate the change in wheat yields of 2020 (2016-2035), 2050 (2046-2065), 2080 (2080-2099) and compare it with the current (1985-2005) yield level, it is expected to decrease by 9 %, 18 % and 37 %, respectively. The cultivation period was determined by the period following May 15 (1986-2005). In this estimation, we postulated no changes in crop variety and soil fertility conditions.

CONCLUSION

Mongolia is considered to belong to a continental harsh climate with a risky zone to conduct non-irrigated farming. The fact that global warming is affecting Mongolia at three times the global average (0.85 °C/100 years) and is anticipated to increase in intensity over the years, and the amount of precipitation is not expected to rise but more likely to decrease in the summer may further limit the possibility of utilizing conventional technologies in agricultural productions.

According to estimations based on the results of regional level climate models that are adjusted by the widely used international level models, the climate change trend observed in the previous 50 years is expected to continue to hold its projected trend in the 21st century *(MET, 2018)*.

Based on the impact and consequences of climate change on the agro-climate of Mongolia's crop farming regions over the recent years, we have drawn the following conclusions:

Since the sixties of the last century, the cumulative effective temperature over 10 °C has risen at a pace of 80-90 °C/10 years across crop farming regions, and the durations of both active and effective temperatures above 5 °C and 10 °C have been extended by approximately three weeks. This indicates that the increased heat accumulation could cause an expansion in crop farming regions. However, the moisture supply and overheating effects, which are the main limiting factors of crop yields, must be considered in this case.

1. It is understood that the cumulative precipitation across Mongolia since the forties of the last century as well as the amount of rain in warm seasons since 1961 have decreased by 6 % and 23 mm, respectively. This is an indication of a change in natural variability; however, the precipitation variability coefficient of warm seasons has increased significantly across crop farming regions, except the northern border area of the central region. Thus, there is a possibility that the yearly crop yields may fluctuate.
2. Due to global warming, the evaporation potential or evaporation (evaporation capacity plus plant transpiration potential) in the central crop farming region is rising at a rate of 24 mm/10 years, and the cumulative precipitation is decreasing at a rate of 9 mm/10 years which is the main reason for the drought and dryness in Mongolia. This is why the indicators that show the dry-moist condition (Selyaninovs hydrothermal coefficient, Shashko's moisture index, etc.) are shifting towards dryness. Due to climate dryness, indicators of the drought and reliable summer condition (Ped Index (S_i) and Standardized Precipitation Evapotranspiration Index (SPEI)) are shifting towards a dry state. This situation is also confirmed by the Soil-Moisture Index (SMI).
3. Based on the DSSAT v4.6 model that estimates growth stages of crop plants, as well as with the assumptions of wheat varieties, soil fertility and seed sowing date (May 15) all remaining the same as the current condition, we determined that wheat yields will be expected to decrease, on average, by 9 %, 18 % and 37 % for the years 2020 (2016-2035), 2050 (2046-2065) and 2080 (2080-2099), respectively *(Source: Ministry of Environment and Tourism, 2018)*.

RECOMMENDATIONS

- Since it is known that current methods and technologies used for non-irrigated crop farming are not suitable due to climate change, which is expected to intensify, and an increased food demand of the population is expected, there is an urgent need to take decisive action to develop and implement adaptation policies or measures for crop farming for the next 25-30 years to come.
- The wording 'climate change adapted crop farming' should rather be interpreted as a challenge of developing and implementing a strategy of smart crop farming adapted to climate change.
- Improve and refine the agro-ecological monitoring system.

REFERENCES

Atlas of climate resources and surface waters of the Mongolian People's Republic (1987) -M., Ed. Factory number 10 GUGK USSR, 160s.

Bayarmaa V. (2015): Agroclimatic resources and their impact on productivity (Western somons of the Selengiaimak, Mongolia) - Vestnik of Tomsk State University, No. 399, DOI: 10.17223 / 15617793/399/39

Beguería S., Vicente-Serrano S. M., Reig F., Latorre B. (2014): Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. Int. J. Climatol., 34, p. 3001 – 3023.

Chumichev D. A. (1964): Development issues in the allocation of agriculture in the MPR-Izv. AN USSR,

Dagvadorzh D. (1988): Applied dynamic - statistical model of spring wheat productivity in the MPR. L., Dep. in VNIGMI-WDC., No. 837, GM-88

Davaadorj D. (2011): Mathematical Modeling of Agroecosystems: Theoretical Basis and Practical Uses UB., 2001, 202

Gomboluudev P., Kurosaki Y., Natsagdorj L., Munkhbat B. (2018): Climate of Mongolia. Rangeland Ecosystem of Mongolia - Ulaanbaatar, pp: 75-107.

Gordeev A. V., Kleshenko A. D., Chernyakov B. A., Sirotenko O. D. (2006): Bioclimatic potential of Russia: theory and practice-M., T-in scientific publications KMK., 512c.

Ivanov N. N. (1948): Landscape and climatic zones of the globe. M.: L., S. –117 (Notes of the Geographic Island, New Series; V.1.).

Ivanov H. H. (1962): Climate Biological Efficiency Index / H.H. Ivanov // Izv. VGO. T. 94. Issue 1.S.650.

Jambaajamts B. (1970): Climatic zoning of the territory of the Mongolian People's Republic in connection with the placement of the agricultural dissertation, L.,

Jambakhamts B., Sanjiddhanjanjanjav S. (1977): Climate Resource Guide for Mongolia-Photo-offset printing press, 102 face

Jambaajamts B. (1984): Mongolia's Agricultural Climate-UB, UHG, 9.75 pph.

Koloskov P. I. (1971): The climatic factor of agriculture and agroclimatic zoning - L., Gidrometeoizdat., 328s.

MARCC 2014 Mongolia assessment report on climate change 2014: MNET Ulaanbaatar.

Mezentsev V. S. (1973): Water balance. Novosibirsk, 229 p.
Mongolia Third National Communication to the United Nations Framework Convention on Climate Change, 2018

Munkhdulam O., Avirmed E., Sainbayar D. (2017): Climate change assessment of Mongolia's climate based on satellite and meteorological data-News of the Academy of Sciences, Vol. 57, Number 3 (223), p. 5-20

Natsagdorj L. (2004) for changes in the total surface area of the Mongolian surface area of the evaporation-IPPF, No. 2, p. 42-55

Natsagdorj L., Munkhbat B., Gomboluudev P. (2019): Climate biocapacity of Mongolia and its change - Proceedings of the Mongolian Academy of Sciences, vol. 59, No. 2, in printing

Natsagdorj L., Tsatsral B., Dulamsuren J. (2002): The issue of steel-field research on the territory of Mongolia - "Climate Change and Crop Production" p. 26-47

Natsagdorj L., Altantsetseg Kh. (2008): Preliminary results of the study of changes in summer rainfall events in Mongolia – Compilation of reports of "Conference on Climate Change" of the Conference of the

West Region
Natsagdorj L. (2012): For the annual productivity trend of vegetation depending on modern climate change - MAS data, Volume 52, No. 3 (203) p. 24-30
National Atlas of Mongolia / Editor in Chief: D. Dorjgotov / (2009): - Ulaanbaatar
Oyun, J. (2001): Impact on agro-climate change and crop production in Central Mongolia. Doctorate degree in Agricultural Science, Ulaanbaatar.
Ped D. A. (1975): On the indicator of drought and excess moisture - Proceedings of the GMC. THE USSR, vol., 156 p. 19-39
Sanguidansranzhav S., Bayasgalan Sh., Erdenetsetseg D. (1989): The use of dynamic-statistical models for "weather-crops" for some agricultural climate policies - Journal of Symposium Report on the Use of Mathematical Models in Natural Science, 1989-11-17, UB, MNE, p. 65-74
Sanguidansranzhav S. Voronin A. N., Buudaykhγγ D. (1985): Climatic conditions of land cadastral areas - Proceedings of the Institute of Meteorology and Hydrology of Mongolia, No. 10, p. 145-159
Sanguidansranzhav S. Dagvadorzh D. (1985): Application of the dynamic-statistical model in forecasting the yield of spring mildew in Mongolia - Proceedings of the Institute of Meteorology and Hydrology of Mongolia, No. 10, p. 115-125
Sapozhnikova S. A. (1979): Experience in integrated agricultural climate assessment of the territory of the socialist countries of Europe // Agroclimatic zoning of the five main agricultural crops in the territory of the socialist countries of Europe // - Sofia, Izd. Bulgarian Academy of Sciences 99-120
Shashko D. I. (1985): Agroclimatic resources of the USSR - M.: Gidrometeoizdat, p. 243
Sirotenko O. D., Abashina E. V. (1982): On the use of dynamic models for assessing the agrometeorological conditions of crop formation - Meteorology and Hydrology No. 6, p. 95-101
Shubin V. F. (1953): Agriculture of the Mongolian People's Republic - Proceedings of the Mongolian Commission, vol. 52, M.
The Directory of Mongolian Agricultural Climate Records / edited by Bayasgalan Sh., D. Dagvadorj / (1996): - Building of the Institute of Communication and Multimedia
Taylor K. E., Stouffler R. J., Meehl G. A. (2012). An overview of GMIP5 and the experiment design. In: Bulletin of the American Meteorological Society (93), 485-498.

TECHNOLOGICAL SOLUTIONS FOR CLIMATE CHANGE ADAPTED FARMING

Authored by::

***Prof. Dr.* Gantulga G.**
***Prof. Dr.* Odgerel B.**
***Dr.* Bayarmaa Kh.**
Mongolian University of Life Sciences

***Dr.* Ganbaatar B.**
***Dr.* Nyambayar B.**
Plant Science and Agricultural Research Institute of the Mongolian University of Life Sciences

Tsogtsaran B.
“Uguumur Khan Taij” LLC

CONTENTS

INTRODUCTION

CLIMATE CHANGE IN MONGOLIA AND THE NEED FOR ADAPTED CROP FARMING TECHNOLOGY

The geographic location of Mongolia, the delicate state of its nature and ecosystems, and the extreme climate conditions necessitate the introduction of environmentally friendly, resource-saving green technologies that are suitable for these conditions. According to the Long-term Global Climate Risk Index, our country is ranked as the 8th riskiest country in the world. In Mongolia, the intensity of global warming is expected to reach the maximum of 2.4 °C, which is three times the intensity of the global average, resulting in the reduction of precipitation during the crop vegetation period. The increased frequency of extreme weather events such as dzuds and droughts in our country is a direct consequence of global warming and climate change.

Climate change in Mongolia has the following positive and negative effects. The increased number of frost-free days (9 to 15 days) with the consequent heat accumulation allows for an increased number and types of crops, and in some regions, increased winter precipitation (by 20-25 %) is positively improving the moisture supply during the seed sowing period. However, the adverse effects of the climatic changes on the agro-ecosystem have become dominant. These adverse effects are defined by the increase in soil erosion and degradation by 7 to 25 times the normal rate, the reduction of soil humus by 37-52 %, the mineralization of humus by 0.5-1.5 t/ha per year, the alteration of growth parameters of some crops and varieties, and the prevalence of plant diseases and pests.

Therefore, there is an urgent need for Mongolia to develop and implement new technologies to adapt to climate change. Adaptation to climate change requires a set of human activities or measures that are aimed at reducing current and future adverse effects and consequences from climate change for the environment and the society, or at maximizing the utilization of favorable impacts of climate change.

The main focus of climate-adapted crop farming technology for a sustainable production of healthy and safe food is on the development of crop varieties through: (i) creation of drought tolerant, disease and pest resistant and early ripening crop varieties; (ii) development of high quality seed production systems for acclimatized varieties; (iii) introduction of reduced or zero tillage, resource-saving technologies; (iv) systematic usage of mineral and organic fertilizers; (v) application of proper crop rotation systems to improve soil fertility and crop yield; and (vi) development and implementation of crop irrigation technologies.

1. SEED AND VARIETY SELECTIONS AND SEED PRODUCTION SOLUTIONS

1.1. CURRENT STATUS AND FUTURE OBJECTIVES FOR EARLY RIPENING CROP VARIETIES THAT ARE RESISTANT TO DROUGHT, DISEASES AND PESTS

Climate change, in an overview, may have the following negative impacts on crop farming: an increase in air temperature by 1.0 °C can cause a shift of the natural zones by 200-250 km to the north; a cease of overall fitness of the growth parameters of crops currently being cultivated; a 25-30 % decrease in crop yield by 2030-2040 due to warmth and moisture insufficiency; a threefold intensified erosion and degradation of soils; and a 25-35 % increase of crop damage due to diseases and pests *(Mijiddorj R., Tuvaansuren G. 2009, Gomboluudev 2012)*.

The crop most affected by climate change is spring wheat. Researchers warned that yields of heat-sensitive spring wheat will decrease by 2 % every 10 years *(43)*.

Therefore, it is important to expand research and development (R&D) in terms of adaptation to climate change. It is of foremost importance to pay attention to the correct determination of crop farming regions, maturity ratios and cultivation parameters, to the development of irrigated farming, the use of rain and snow water for irrigation, and the development of new varieties.

The crop farming regions of Mongolia are divided into 5 main zones and 10 sub-zones *(Davaadorj G., et al. 1989)*. Due to the changes in the amount and distribution of precipitation during the past 20 years, the sum of growing-degree-days (GDD) above 10 °C, the occurrence of last and first frosts in spring and autumn, and the number of frost-free days, it comes to a shift and displacement of the crop farming zones.

In the central crop farming region (located in arid and semi-arid cold sub-zones at a relatively low altitude of 700-1,100 meters above sea level) some high-yielding, mid- and late-season varieties of wheat are being cultivated and produce an increased unit yield in connection with changes in climate conditions that have proved favorable to a certain extent such as, for instance, the sum of GDDs above 10 °C which increased by 87-215 degrees and the number of frost-free days which increased by 11 days. Research suggests that the northern soums, located in the Khentii Mountains, have formed the climatic conditions for growing mid- and early-growing varieties of wheat due to climate change *(34)*.

Researchers suggest that wheat crops are suitable to be cultivated in highland crop farming zones with a composition of 70 % of early-season varieties and 30% of mid-season varieties. Studies show that this is a result of the climate changes over the last 20 years as the sum of GDDs above 10 °C increased by 176 to 179 degrees and the number of days without frost and above 10 °C increased by 4 to 10 days, which makes the climate suitable for early- and mid-season barleys, early-season rye, mid-season barley, buckwheat and peas rather than for the formerly cultivated crops such as early-season barley, buckwheat, peas and potatoes. For example, prior to 1990, in the northern soums of Zavkhan, Khuvsgul and Arkhangai provinces, only barley and buckwheat were cultivated; however, due to climate change in these areas the conditions required for growing very early- and early-season wheat varieties are met *(15, 40)*.

Although precipitation is rare, soil is light, and winds are strong in the steppe zone, the vegetation period is long and the sum of GDDs is high, making it possible to cultivate 20-30 % early-season varieties, 40-60 % mid-season varieties, and 20 % mid- to late-season varieties *(Myagmarsuren Ya., et al. 2005)*.

Over the last 20 years, in the steppe crop farming zone, the sum of GDDs above 10 °C has increased by 129-302 degrees and the number of days without frost and above 10 °C has risen by 5 to 11 days. This suggests that under irrigated conditions, crop plants and varieties with a long vegetation period are able to be cultivated in this zone.

Variety selection: Cultivation of the right varieties with parameters suitable for the existing capacities of soil and climate condition of the relevant region will facilitate fully ripened, high-quality and rich yields. The main factors limiting high yields in Mongolia are the short vegetation period, the low precipitation, and the frequent occurrence of high temperature days. Many researchers around the world recognize that heat-resistant, high-quality and high-yield varieties are also applicable to areas having low moisture and inadequate heat accumulation, and therefore, such varieties can be produced by a selection method. Plant breeding, which began in the late 1950s in Mongolia for the selection of wheat varieties, is now thriving with the production of new varieties of grains, potatoes, vegetables, fruits and berries. During the more than 60 years of developments in breeding and the selection of grain crops, stress-resistant, high-quality and high-yield varieties suitable for the agro-ecological region and intensive irrigated farming were acclimatized and produced by methods of hybridization, factorial mutagenesis and marker gene techniques. For example, until 2018, more than 110 varieties of grains had been developed, including 86 spring wheat, 13 spring durum wheat, 5 barley, 4 rye, and 2 brown rice varieties. Out of them, 9 wheat, 3 durum wheat, 4 barley varieties are being cultivated on 40-45 % of the crop farming regions of Mongolia *(10, 36)*.

Researchers have found that crop yields of varieties that are adapted to the region may be increased by up to 25-30 % and further up to 50 % by utilizing the soil capacity and the climatic conditions without any additional costs *(14, 16, 34)*.

The main criteria for the selection of wheat varieties for dry land farming in our country are drought resistance, short maturity, good quality and high yield. High-yielding oversea varieties are not particularly suitable for the cultivation in our country, for example due to crop loss, reduction of maturity rate, low quality of seed, flour and bread production, and insufficient resistance to pests and lodging. All these things tend to occur together during drought conditions.

When selecting and cultivating certain varieties, it is of foremost importance to focus on their full ripening period. In general, ripening length of wheat crop is determined between growth stages from germination to hard dough in our country, and it can fluctuate between 3 and 10 days depending on the moisture supply. Therefore, early and mid-season ripening varieties with ripening lengths between 78 and 95 days are most suitable in Mongolia. Varieties that ripen within 75-82 days, or 85-90 days, or 90-95 days are considered to be early, mid and mid to late ripening varieties, respectively *(15, 24)*.

The main criteria for selecting varieties in dry land farming are traits of drought and heat resistance, short ripening, and good quality and high yield. Generally, it is suggested for farmers to cultivate 2-3 locally acclimatized varieties with different ripening lengths. When doing so, it is important to cultivate early, mid, and mid-late ripening varieties in a specific ratio and correctly determine the composition while considering the environmental and climatic impacts in order to reduce the risk of drought and increase the likelihood of harvesting a constant yield.

For instance, in order to reduce the risk of drought in the central farming region when soil moisture levels are low, and ensure stable yields, 30-40 % of the total wheat cultivation area should be planted by Darkhan-144, Darkhan-181, Buryatskaya-34, Selenga, and Altaiskaya-530 varieties at the earliest time, 40-60 % of the area should be cultivated by mid-ripening Darkhan-34, Darkhan-74, Arvin /Darkhan-166/, Buryatskaya-79, Buryatskaya osteti, Altaiskaya-100, and Altaiskaya-325 varieties in the mid planting season, and 10-15 % of the area should be cultivated by early-ripening Khalkh lake-1, Darkhan-131, and Darkhan-160 varieties later in the spring *(14, 15, 24, 25, 35, 40)*.

For the highland farming regions, it is appropriate to cultivate early-ripening varieties

such as Khalkh gol-1, Darkhan-131 and Darkhan-160 on more than 70% of the field, and Darkhan-34, Drakhan-74, Arvin /Darkhan-166/, Buryatskaya-79, Buryatskaya osteti, Altaiskaya-100, Altaiskaya-325 on up to 30 % of the area.

In the Great Lakes Depression zone, it is suggested to cultivate early-ripening varieties on more than 80 % and mid-ripening varieties on up to 20 % of the farming area.

In the Eastern steppe zone, 60-70 % of the cultivation area should be planted with mid-ripening varieties such as Darkhan-34, Darkhan-74, Arvin /Darkhan-166/, Buryatskaya-79, Buryatskaya osteti, Altaiskaya-100 and Altaiskaya-325, and 30-40 % of the area should be cultivated with Darkhan-144, Darkhan-281, Buryatskaya-34, Selenge and Altaiskaya-530 varieties.

In case of wheat cultivation under irrigated conditions, it is advisable to cultivate varieties that are hypersensitive to water and fertilizer, disease and pest resistant, early-to mid-ripening, and show a high yield and good quality. For the Mongolian irrigated fields, it is recommended to cultivate acclimatized varieties such as Tsagaandeglii and Tsogt *(14, 15, 24, 25, 35, 40)*.

1.2. CURRENT STATUS OF GRAIN SEED FARMING AND THE DEVELOPMENT OF SEED PRODUCTION SYSTEMS

The “Virgin land 3” national campaign provided modernization of farming techniques, introduction of advanced technologies, and acceleration of seed renewal and had a definite effect on crop farming production. However, with today’s environmental and climatic conditions changing from year to year, an effective and integrated seed farming system that produces seeds of varieties that are adapted to the specific climatic features of each region is required.

The lack of major agricultural technology, in particular, for wheat seed production, the neglection of policies on the replacement of old varieties and seed renewals, the lack of cultivation of acclimatized varieties specifically for different crop farming regions, and the usage of poor quality seeds in recent years are all considered to be major reasons for the deterioration of crop stability in our country.

New varieties of wheat have been developed by domestic breeding techniques comprising enriched genetic resources. Accelerating the production of new elite seeds that are drought resistant, adaptive and well acclimatized allows for an intense replacement of varieties and seed renewals within a short period, which is a key condition for the restoration and sustainable operation of crop production. For example, according to the crop production data provided by the Ministry of Food, Agriculture and Light Industry (MoFALI) in 2018, out of the total 27 varieties of wheat cultivated on 329.9 thousand hectares, 428.6 thousand tons of yield or 13.7 centners per hectare (ce/ha) were harvested. The most cultivated variety was the mid-late ripening Darkhan-144 which was cultivated on 26.9 % of the total arable land, providing 24.3% of the total harvest and with 16.7 ce/ha achieving the highest yield per unit.

Furthermore, 58.8 % of the cultivated wheat varieties are verified to be acclimatized to the environmental and climatic conditions of our country. In contrast, the remaining 41.2 % of the varieties are neither officially certified nor acclimatized for cultivation in the conditions indicating the weight of the risk on crop yields. For instance, although early-ripening varieties are suggested for cultivation in highland areas, mid-late ripening varieties have been cultivated on 84.0-85.8 % of the region's arable land causing crop to be damaged by the cold/frost prior to complete ripening and resulting in yield loss. This is an incident of significant neglection of the state policy on varieties and seed production systems of wheat, the main strategic crop of our country.

Currently, the primary seed growers in the seed production system are research organizations and seed production entities; whereas the Support Fund for Crop Farmers (SFCF) is responsible for the marketing and distribution of seeds, and the State General Agency for Specialized Inspections (GASI) is responsible for the control of state seed reserves and seed varieties. As they belong to different ministries and implementing agencies, it is difficult to integrate the policies and strategic plans of these authorities. One of the recent state-supported efforts to address this system failure was the establishment of the "Darkhan Elite" startup company at the Plant Science and Agricultural Research Institute (PSARI) for the production of elite acclimatized seeds. The company is supplying 300-400 tons of elite seeds per year to MoFALI, SFCF and 10 other seed production entities. This is an indication of the start of reformation in the seed farming system.

The production of elite grain seeds requires 6, 4 and 2-3 years if produced by single, bulk and reverse or accelerated selection approaches, respectively. As the production of super elite and elite seeds requires costly advanced technologies and methods, it must be conducted by research organizations. There is a need to produce elite reproducing seeds with the incorporation of private sectors and entities with a license for the purpose of seed renovation in the supply chain of the state domestic demand.
Therefore, further state policies and regulations are needed for the cultivation of acclimatized varieties that are suited to meet the characteristics of the region and to increase and stabilize current wheat yields, as there are:

1. Updating seed farming systems and establishing mechanisms and structures for cultivating acclimatized varieties suitable for each region;
2. Providing government investment for strengthening the experimental facilities and conditions of research institutions required for the production of primary seed materials, and expanding the renewal of primary seed stocks;
3. Controlling the supply of seeds produced by seed production entities to the state seed reserve, and entitling the MoFALI to distribute and regulate seeds in the state reserve in line with the relevant policies;
4. Organizing the seed production system with the following structure: Primary seed production, Elite seed production, Seed reproducing centers, Seed production entities, and Domestic commercial seed production.
5. Separating the Plant Quarantine Office and the State Central Seed Laboratory from GASI and establishing them under the structure of the Plant seed variety department in order to update the system of seed quality control;
6. Updating the legal environment to replace, renew and verify crop varieties, to improve quality control of seeds and varieties, and to establish a state seed reserve fund;
7. Transitioning into a differentiated grain incentive system depending on whether the farmers or entities have updated the seeds and varieties, whether the quality of the cultivated seeds complies with the standards, and whether the measures to protect soil fertility have been implemented according to the law or not.

1.3. USE OF NUCLEAR TECHNOLOGY AND GENETIC ENGINEERING IN PLANT BREEDING OF MONGOLIA

The increased food demand due to the rapid growth in the world's population indicates that agricultural production, including crop plant based production, must be increased. Modern research on increasing production yields is focused on improving the quality of products and fully utilizing the genetic potential of crops rather than increasing the area of cultivation. At present, only 50 % of the genetic potential of crop plants are utilized. One method of full utilization is to develop new varieties that fully expose the genetic potential of the crop.

Plant breeding techniques to create new varieties are the least costly and the most beneficial factors that influence the increase of crop yields. Among the numerous methods for producing new varieties, the use of nuclear techniques or radioactive radiation methods to produce mutant varieties is the most widely spread one around the world and has the following advantages:

1. Easy to use and highly efficient with crops where conventional breeding techniques are difficult to apply.
2. By creating genetically diverse, beneficial mutant lines, the breeding stocks are enhanced.
3. The time span for creating new varieties can be reduced since less effort is required compared to conventional selection.

Since the discovery of the method to produce mutations using chemical and physical mutagens by De Frez, research has been carried out on many crops, and until 2018, the world has produced 3,275 mutant varieties of 220 species *(http://mvd.iaea.org/)*. Out of these varieties, 45 % are grains, 18 % are flowers and ornamental plants, 8 % are legumes, 7 % are oil plants, and 22 % are other crop varieties *(60)*.

Through mutation selection many characteristics of crop plants can be positively improved. So it is possible to increase the yield, increase the resistance to drought, heat, salinity, disease and pests, accelerate ripening periods, increase durability for storage and transportation after harvest, and improve endurance to mechanical harvesting.

Gene enhancement is easily and efficiently solved by mutation techniques for crops where a conventional selection is complex and time-consuming. This method is effective, for example, on plants with a closed flower spike such as barley and rice, as many varieties of these crops have been produced in many parts of the world. Some of the biotechnological issues in the beer producing industry have been solved through this kind of mutation techniques.

In our country, Baast B. started work on mutational selection research in 1969 by developing a method for using experimental mutagenesis in plant breeding and producing various valuable breeding stock materials for selection. For instance, by treating wheat seeds with gamma rays and fast neutrons, high-yield, high-quality and early-ripening mutant lines were produced *(Baast B. 1976)*. He determined that the Orkhon variety is gamma ray resistant and the Sarrubra variety is sensitive to ionizing radiation, with discovering 15 mutants of the Orkhon variety and 7 mutants of the Sarrubra variety. Following the analysis of the 5,200 plants of the M2 generation, 4.6 % and 35.8 % of mutant lines in the backgrounds of Orkhon and Sarrubra, respectively, showed some genetic variations, and dosages of 10.15 kP of gamma radiation and 1,000 rad of fast neutrons were most efficient to create new mutations in both genetic backgrounds *(Baast B. 1980)*. From the selected 78 mutant lines of the Orkhon variety and 18 mutant lines of the Sarrubra variety, the early-ripening Kharaa-86 variety was created and introduced into industry *(5)*.

Researchers Amarsanaa J. and Sarantsetseg M. have revealed that spring wheat species (Triticum aestivum), Orkhon and Saratovskaya-29, were hypersensitive and durum wheat (Triticum durum), Narodaya, showed resistance to 2.2, 4.5, 9 and 27 kP gamma radiations and to PH_3 10^{-3} sodium nitrite treatment for 8 h and 2 h with and without water application for 8 h *(48)*.

PSARI has implemented a joint project with the International Atomic Energy Agency (IAEA) since 1982, which expands research on new varieties and breeding stock materials by artificial mutation, introduces new techniques and technologies and allows young scientists to receive education overseas.

From 1989 to 2018, out of the total 74 varieties, which consisted of 54 domestic and 20 foreign varieties treated with chemical and physical mutagens by researchers at the institute, Darkhan-106, Darkhan-141, and Darkhan-172 varieties were transferred to the State Seed Testing Unit (SSTU). Studies were conducted to determine the appropriate dosages of the chemical and physical mutagens for each variety while considering the growth parameters of the crops such as length reduction of cotyledons and roots, and germination rate. Results revealed that the dosages of gamma ray and nitrogenous sodium (chemical mutagen) for wheat varieties were between 120 Gy and 180 Gy and 0.75 mM and 1.5 mM, respectively *(Dolgor Ts. 2009)*. As a result of the mutational selection research, varieties MO-5, MO-6, MO-8, MC-78, Kharaa-86, Darkhan-35, Darkhan-49, Darkhan-106, Darkhan-141 and Darkhan-172 were created and transferred to the SSTU. Out of the new varieties, Kharaa-86 was acclimatized, and Darkhan-141 and Darkhan-172 varieties were certified as promising varieties. Since 2018, the world-wide used ion beams have been tested on 4 varieties and the suitable dosages for use on Darkhan-144 and Darkhan-181 have been determined. The variety certified to be promising from the 2015 SSTU Conference, i. e. Darkhan-141, was proven to be drought resistant and suitable for animal fodder; and the variety certified to be promising in 2018, Darkhan-172, has early-ripening properties, produces high yield and is suitable for cultivation in high altitude lands *(22, 23, 24)*.

Genetic engineering techniques. The marker gene transfer research was started in 2008 in Mongolia with the objective to improve rust resistance of wheat species. Through this research, the leaf rust resistant Anza *Lr37, Yr17*, and *Sr38*, the brown rust resistant Kern *Lr47*, and the stem rust resistant Yecoro Rojo *Yr36*/Gpc-B1 genes were crossbred with native varieties to create hybrid lines. In addition, genes resistant to diseases specific to Mongolia were detected through artificial infection and PCR selection, which resulted in the introduction of 30 varieties with the disease-resistant marker gene into practice of plant breeding *(15, 40)*.

1.4. INTRODUCING ADVANCED METHODS OF PLANT BIOTECHNOLOGY AND MOLECULAR GENETICS INTO CROP PLANT BREEDING AND ACCELERATING THE SELECTION ACTIVITIES

At the international level, genetic markers are used to identify varieties by genotype, and as time passes, the approaches are becoming more sophisticated as gene studies of each chromosome are conducted. Over the past 20 years, the use of marker genes in global wheat selection has expanded the study of wheat genomes, which in fact accelerated breeding activities and increased selection efficiency. Since their detection in 1991 by Paterson, more than 3,000 molecular markers and 16,000 gene maps were developed. In addition, research conducted to create gene markers for a large part of the wheat chromosomes identified the marker genes for use in plant breeding concerning: stickiness of gluten, starch crystallinity, developmental pattern, short stalk, and leaf rust resistance *(3)*. Furthermore, countries are using marker genes to identify the varieties produced from breeding and to determine polymorphism, and are obtaining the copyright for their wheat varieties to register them in the International Wheat Atlas *(http://wheatatlas.org/)*.

In Mongolia, however, wheat varieties are only distinguished by phenotypic characteristics as studies on genotyping wheat varieties using markers are still in their early stages.

Researchers from PSARI in cooperation with researchers from the Institute of Crop Sciences of China selected 42 pairs of primers recognizing sites on the 2 arms of 21 wheat haploid chromosomes and developed SSR markers according to the gene mapping proposed by S.J. Chu and S.S. Shu in order to determine the suitable dosage of gamma rays for Darkhan-193, Darkhan-197, Darkhan-199, and Darkhan-200 and whether any polymorphisms occurred by the SSR markers. As a result of this study, 13 polymorphisms in Darkhan-193, 4 in Darkhan-197, 8 in Darkhan-199, and 10 in Darkhan-200 were detected *(Dolgor Ts. et al., 2014)*. In addition, when comparing 2 wheat mutant varieties to the parental lines by using 49 pairs of SSR primers, the mutant Darkhan-175 variety differed by 23 pairs of primer sites, and mutant Darkhan-196 variety differed by 9 pairs of primer sites.

Researcher Odgerel B. conducted a study in South Korea to identify salt-resistant genes in wheat varieties and determined Darkhan-74 and Darkhan-34 varieties as salt resistant *(44)*.

With the funding from the IAEA technical cooperation project, MON5021, a molecular genetics laboratory was established at the PSARI where studies for genotyping wheat varieties using markers have begun. The study identified genetic polymorphisms of national wheat varieties such as Darkhan-34, Darkhan-131, Darkhan-144, Darkhan-166, Tsogt, and Khalk gol-1 by using a total of 22 markers. Among the 22 primers, GluAx2, Bx, Bx7, GluB1 Non By9, GluD1d, Lr34, Lr37, P3/P4, UMN25, UMN26, and Yr36 marker genes were detected and GluA1x1, GluD1a, Lr47, and ZSBy9a marker genes were not detected. As a result, primers were determined to identify the varieties, such as: the Bx7 and Dx5 primers for Darkhan-34; the Bx, Bx7 and Dx5 primers for Darkhan-13; the GluAx2, Bx7, Dx5 and ZSBy9 primers for Darkhan-144; the Bx, Bx7 and Dx5 primers for Arvin (Darkhan-166); the Bx, Bx7, Dx5 and ZSBy8 primers for Khalkh gol-1; and the Bx, Bx7, GluA1c, GluB1 and Bx642 primers for Tsogt *(52)*.

At the molecular biological laboratory of PSARI, research on determining homozygosity of locally acclimatized wheat varieties was performed using the ISBP, ISSR, and RAPD markers. This study indicates that molecular markers can be used to detect differences not only in wheat varieties but also in other crop varieties *(3)*.

Accelerate the **breeding program**. Following the grain production industry, there is an increasing need for the introduction of new crop varieties that are suitable for and fulfil demands of each region.

The conventional method of producing varieties through breeding or hybridization is more time-consuming, thus creating some difficulties in mass production of new crop varieties. Mutagenic approaches are widely used to accelerate the selection process, thereby reducing the length of production span by 3-5 years. By accelerating the breeding program of grain crops using biotechnological methods, such as the use of anther and pollen tissue cultures, it is possible to create homozygous plants, to shorten the production time span by 4-7 years, and to increase the yield by 15-20 %. Furthermore, the introduction of molecular genetic methods into plant breeding shortens the selection and regeneration time span by 5-8 years and provides the conditions for optimal selection *(1, 9)*.

1.5. FUTURE GOALS FOR GRAIN SELECTION

By closely integrating plant breeding research with the sciences, such as physiology, genetics, biotechnology, chemistry, plant disease research, molecular biology and soil science, it is possible to increase agricultural crop yields, improve quality, increase resistance to the external environment, and fully utilize the genetic potential of crops. Scientists around the world are successfully conducting researches to improve the yield and quality of agricultural crops through the use of modern biotechnological techniques, to enhance selection efficiency by diagnosing with molecular marker techniques, to transfer beneficial genes through genetic engineering, to produce donor plants with the disease, pest, drought and frost resistant genes through remote hybridization for usage as genetic material, and to improve crops using nuclear technology. From these fields of research, the studies of genetic engineering, biotechnology, and molecular markers are just in the beginning stage, and therefore, further goals for breeding are in need of being developed in the following directions *(24)*:

1. Develop and introduce drought-resistant varieties into breeding practice based on studies of the physiological functions of the crop, such as respiration, nutrition and photosynthetic processes, in connection with the increased frequency of drought currently occurring due to climate change;
2. Create new varieties through the production of homozygous offsprings with diverse genetic polymorphisms by the combination of gamma rays and ion radiation;
3. Use genetically different genus or wild-type species for hybridization to improve crop resistance to drought, frost and diseases;
4. Improve crops that are difficult for conventional breeding, such as barley, soybean, and corn, using mutagens such as gamma and ion beams;
5. Enhance selection efficiency by using molecular markers to identify beneficial traits in the early stages of selection and to intensively shorten the production span;
6. Implement intercontinental selection; in other words, considering that different parts of the world have different crops with different growing periods, allow up to 2 generations per year to shorten the breeding process.

Technological innovations are needed to bring crop breeding efforts closer to the

world ranking and to introduce production of new varieties adapted to the agroecological conditions. The foremost issues to be resolved are the establishment of a complete physiological laboratory and the intensification of the operation at the molecular genetic laboratory.

2. TECHNOLOGICAL SOLUTIONS FOR SOIL CULTIVATION AND PROTECTION

2.1. SOIL FERTILITY STATUS OF ARABLE LAND OF MONGOLIA

The total arable land of Mongolia, including field areas of soums above 50 hectares, is 1,246,351 hectares. This total area is broken down by region as follows: 859,297 ha in the central crop farming region; 224,922 ha in the steppe region; 162,132 ha in the highland region *(Davaadorj G., 2018)*.

According to the 60 years of intensified crop farming history in Mongolia, only 107,400 ha of land were under cultivation in the initial year 1958, and with the subsequent first campaign to reclaim virgin land in 1959 the cultivated area increased up to 441,000 ha by 1962. Furthermore, in 1976, the “2nd Virgin Land Campaign” was organized and implemented with the goal to cultivate 230,000 additional hectares of land between 1976 and 1980 *(51)*.

By the end of the “2nd Virgin Land Campaign” in the early 1980s, the total crop rotation area in Mongolia had reached 1.3 million hectares, and the grain yield had arrived at 640.0-800.0 thousand tons that were harvested from 700.0 thousand hectares of planted areas *(35)*. However, since 1990, the farming sector has faced a decline with only 174.1 thousand ha of cultivated land and harvested 226.9 thousand tons of grains, potatoes, and vegetables until 2005 *(36)*. The agricultural sector has been recovering since the “3rd Virgin Land Campaign” announced by the Government of Mongolia in 2008. According to the MoFALI in 2019, the total cultivated area in crop rotation had reached over 700 thousand ha, and crops had been planted on 512 thousand ha.

Only 9.1 percent of the total arable land has a high fertility and is categorized into Agro-industrial Group I, 80.7 percent of the land has an average or below-average fertility and is categorized into Agro-industrial Groups II and III, and 3.2 percent of the land has a poor fertility and falls into the Agro-industrial Group IV. Therefore, Mongolia’s crop farming production must be brought to a level to restore soil fertility.

In the framework of the “3rd Virgin Land Campaign” from 2008 to 2010, researchers from PSARI performed an agrochemical soil analysis to determine soil humus, ammonium nitrate, extractable phosphorus, exchangeable potassium, soil compactness, soil erosion, and soil acidity by testing 15,790 samples from 579.3 thousand ha of 1,942 crop farming entities and households of 102 soums in 15 provinces. The results of the analysis showed that 60.6 % of arable land was affected by severe erosion, 67 % had less than 2.5 % humus, 20 % had more than 3% humus, and soil fertility in most regions is below average. In addition, about 60 % of the total arable land has low nitrogen and potassium compositions that are easily absorbed by plants, and 34.7 % has a low phosphorus content *(62)*.

According to the results of the research project “Effect of minerals and fertilizers on sustainable improvement of crop soil fertility and crop production” implemented by the PSARI from 2015 to 2017, the amount of soil nitrogen was low in 73.8 % of the total arable land of Mongolia, moderate in 11.1 %, good in 15.1 %, and the content of exchangeable potassium is low in 66.7 %, moderate in 20 %, and good in 13.3 %, while the amount of extractable phosphate was low in 40.4 %, moderate in 43.6 %, and good in 15.9 % of the total arable land *(61)*.

According to the results of the soil research conducted on 30,000 ha located in the central and steppe regions of crop farming between 2016 and 2018 by researchers at the School of Agroecology of the MULS, the soils had the following mechanical composition: 1 % was heavy loamy, 10 % medium loamy, 39 % light loamy and 50 % sandy. Furthermore, following the analysis of the humus content, 59 % had 1-2 %, 15 % had 2.1-3.0 %, and 26 % had more than 3 % humus. In terms of nutrient supply, nitrogen was low in 58 %, moderate in 36 %, good in 6 %, and extractable phosphate was low in 42 %, moderate in 43 %, and good in 15 %, while exchangeable potassium was low in 73 %, moderate in 21 %, and good in 6 % *(Odgerel B. et al, 2018, non-published)*.

The results of the above research revealed that the fertility of soil used for crop farming has significantly degraded.

2.2. ANALYSIS OF THE ADVANTAGES AND DISADVANTAGES OF SOIL CULTIVATION TECHNOLOGY DURING THE MONGOLIAN CROP FARMING DEVELOPMENT PERIOD

Since the acquisition of virgin lands for the development of crop farming, fallow cultivation technology has been used in our country. The main reason for such a technology was to reserve the moisture and nutrients in the soil and eliminate weed plants from the fields. Although there are many types of fallow cultivation, Mongolia mainly practices bare fallowing. At first, fallow cultivation was accomplished via turning over the soil by plough. Later, there was a shift towards tillage technology. Recently, chemical cultivation methods have been widely used for fallow cultivation, but often in combination with tillage technology. This type of fallow cultivation is called combined cultivation of fallow.

Advantages of fallow land cultivation through ploughing:

In years with high precipitation, it performs well in accumulating moisture and minerals, and eliminating excess substances and weeds.

Disadvantages of fallow land cultivation through ploughing:

In years with drought, the soil will easily lose moisture and erode due to winds, and structural changes and excess mineralization will occur resulting in poor productivity and high economic costs.

Advantages of tillage on fallow land:

Protects soil from wind erosion; slows down mineralization of organic substances in soil; reduces soil moisture evaporation; improves moisture regime; deeply damages roots of perennial weeds; reduces dust production; reduces cost of cultivation and increases labor productivity.

Disadvantages of tillage on fallow land:

Increased moisture loss in years of drought; a small percentage of vegetation cover will remain; costs are not low; and soil erosion may occur to some extent.

Advantages of combined cultivation of fallow land:

Protects soil against wind erosion; accumulates moisture; retains residue cover to some extent; accumulates moisture well in the second half of summer; eliminates weeds; low soil processing costs with increased productivity.

Disadvantages of combined cultivation of fallow land:

Moisture accumulation decreases and vegetation cover is reduced during drought years.

Recently, no-till cultivation is a new technology being introduced into our crop farming practices. The implementation of this technology requires chemical cultivation of fallow land. In addition, it retains grain residue and allows for straw covering.

Advantages of no-till technology:

Retains moisture well; eliminates weeds; retains residue covers well; low soil organic substance loss; allows for straw covering on soil surface.

Disadvantages of no-till technology:

Poor mineralization; increases cost; reduces opportunity to conduct organic farming.

2.3. CHANGES IN MONGOLIAN SOIL CULTIVATION METHODS AND TECHNOLOGIES THAT NEED TO BE IMPLEMENTED IN THE FUTURE

In Mongolia, the traditional cultivation technology of ploughing had been used since 1959 when virgin lands were occupied for the first time. Then, since 1974, tilling technology has become more predominant. The United States began replacing ploughing technology with tilling technology in 1934.

Soil cultivation technology has developed to focus more on soil protection against erosion. With the purpose to protect soils, measures to reduce soil destruction and to utilize no-till cultivation technology have recently been introduced into crop production. Reduced soil cultivation technology decreases the depth of cultivation and the frequency of mechanical tillage, and integrates technological operations as much as possible, while no-till cultivation does not require any mechanical processing other than the narrow cutting that takes place during sowing.

The no-till technology has been intensively introduced into the countries of the Americas and Europe since the 1960s and into Africa and Asia since the 1970s. In addition, the United States have set the target to use no-till technology on 75 % of their total arable land by 2020 *(30)*.

In Mongolia, no-till technology has been tested since 2010 for introduction into crop farming.

Clause 1 of Article 18 “Technological Innovations in Crop Production” of the Crop Farming Law of Mongolia states that “Zero-tillage cultivation and reduced processing technologies that protect soils shall be used for grain production.” Furthermore, Clause 4 of the same Article states that “It is forbidden to use ploughing techniques and technologies in grain production, except for bringing virgin lands under the plough for the first time, developing irrigated fields according to the relevant technologies and cultivating fallow land with green manure technology.”

According to “Mongolia’s Sustainable Development Concept-2030” and the 19th Resolution of 2016 approved by the Parliament of Mongolia, zero-tillage technology shall be implemented in 70 % of grain production fields by 2020, 85 % by 2025, and 90 % by 2030.

Currently, it is unclear how much of Mongolia's crop farming land has already introduced zero-tillage and reduced processing technologies. However, it is known that 40-45 % of cultivated fallow land is undergoing a combination of chemical and mechanical tillage.

2.4. DIRECTION OF SOIL PROTECTION MEASURES TO BE IMPLEMENTED IN CONNECTION WITH CLIMATE CHANGE FACTORS

Agrotechnology is the basis of soil protection measures for crop farming fields. In Mongolia, some of the laws governing the production of sustainable harvest as set by crop science have been violated. When adapting to climate change and implementing soil protection measures, it is essential to work on the basis of agrotechnology which has enforced the relevant laws.

Strip farming: Strip farming is a method which involves placing narrow strips of fallow land between grains and other crops. This method of soil protection had been widely used in the crop production of Mongolia, although its use has declined recently. Prior to the full-coverage introduction of zero-tillage technology, the soil has to be protected from wind erosion by the strip farming method. This method is particularly important in the windy steppe zone and near the Khalkh River.

Our researchers found that 30-33 m wide strips for flat sandy soils, 50 m wide strips for light loamy soils, and 100 m wide strips for medium loamy soils, which block the direction of the wind, would reduce dust storms significantly. However, strip farming is not suitable for fields with slopes above 2 degrees as soil erosion occurs due to water trenches that form between the strips because of melted snow in spring and heavy rain in the summers; in this case, the strips are placed to run across the slope *(25)*.

Crop rotation: Laws on crop rotation in Mongolia have also been violated in some ways. Fallow land-maintaining a single crop rotation is one of the main reasons for reduced soil fertility. At a time when soil fertility has significantly degraded, it is important to introduce perennial grass, which has an abundant high and low ground mass and is of particular importance for soil fertility, into crop rotation.

According to a study conducted by researchers at the MULS, after growing perennial grass and legumes for 5 years on moderately degraded land, soil humus content at 0-20 cm depth increased by 22 % and by 33 % for fields planted with grass and legumes, respectively, and the percentage of aggregate structures with diameters of more than 1 mm had doubled *(Odgerel B. et al. 2017, non-print)*.

It is important to include legumes and other crops which have high nutritional values and positive effects on soil fertility in crop rotation. Climate change lengthens the growing season and increases heat supply, which leads to an overall positive effect on our country. Therefore, with this effect, it is best to amplify the number of crop varieties and to acclimatize and cultivate economically beneficial crops and introduce them into crop rotation. At the same time, it is important to considerably reduce bare fallows from rotation and to introduce fallow with green manure.

Soil cultivation: The intensity of soil cultivation should be reduced and the disturbance of crop roots by soil tillage avoided. The soil should be cut, in any case, at the surface slopes in the direction of the prevalent winds in order to mitigate the main forces causing soil erosion. The introduction of zero-tillage cultivation is particularly important.

Development of soil cover crop farming: Mongolia has a dry, harsh climate and is

characterized by a sparse vegetation cover and a thin humus layer; the soil is predominantly lightweight, precipitation is low in winter and the soil is dry in spring. On the other hand, the practice of fallow and the short turnover grain rotation create a very fragile agro-ecological environment with poor rehabilitative abilities. Therefore, the development of technologies for cultivating a covered crop field, which is the method of covering the surface of the field with grain straws, will be an excellent soil protection solution. In order to develop this technology, it is first necessary to protect the land from trespassing livestock.

According to some researchers, moisture accumulation in Mongolia is higher by 8.6 mm in covered fields than in uncovered fields, the number of nitrogen-fixing bacteria is 1.3-2.2-fold, and wheat yields are 1.4 ce/ha or 9.8 % higher. Furthermore, the combined effects of mineral fertilizers on cultivation increased in covered fields *(27)*.

Fertilizers: The Law of Restoration in crop farming has rarely been enforced in our country. However, in recent years, domestic fertilizer manufacturers have emerged and a positive trend focused on fertilizing farmland has developed. Regular fertilization of soil with minerals and fertilizers continuously increases the fertility of the soil.

According to research carried out by the PSARI, systematically applying a combination of minerals (N60P40K40) and fertilizers (manure 20 t/ha) on a 3-field fallow-wheat rotation over 14 years revealed that the average level of humus increased by 13.0 % or by 5.1 t/ha at 0-20 cm soil depth, and by 6.31 % or by 7.8 t/ha at 20-40 cm soil depth *(Tuul, 2004, non-published)*.

As demonstrated by researcher Bayarsaikhan B., the humus content of brown soil cultivated by spring wheat on irrigated fields increased by 0.87 % with the assistance of basic and additional fertilizers, and nutrient supply levels elevated from low to medium [9].

Windbreaks. Protecting the cultivated land with windbreaks is especially important for mitigating the strong winds, ensuring uniform snowfall, and reducing moisture evaporation. The establishment of windbreaks depends on many factors such as technological choices, possibility of introduction into production, and its outcomes.

3. CROP ROTATION SYSTEM AND SELECTING CROPS FOR ROTATION

3.1. CROP ROTATION SYSTEM IN MONGOLIA AND ITS REQUIREMENTS

Although the PSARI had developed and implemented a 3 to 4-field rotation system for fallow-grain cultivations since the 1980s, due to privatization in 1991 and lack of state support and available markets for the produce, the crop production sector experienced a fall as a result of climate warming, drought and dryness and reduced crop rotation to 2 fields. In recent years, due to the expansion of potato cultivation, its percentage in crop rotation has grown to 33-50 %. In other words, Mongolia's non-irrigated crop farming predominantly focusses on wheat and potatoes. There is no existence of soil improving crops in the rotation. Due to the lack of a proper balance of soil nutrient elements and the loss of fertility from year to year, 0.4-0.5 t/ha humus is mineralized on average per year in the short turnover rotation including grain and fallow (Purevsuren Sh. 1990, Mijiddorj J. 2000, Tsermaa D. 2001). As a result, humus levels have sharply dropped by 37-52 % over the last 40 years.

Current commonly used rotations of non-irrigated land in Mongolia are 50 % fallow consisting of two-field rotation for seed production: bare fallow - wheat or bare fallow -

grain; and 33 % fallow consisting of three crop farming fields for commercial purposes: bare fallow - wheat or bare fallow - wheat - grain, while mainly implementing 2-3 short turnover rotations. For the rotation of grains, fallow and wide-row crops, crops other than grains and fallow such as potato, corn, sunflower, and sweet beet cover at least one turnover. 2-4 fields of rotation are cultivated in the central crop farming region where moisture supply is higher, and 2-3 rotating fields in the more arid Dornod region *(20)*.

In the case of non-irrigated farming in Mongolia's arid and drought conditions, bare fallows are required for crop rotation, because their main purpose is to accumulate moisture and eliminate weeds. Rotating wheat after fallow does not fully satisfy the requirements of the crop farming system. Therefore, there is a need to increase the selection of crops in rotation.

3.2. CROPS TESTED WITH PROMISING RESULTS IN MONGOLIAN CROP FARMING REGIONS AND THEIR VARIETIES

In the conditions of Mongolia, wheat, barley, and oat dominate the grain crops, rapeseed dominates oilseed crops, potatoes dominate tuber crops, turnips and carrots dominate root vegetables, and cabbage and onions dominate other vegetables in the crop farming fields. Conversely, for animal fodder and rehabilitation of damaged fields, alfalfa is predominantly cultivated over other legumes, and perennial grasses such as wild rye, bromegrass and wheatgrass are planted individually or in combination.

Several varieties of wheat suitable for Mongolian climate and soil conditions are being cultivated: Darkhan-165, Buryatskaya-34, Darkhan-74, Darkhan-131, Darkhan-173, Khalkh gol-1, Orkhon, Darkhan-106, Selenge, Darkhan-34, Darkhan-166, and Darkhan-144.

Concerning barley, Burkhant-1, Sutai, Alag-Erdene, and Shimt have been acclimatized along with Winer, Taplan, and Nutans-47 in the field of food and nutrition. Other varieties such as Noyot, Onohoiskaya /rye/, and Rovestnik /buckwheat/ have proven to be promising *(40)*.

With regard to potato crops, there are Gala, Solist, Kuarta, Atar-1, Vitara, Esprit, Shepoda, and Borvina varieties; and to root vegetables, there are Shweidskaya jyoltaya /turnips/, Bordo /beet/, and Shantene /carrot/.

With perennial crops, the following varieties have proven suitable for cultivation in Mongolia: Khuduu-aral of Dahurian wild rye *(Elymus dahuricus)*, Kherlen of Siberian wild rye *(Elymus sibiricus)*, Sumber-1 and Chuluut of wheatgrasses *(Agropyron pictinatum)*, Naiman of Mongolian wheatgrass *(Agropyron mongolicum)*, Nart-1 of Siberian needlegrass *(Stipa sibirica)*, Tamir of bromegrass *(Bromus inermis)*, Mandal of Russian wild rye *(Psathyrostachys juncea)*, Telmen-1 of prairie milkvetch *(Astragalus adsurgens)*, Selenge-1 of sweet clover *(Melilotus dentatus)*, Burgaltai, Tuyana and Nutag belcheer-2 (Inner Mongolian) of yellow alfalfa *(Medicago falcata)* from legumes.

Although there is a great need to introduce legumes into the crop rotation system of Mongolia, its mass cultivation and its market for sale are not clear. However, research institutes have conducted research on legume varieties, such as Bayalag and E-2964 of peas and OAC Vision, Neidou-4, SibNIIK-315 of soybeans, and have proven them to be promising for cultivation in Mongolia *(10)*.

As Mongolia has been paying close attention to the development of intensive livestock farming in recent years, the cultivation of corn as its main feed has become an important

issue. Therefore, some researchers have conducted studies on corn varieties and selected the GG-5179 and Sin Ken-9 varieties as promising for acclimatization.

Furthermore, there is a need to conduct research and acclimatize varieties with economic and health benefits, and to hybridize and breed foreign and domestic crop varieties. Such crops may include: buckwheat, millet, quinoa, oat, camelina, common flax, soybean, peas, and beans.

3.3. TYPES OF CROP ROTATION FOR IRRIGATED AND NON-IRRIGATED FARMING

Crop rotation for irrigated farming

As the agrophysical properties of soil are easy to change under irrigated conditions, legumes need to be mixed or replaced in rotation. In addition, the following must be considered for irrigated farming:

1. Soil conditions may tend towards the alkaline side under irrigated conditions, so crops which mitigate this reaction must be cultivated;
2. Clover must be cultivated in rotation in areas prone to salinity;
3. The use of fertilizer in rotation is imperative under irrigated conditions;
4. Economically beneficial crops must be cultivated under irrigated conditions;
5. It is important to select the varieties according to their suitability for irrigated conditions.

Irrigated farming requires 3-4 fields that incorporate crops for soil improvement. These include:

***A.** Crop rotation on 3 fields:*
1. Wheat **2.** Wheat **3.** Peas + Oat

***B.** Crop rotation on 4 fields:*
1. Wheat **2.** Wheat **3.** Peas + Oat **4.** Wide-row crops (potatoes, corn, soybean, Sudan grass etc.)

Potatoes should be introduced into rotation to improve soil fertility and increase yields. Irrigated fields should be cultivated with 3-4 rotations: **1.** Potato - Grain - Legumes, **2.** Potato - Grain - Oilseeds/Fodder, **3.** Potato - Grain - Legumes - Oilseeds/Fodder, **4.** Potato - Root seeds - Grain (oat, barley)

Crop rotation for non-irrigated farming

Rotation of wide-row crops: There are few types of wide-row cultivars in Mongolia and therefor rotation period is short in the crop rotation system.

Entities and farmers producing elite and certified seeds of potatoes are required to implement crop rotations to provide the basis for healthy, quality tuber harvest. Crop rotation of seed production fields shall have the following structure for non-irrigated farming: **(1)** Fallow - Potatoes - Grain **(2)** Fallow - Potatoes - Grain - Fodder.

Due to the adverse effects caused by short crop rotations, such as soil erosion and damage, and rapid decomposition of humus, it is important to reduce the amount of fallow by increasing the number of the crop types to be cultivated. In Mongolian conditions, there is a limited opportunity for independent rotations of corn and sunflower; therefore, winter crops such as rye, buckwheat, buckwheat and millet can be widely used for crop rotation. Demand for these crops has increased recently. Therefore, 3-5 rotational fields are suitable for our climatic conditions such as: ***firstly*** - **1.** Fallow **2.** Winter rye **3.** Potato **4.** Millet **5.** Grain; ***secondly*** - **1.** Fallow **2.** Wheat **3.** Potato **4.** Buckwheat **5.** Millet. Due to the arid conditions of Mongolia, it is not possible to introduce perennial legumes and grasses into crop rotation. However, it is effective to cultivate a mixture of these crops to quickly restore abandoned fields with degrading fertility *(6, 29, 42)*.

Crop rotation of fodder crops: Grains are not included or occupy a small part in the rotation of fodder crops. Instead, silage (corn, sunflower, root crops for fodder), annual fodder crop (rapeseed), fodder grains, and their mixtures are cultivated. Therefore, crop rotation fields near an animal farm have wide-row crops, annual fodder, and mixtures of grains. These include: **1.** Silage; **2.** Mixture of buckwheat and peas for fodder; **3.** Root crop; **4.** Silage crop *(6, 37)*.

Crop rotation for soil protection: Crop rotation to protect soils shall be implemented in areas with moderate to severe erosion. There is evidence to show that a predominant part of the arable soil in Mongolia is affected by erosion above the moderate level. For soil protection, the practice of bare fallows and wide-row crops for crop rotation is not suitable and should be kept to a minimum. In harsh, arid climates, clover can be cultivated as a green fertilizer to protect soil fertility. Clover is one of the most suitable crops for green fertilizer in Mongolia due to its abundant growth under natural conditions and the cultivation of some varieties in experimental research and production. Clover is a biennial legume capable of accumulating 150-500 kg/ha of biological nitrogen in the soil depending on the climatic conditions. This is equivalent to 40-60 t/ha of manure *(46, 47)*.

On fields slightly affected by erosion, the existing 2-3 rotating fields of grain and fallow can be combined with integrated soil protection measures, as follows: **(A)** For seed production **1.** Bare fallow - Wheat; **2.** Bare fallow - Grain; and **(B)** For commodity grain production: **1.** Bare fallow - Wheat - Wheat; **2.** Bare fallow - Wheat - Grain; **3.** Bare fallow - Wheat - Fodder; **4.** Bare fallow - Rapeseed - Wheat.

However, in areas moderately affected by wind erosion, it is suitable to use 2-5 rotating fields of green fertilizer fallow and cover crop fallow, as follows: **1.** Cover crop fallow (Peas + Buckwheat combination) - Wheat; **2.** Cover crop fallow (Peas + Buckwheat combination) - Wheat - Barley; **3.** Green fertilizer fallow - Wheat - Grain + Clover combination; **4.** Bare fallow - Wheat - Cover crop fallow (Peas + Buckwheat combination) - Wheat; **5.** Bare fallow - Wheat - Grain + Clover combination - Green fertilizer fallow - Wheat; **6.** Bare fallow - Peas + Buckwheat combination - Barley - Cover crop fallow (Peas + Buckwheat combination) - Wheat.

In order to prevent further erosion and support recovery of areas that are strongly affected by erosion, it is suitable to use 3-5 rotating fields incorporating green fertilizer fallow and cover crop fallow, and 8 rotating fields of perennial grasses, as follows: **1.** Green fertilizer fallow - Wheat - Grain + Buckwheat combination; **2.** Green fertilizer fallow - Wheat - Peas + Buckwheat combination; **3.** (1-5) Combination of perennial grasses - Bare fallow - Wheat - Grain. Perennial grasses, which are drought-resistant, less susceptible to herbicides, and capable of leaving 10 15 t/ha of roots after 5-7 years, are well adapted to our conditions and suitable for soil improvement and protection *(46, 47)*.

To increase the soil protection ability of crop rotation, additional measures must be implemented such as cultivating fallow crops in strips at a distance of 30-50 m and soil

tilling. It is more effective to cultivate perennials in years with adequate moisture and rain. Studies in Eastern Europe and Western Siberia have shown that it is most effective to cultivate perennials as protective strips in inclined areas where wind and water erosion are most likely. As it is not suitable to directly rotate grain crops with perennial crops, they are implemented in the form of a special-purpose field or left non-cultivated.

Perennial grasses are a good prerequisite for all regions of Mongolia under irrigated conditions; however, it is not suitable to introduce perennial grasses in the first year of crop rotation as it should gradually pass into the 2nd to 3rd year. ***For example:*** Option-1 Option-2, **1.** Perennial grasses **1.** Wheat + Alfalfa **2.** Perennial grasses **2.** Alfalfa - leave non-cultivated **3.** Spring wheat + Intermediate crop 3. Alfalfa - seed collection **4.** Spring wheat + Intermediate crop **4.** Alfalfa - seed collection 30 **5.** Corn and Sunflower for silage **5.** Alfalfa - seed collection **6.** Spring wheat + Intermediate crop **6.** Wheat **7.** Corn and Sunflower for silage **7.** Wheat **8.** Spring wheat + Perennial grasses **9.** Peas + Wheat.

Crop rotation of oil crops: Among the 15 main oil crops cultivated around the world, 12 or 86 % have been scientifically researched and proven to be suitable for the soil and climatic conditions of Mongolia *(36)*. More than 80 % of the experimental research and production activities on oil crops were conducted in the Eastern /Dornod/ region showing that the region's soil and climatic conditions are more suitable and promising than in any other region. Cultivating the major oil crops such as sunflower, spring rapeseed, soybean, and flaxseed under intensified conditions (irrigation, fertilization, toxic herbicide) in the Eastern region provided relatively high yields and proved to be an economically viable crop. When using minerals and fertilizers in combination with irrigation, the yields of sunflower increased by 9.5 ce/ha, oilseed increased by 5.43 ce/ha, spring rapeseed increased by 3.9-10.7 ce/ha, and oil crop increased by 1.9-2.9 ce/ha *(37)*. The introduction of certain types of oil crops into crop rotation of grains will not only improve soil fertility, but also free the fields from weeds, protect against ergot, and increase crop yields. The following crop rotations are recommended: Under non-irrigated conditions: **1.** Fallow - Sunflower - Wheat; **2.** Fallow - Rapeseed - Wheat; under irrigated conditions: **1.** Peas - Wheat - Rapeseed.

Combining the following two approaches to crop rotation will reduce its climate dependence and ensure the agroecological stability of the prevailing crop rotational system *(21)*:

1. Use no-till cultivation technology on the soil and establish straw covers on field surfaces;
2. Mainly introduce perennial grasses and legumes, and annual legumes into crop rotation to improve soil fertility.

4. AGROTECHNOLOGY OF CULTIVATION AND APPLICATION OF FERTILIZERS

4.1. RESULTS OF A COMPARATIVE STUDY ON FALLOWING TECHNOLOGY

The soil cultivation system, which is the basis of crop farming technology, must be adjusted to the soil and climate characteristics of each region prior to agricultural production. Failing to do so can lead to many adverse consequences, such as soil compacting, loss of structure, dust creation, soil erosion, and intense mineral degradation causing sharp reduction of soil fertility. These consequences have become increasingly noticeable in Mongolian crop farming.

Crop farming and rangeland soil degradation have intensified in recent years due to climate change and human activities. According to the results of the 2010-2012 study conducted at the Soil-Agrochemical Laboratory of the Plant Sciences and Agricultural Research Institute, 4.5 % of the arable land in Mongolia has slightly eroded, 34.9 % has moderately eroded and 60.6 % has severely eroded *(29)*.

It is possible to naturally recover dust that has blown away from the cultivation field if the annual loss is within 2.0-5.0 t/ha; however, in Mongolia, this figure is 5-10 times higher. As a result, 70-100 % of the arable land of Arkhangai, Uvurkhangai, Uvs, and Khovd provinces and 48.8-81.3 % of the arable land of the main crop farming regions in Selenge, Tuv, Khentii, and Dornod, have been severely eroded with a reduction in soil humus by 40-50 %. Thus, most of the arable land in Mongolia is starving for soil fertility *(30, 34)*.

The basic technology ensuring that the soil surface is resistant to wind and water, retains soil moisture, mitigates the growth of weed plants, regulates soil microflora activation, forms protection covers of soil, restores soil fertility, and stabilizes and increases crop yields, is the "no-till" method which has already been introduced in most parts of the world.

Type	Prior to cultivation		
	Soil compactness %	Crop residue pcs/m2	Amount of dust blown away in 5 minutes, g
2007-2010			
No-till cultivation	49.0	97.1	25.83
Mechanical cultivation	38.5	28.2	119.7
2014 он			
Ploughed cultivation	41.3	-	97.1
Reduced cultivation	45.5	48.0	61.0
No-till cultivation	51.75	111.0	29.0

Table 1. Dependence of soil wind resistance on fallow cultivation technology.

The no-till technology, developed by the Crop Technology Research Sector of the PSARI, saves energy, soil resources and time, reduces costs, mitigates the mineralization and degradation of soil organic matter, creates an ecological farm by preventing further degradation, and improves climate change adaptation abilities and increases yields.

The study to assess soil resistance to wind showed that at the beginning of the fallow, both under no-till and mechanical cultivation technologies, 126-150 pcs/m² of leftover crop residues to cover the soil surface was sufficient enough to withstand wind with a dust blowing rate of 5.46-8.55 g/5 min. However, at the end of the fallow period, in areas where no-till cultivation was practiced, 110 pcs/m² of crop residues remained with a dust blowing rate of 18.2 g/5 min and proved to be highly resistant to wind. On the other hand, in areas where mechanical cultivation was practiced, an amount of 48 pcs/m2 of crop residues remained with a dust blowing rate of 55.78 g/5 min, which is deemed as moderately resistant to wind *(32, 33, 42)*.

Assuming that the acceptable soil wind resistance is 50 g/5 min and the maximum

loss is 120 g/5 min, although soil loss due to dust for tilled fallow is 1.6 (61.0 g/5 min) times less than for ploughed fallow, it is still not considered to be wind resistant; but soil loss for no-till cultivation is 29.0 g/5 min which is considered safe from wind erosion.

After summarizing the results of recent studies conducted in the conditions of our country, it has turned out that in case of a remaining straw amount of 1.5-2.5 ce/ha or 200-250 pcs of straw per 1 m² at the end of the fallow cultivation a complete protection from erosion is possible *(17)*.

4.2. THE INFLUENCE OF FALLOW TECHNOLOGY ON THE STRUCTURE AND COMPOSITION OF MICROFLORA IN SANDY BROWN SOIL IN THE CENTRAL CROP FARMING REGION

When comparing the results of Tseveendorj S's 1979-1980 study on the types and number of soil microorganisms with Sunjidmaa O's 2014-2015 analysis on soil samples of the Khonkhor experimental field, Tseveendorj S's detailed results showed that the microorganisms present in the soil had a suitable ratio comprising 61-63% bacteria, 38-39% actinomycetes, and 0.9-0.97 % fungi. However, according to Sunjidmaa O's detailed analysis from 2014-2015, due to changes in climate and soil fertility, the total number of microorganisms increased by 31.0 times compared to 1978-1980, including a 30.7 % increase in the number of bacteria, a 1.2 % increase in the number of fungi, and a decrease in the number of actinomycetes, the main fertility index, by 31.9 % *(53)*.

The increase of the bacterial content by 30 % and the decrease of actinomycetes by 31.9 % are the main reason for the intensified decomposition of soil organic matter and humus *(53)*.

According to a 2013-2015 study by Mijiddorj J. et al, the total number of microorganisms in no-till /chemical/ cultivation is 53.2 million units or 1.8-2.1 times less than in other methods of cultivation, indicating one condition for low organic matter degradation *(33)*.

The sharp increase in the total number of microorganisms due to soil ploughing is a key precondition for the intensification of microbiological processes, which is the basis for biological processes occurring in the soil due to the increase in soil thinning and respiration.

According to the 2017-2018 study conducted by researchers from PSARI on 2-field Fallow-Wheat rotations and 3-field Green manure fallow-No till + Silage-Wheat rotations, the total number of microorganisms, including bacterial actinomycetes, had increased. This suggests that following these rotations can assist in soil recovery *(57)*.

4.3. A STUDY ON THE EFFECT OF FALLOW CULTIVATION TECHNOLOGY ON SOIL HUMUS, ORGANIC CARBON DECOMPOSITION AND BIOLOGICAL ACTIVITY INDEX

As seen in crop farming practices, improving carbon accumulation reduces soil erosion and increases crop yields. The organic carbon accumulation in the soil includes the residual biomass of the crop, the organic matter in the soil and the carbon contained in the humus; on the contrary, carbon is leached out of the soil through the flow of wind and water and during the decomposition of humus due to soil microorganisms.

Many methods are being implemented to reduce organic carbon emissions in crop farming, such as using no-till technology, applying proper crop rotations, growing crops for cover, applying local organic fertilizers such as manure, sawdust and bird droppings, and establishing windbreaks.

Nambar B. et al's study on the dependence of soil humus and organic carbon accumulation and decomposition on the soil cultivation technology (2014-2015) shows that, in Mongolian conditions, a significant part of the decomposed humus is lost in the form of organic carbon.

Results of the study showed that the amount of organic carbon decomposed and lost is 1.5 t/ha in ploughed fallow, 0.75 t/ha in tilled fallow, and 0.16 t/ha in untilled fallow. Considering that 300,000 hectares of land are cultivated per year, 390.0-600.0 thousand tons of organic carbon are released into the atmosphere per year from topsoil (0-20 cm) *(42)*.

According to research by Nambar B. et al, indicators of biological activity or soil respiration were 1.7-3 times higher in ploughed fallow than in tilled fallow and chemically cultivated fallow, and 1.8 times lower in chemically cultivated fallow than in tilled fallow *(42)*.

In conclusion, soil respiration is low in chemically cultivated fallow and relatively high in ploughed and tilled fallows. High soil respiration is an important indicator of the negative impact of improved microbiological activity and intensive decomposition of organic matter.

The need for crop rotation and cover crop and irrigated farming:

Changing the mono-crop rotation which is widely used in the crop farming sector of Mongolia, and prolonging the rotational cycles as well as amplifying the types of varieties cultivated can reduce the tillage frequency, improve soil biological activity and physical, chemical and biological properties, and promote soil nutrient circulation for soil rehabilitation.

It is necessary to introduce 3-4 CRSs (Crop Rotation Systems) by incorporating legumes and wide-row crops such as corn and sunflower, by reducing bare fallows, and by increasing fallows with green manures.

Wheat shall be cultivated in the fallow-wheat rotation for seed production.

The following 3-5 field CRS is recommended for regions predominantly growing commodity wheat:

1. Bare fallow - Wheat - Wheat
2. Bare fallow - Rapeseed - Wheat
3. Bare fallow - Wheat - Green manure fallow /Peas + Buckwheat/ - Wheat
4. Bare fallow - Rapeseed - Fodder - Green manure fallow - Wheat
5. Bare fallow - Wheat - Corn and fodder + Clover - Green manure fallow - Wheat or rapeseed - Fodder

Researchers of the PSARI have proved that in case of using the Fallow - Wheat - Green manure rotation for the protection of soils, yields can be increased by 13.7-23.0 %, humus can be reduced by 0.13 % or 0.25 tons per year; and if the Fallow - Wheat - Potato - Wheat rotation is used, yields can be increased by 15.0-19.0 %.

Considering the degree of soil erosion, the following rotational patterns have been selected for introduction into the current market conditions:

A. Bare fallow - Wheat - Peas + Buckwheat - Wheat for fields that are slightly eroded or not eroded

B. Bare fallow - Wheat - Grain + Clover - Green manure fallow - Wheat for moderately eroded fields

For severely eroded fields, the following rotations can be used to prevent further erosion and improve soil fertility:

C. Bare fallow - Wheat - Wheat + Alfalfa - Alfalfa - Alfalfa

D. Green manure fallow - Wheat - Grain, Peas + Clover

For increasing yields of irrigated grain crop fields the Peas - Wheat - Rapeseed, Potato - Wheat - Wheat rotations are recommended and for increasing yields and improving soils the Peas - Wheat - Barley - Sunflower or Corn, Potato - Wheat - Legume - Rapeseed rotations are recommended.

The need for irrigated farming:

With increasing aridness and frequency of droughts, irrigation is of utmost importance; however, it should not be forgotten that irrigation is also followed by drought. In addition to cultivating the valuable farming crops, some beneficial crops must also be cultivated to increase irrigation efficiency; these crops may include: fertility enhancing perennials and annuals such as soybeans, peas and alfalfa, and salinity and leaching reducing crops such as corn, Sudan grass, and rye, which also improve soil fertility and increase yields.

- Warming in Mongolia is 3 times higher than the global average, and the permissible maximum increase by 2.0 °C, as declared by international research organizations, is very near which means that precipitation during the growing period is expected to decrease.
- If the average air temperature increases by 1 degree, the climate zones are expected to shift by 200-300 km. Researchers predicted that by 2050 the area of high-mountainous zones of tundra and taiga will be reduced by 4-14 % and the area of forest steppe by 7 %. In addition, the steppe zone will push the forest-steppe zone in the northern direction towards the desert and the Great Lakes Depression zones, thus increasing its area by 18 %.
- As moisture depletes during the vulnerable stages of crop development, wheat and potato moisture requirements are met by underground moisture reserves within a soil depth of 0-50 cm, so that the importance of fallows is decreasing and the importance of irrigation is rising.
- There is a need for irrigated farming as the agro-climatic conditions of Mongolia, including annual precipitation level and distribution, number of frost-free days, and number of growing degree days, are 1.5-2.5 times lower than in Russia and 4-5 times lower than those of Western Europe and North America.

Cover crop farming:

Under the current conditions of drought, depleted soil fertility, and dramatic changes in the key climate indicators, there is a need to introduce cover crop farming into the cultivation technology.

The following results are obtained by cultivation with straw covers (3-7 t/ha):

1. By placing 3 tons and 5-7 tons of straw covers on the soil surface, it is possible to reduce underground soil warming by 2 and 3 times, respectively *(41, 49, 57)*.
2. By reducing soil warming, the moisture content of fallow land is 30.0 mm higher than after the fallowing period in autumn with uncovered soil up to a depth of 1 m.

The next year, prior to wheat cultivation, depending on the coverage, soil moisture content was 78.9-194.8 mm which was 7.7-24.6 mm higher than the control. This effect is observed after harvest and in the 3rd to 4th year of crop rotations *(49, 57)*.

3. The yield per hectare cultivated area of wheat on 2-rotation straw-covered fields in dependence upon the climate condition of the respective year was 0.8 ce/ha higher than the yield of uncovered cultivation, and the yield increased by 7.3-9.3 ce/ha with fertilizer supply, thus being 1.4-3.4 ce/ha higher than on the uncovered fields. Further, the yield was 0.4 ce/ha higher in the 3rd year of 3-field rotation and 1.7 ce/ha higher in the 4th year of 4-field rotation *(41, 49, 57)*.
4. By using fodder crops for rotation in covered fields, the profit per unit area depending on the yield of fodder crops is MNT 478.0-1,104.0 thousand for 3-field rotations and MNT 547.2-773.0 thousand for 4-field rotations. With 3-4 crop rotations of Fallow - Wheat - Grain/fodder and leaving 25-33 % in fallow, it is possible to increase the yield per unit area *(49, 57)*.
5. There are 26 species of weeds on fields with a straw cover of 7 t/ha, which is 1.8-2.4 times less than on fields with straw covers of 5 t/ha and 3 t/ha, which had 21 and 37 more species of weeds, respectively. When comparing the weed content of fields with a straw cover of 7 t/ha and uncovered fields, the uncovered field had 56 species of weeds or 3.1 times more than the covered field - proving that coverage reduces the amount and types of weeds grown.
6. Prior to cultivation, 2-rotation fields had weeds of 6 species belonging to 6 families, 3-rotation fields had 11 species of 9 families, and 4-rotation fields had 9 species of 8 families. This result indicates that there is tendency for the amount and types of perennial weeds to increase when rotations are lengthened *(41, 57)*.
7. Cover crop farming not only affects the amount and types of weeds grown, but also allows for the reduction of their seed stocks.

With covered cultivation it is possible to reduce bare fallows, reduce humus decomposition and protect soil fertility, change sowing norm and sowing depth, cultivate crops other than wheat, and completely stop soil erosion.

4.4. SOIL NUTRIENT BALANCE AND FERTILIZATION DOSE OF ARABLE LAND

The main purpose of fertilizer use in crop production is to increase the crop yields and to restore soil fertility.

In the context of intensive crop farming with advanced technology, there is a need to quickly determine nutrient and fertilizer requirements depending on the crop rotation system and supply levels of chemicals. In this case, the most reliable method of determining nutrient and fertilizer supply required for soil and crop is agrochemical analysis. To do this, the average dosage of fertilizer suitable for crops, determined by the research institutions of the region, will be increased or decreased based on the nutrient source available to the soil.

The soil nutrient balance of areas with spring wheat cultivation in Mongolia and the amount of fertilizer required for the expected harvest (2015-2017) were determined by analyzing 3 years of wheat cultivation. Over the period of 3 years, 1,160.5 thousand hectares were cultivated with spring wheat, 922.1 thousand tons were harvested with an average unit yield of 14.6 centners, and 21,931 tons of mineral fertilizers were supplied. Given the amount of fertilizers used, it is possible to determine the required amount of fertilizer to neutralize the soil fertility balance *(61)*.

According to the estimates of the nutrient balance of the brown soil in which wheat was cultivated for 3 years, a total of 121.9 thousand tons of nutrients consisting of 59.3 thousand tons of nitrogen, 20.3 thousand tons of phosphorus, and 42.3 thousand tons of potassium were used for 922.1 thousand tons of seed harvest, including straws. The amount of nutrients of the soil during this time was calculated by the fertilizers used and nutrient reserves of the soil. The calculation estimated that a total of 52.1 thousand tons of nutrients was supplied to the soil, which comprised 22.2 thousand tons of nitrogen, 8.4 thousand tons of phosphorus, and 21.5 thousand tons of potassium. As the input of nutrients was less than the output of nutrients, the difference must be compensated by fertilizers.

The nutrient deficiency from 3 years of cultivation is 37.1 thousand tons of nitrogen, 11.9 thousand tons of phosphorus, and 20.8 thousand tons of potassium. In order to maintain the soil nutrient balance, fertilizer $N_{64.3}P_{48.5}K_{45}$ kg/ha should be used annually for wheat cultivation *(61)*.

Recommendations for the use of fertilizers in spring wheat cultivation and production:

1. Under the conditions of advanced zero-tillage technology, mineral fertilizers should be used during dry years in low dosages consisting of phosphorus, potassium (P20K20), and nitrogen (N30-50 kg/ha). The use of low dosages can increase seed production, improve seed quality parameters, and enhance the efficiency of the fertilizer.
2. Under the conditions of advanced zero-tillage technology, mineral fertilizers should be used during humid or normal years in higher dosages of N50-80, P20-60, K20-40 kg/ha to improve soil nutrients supply and increase production yields and quality.

5. IRRIGATION METHODS, TECHNICAL OPTIONS AND SOLUTIONS

5.1. OPPORTUNITIES AND SOLUTIONS FOR IRRIGATED FARMING IN MONGOLIA

The natural resources and climatic conditions of a country determine the development of irrigation. For example, annual precipitation levels and distribution in seasons and the ambient temperature have a decisive influence on irrigation development. Researchers found that irrigated farming is required for areas that receive less than 500 mm of precipitation per year. Most parts of Mongolia receive 300-400 mm of precipitation annually, while the Gobi Desert region receives 100 mm, and only 60-70 % of the precipitation falls during the vegetation period. More precisely, annual precipitation in the central or forest-steppe region is 250-300 mm, in the steppe region 150-180 mm, in the Great Lakes Depression zone 120-140 mm, and in the Gobi Desert region 80-100 mm. In recent years, however, the precipitation levels have declined by 20-30 % due to global climate change, with some years experiencing less precipitation in spring and summer and more during the winter season, which causes a high frequency of drought and dzud. This further highlights the need for irrigation in all parts of Mongolia *(7)*.

On the other hand, the possible vegetation period in the forest-steppe region is 90-110 days, whereas it is 110-130 days in the steppe and Great Lakes Depression region, and

130-150 days in the Gobi Desert region, while the total growing degree-days range from 2,000 to 3,000 °C. This shows that, thermally, there is potential for implementing irrigated farming in any parts of the country to cultivate the main crops.

According to the soil and water research conducted for all provinces by the formerly known Water Exploration, Planning and Designing Institute the suitable area for irrigated farming is 418,255 hectares with 34,500 cubic km of available water resources. In particular, the surface water resources, which are most suitable for irrigation, are 28,527 cubic km indicating that there is a good chance of developing irrigated farming *(58)*.

In the Bulgan, Darkhan-Uul, Selenge, Tuv, Orkhon and Uvurkhangai provinces of the central farming region, 310 locations of over 166.0 thousand hectares were identified to be suitable for conducting irrigated farming. 83.0 thousand hectares are available for irrigation around the Selenge basin alone, 44.0 thousand hectares of which are already being irrigated, and thus irrigation can still be extended on areasthat can be cultivated with crops and vegetables *(58)*.

Irrigated farming can reduce the risk of agricultural production and increase the productivity of meat and dairy producing cattle, pigs and poultry by growing the required high-protein, acidic and succulent feeds such as rapeseed, peas, corn, Sudan grass, soybean and alfalfa to develop a settled and semi-settled livestock farming. In addition to growing grain crops on irrigated fields, increasing the proportion of economically viable crops by cultivating mid- and early-ripening varieties that are sensitive to water and fertilizers and are disease and pest resistant will enhance the efficiency of irrigated farming.

According to "Mongolia's Sustainable Development Vision 2030" approved by the Mongolian Parliament Resolution No. 19 in 2016, water-efficient advanced irrigation technology shall be introduced between 2016-2020, with increasing the area of irrigated land to 65.0 thousand hectares by 2020, 100.0 thousand hectares by 2025, and 120.0 thousand hectares by 2030. This indicates that the intensive development of irrigated farming in Mongolia in line with the country's soil and climate characteristics and global climate change is the basis of a sustainable development of crop production.

5.2. IRRIGATION SYSTEMS UNDER MONGOLIAN CONDITIONS, THEIR USAGE AND BENEFITS

The construction of irrigation systems began in the Gobi and western provinces of Mongolia in the 1960s with the first large-scale, fully mechanic irrigation system (2,000 ha) in the Guulin region of Gobi-Altai province. To increase fodder production in the Gobi and western provinces, many irrigation systems were constructed for the cultivation of fodder between 1965 and 1990. These include the construction and commissioning of Kharkhiraa and Torkhilog of Uvs province, Erdeneburen of Khovd province, and Shugui and Hayaa of Gobi-Altai. Since the 1960s, irrigation systems of Bornuur, Jargalant and Shariin Gol with capacities of about 0.5-1.0 thousand hectares each have been constructed and used to produce milk and vegetables for large cities and towns such as Ulaanbaatar and Darkhan. As of 1989, Mongolia operated 482 irrigation systems with a capacity to irrigate 91.6 thousand hectares. 156 engineered irrigation systems among them were established with state funding with a capacity to irrigate 49.5 thousand hectares; the rest of the fields had basic irrigation systems. However, since 1990, irrigated lands decreased

year after year, with only 5,585.5 hectares of irrigated fields remaining until 2000 for the production of potatoes, vegetables, a small amount of fruits and berries, and fodder crop *(7, 39)*.

Since 2003, financial support from foreign loans and state budgets has been granted to restore irrigation systems. As a result, by the end of 2015, out of the 54.1 thousand hectares of land available for irrigation, 40.4 thousand hectares were irrigated, spread over 3.8 thousand ha of grains, 10.2 thousand ha of potatoes, 6.8 thousand ha of vegetables, 4.9 thousand ha of fodder crop, 5.6 thousand ha of fruits and berries, 540 ha of other crops and 8.6 thousand ha of irrigated hay production.

The total irrigated lands occupy 7.2 % of the total crop farming area of Mongolia and amount to 0.9 % of the total grain cultivation, 80 % of the total potato cultivation, and 100 % of the total cultivation of fruits and berries, with a harvesting yield of 21.5, 131.9, and 124.0 centners, respectively. Despite the higher yields in comparison to the dry land farming, it is necessary to increase the yield per unit area by 2-3 times in order to reach the global average.

In 2018, the total irrigated area was 40,477.5 ha, including 3,572.0 ha of grain crops, 4,733.7 ha of potatoes, 8,045.2 ha of vegetables, 2,571.03 ha of fruits and berries, 3,553.0 ha of fodder, 17,958.25 ha of irrigated hay, and 44.65 ha of other crops. The yield per hectare from irrigated cultivations was 33.0 ce/ha of grains, 104.6 ce/ha of potatoes and 120.0 ce/ha of vegetables. Between 2015 and 2018, the total area of irrigated fields did not significantly increase. Although the yield per unit area of grain crops increased by 11.5 centners, there were no significant improvements achieved in the yields of potatoes and vegetable.

5.3. IRRIGATION METHODS, THEIR ADVANTAGES AND DISADVANTAGES, AND TECHNOLOGICAL SOLUTIONS FOR FUTURE USE

The basic irrigation methods include surface irrigation, sprinkler irrigation, fumigation, drip irrigation, and underground irrigation. Surface irrigation, sprinkler irrigation, and drip irrigation among them have been tested and proven to be the most suitable for Mongolian conditions *(7, 59)*.

Surface irrigation. This is a traditional method and has been utilized for ancient times to moisten the soil by spreading a thin layer of water over the field. Methods which are widely used to distribute surface irrigation water are: basin irrigation (boxing), furrow irrigation (earth channel), border irrigation, liman flooding, and selective basin irrigation.

Common advantages of surface irrigation methods include: simple operation; low cost; effective under any weather conditions to fully soak through the soil; washing down surface salinity on the soil, suitable for recharge irrigations in spring and autumn; less requirement on irrigation water purity; and fewer occurrences of mechanical and air resistances during irrigation.

Common disadvantages of surface irrigation methods include: heavy earthworks; low usage of the field under basin irrigation; high water consumption; common development of soil salinization and swamp; water erosion and damage to soil; high loss of water due to leakage and evaporation; compaction of soil surface; washing soil nutrients deep into the ground; rising groundwater levels; reduction of soil aeration; higher labor input for surface levelling; limiting the possibility of using less volume of water; fertilizers cannot be applied with the irrigation water; difficulty in setting irrigation norms; and labor intensity.

Sprinkler irrigation. Irrigation water is sprinkled with drops similar to natural rain with a specially designed spray nozzle that simultaneously moistens the soil and crop.

The sprinkling method is usually used to irrigate fields growing grains, annual and perennial crop plants, potatoes, vegetables, oil and technical crops, fruits and tree nursery fields. Models of the sprinkling irrigation system exist in a variety of forms depending on the type, design and capacity of the sprinkling machine.

Advantages of the sprinkling irrigation method include: low human participation as the process is fully mechanized; adjustable irrigation regimes; low requirements on the surface slope and groove of the soil; high coefficient of utilization of the field; soil structure is not damaged by irrigation; no leaching of soil fertility; fertilizers and plant protection agents may be applied with irrigation; creating favorable conditions for plant growth and development by simultaneously moisturizing soil, crop and air; possibility of irrigation with lower norms; moisturizing the stems and leaves of the crops promotes respiration and sunlight absorption; no development of swamp, salinization and compaction of soils; and no affect on groundwater levels.

Disadvantages of the sprinkling irrigation method include: energy consuming; an engineered irrigation system is required; irrigation is not possible with strong winds and unsuitable wind directions; irrigation is only conducted within the radius of the spray nozzle; high requirements on water purity and transparency; high loss of irrigation water by evaporation; limiting the possibility of irrigating in higher volumes; and unsuitable for recharge irrigation.

Drip irrigation method. This method involves irrigating the area around the root of the crops through drips production equipment to moisten the soil.

The advantage of this method is that a continuous water supply is provided to each crop with the assistance of droppers. Drip irrigation will provide favorable outcomes for regions with arid, hot climates and low water supply as water is only distributed at the roots of the crops and not across the whole field.

Other advantages of drip irrigation include: very low labor costs; no damage of the soil structure; no development of air resistance during irrigation; irrigation can be conducted late in the night; reduction of irrigation water volume by 30-60 %; water is evenly distributed on uneven, rough surfaces; low evaporation from the soil surface; no leaching of soil nutrients; low growth of weed plants as the water is only supplied to the roots of the main crop; reduced occurrences of some pests and diseases as the water is not applied to the stems and leaves; fertilizer may be applied with the irrigation water; easy to assemble, carry and transport the irrigation system; and drip irrigation pipes can be covered in order to increase soil heat supply and reduce moisture evaporation.

Disadvantages of drip irrigation include: clogging of droppers due to improper water filtration; requiring regular cleaning of water filters; water leakage can occur if the filter and fertilizer tanks are not properly closed; drip pipes are prone to damage during assembly and disassembly; salt marshes grow on the topsoil if fertilizers are applied in high dosages; irrigation and drip pipes must be kept in a warm storage during the winter; the stems and leaves are prone to damage by drought during hot and sunny days;

difficult to conduct cultivation between rows; drip pipelines may be damaged during weed removal and covering and mulching the soil; and unsuitable for recharge irrigation.

Among the three methods mentioned above, the sprinkler irrigation method is suitable for grain, potato, fodder, oil and technical crop cultivations, while the drip irrigation method is suitable for the cultivations of vegetables, fruits and berries in Mongolian conditions.

6. CROP FARMING MACHINES, TECHNIQUES AND TECHNOLOGIES ADAPTED TO CLIMATE CHANGE

6.1. ACCLIMATIZATION AND DEVELOPMENT OF SMART TECHNIQUES AND TECHNOLOGIES IN THE CROP FARMING SECTOR IN MONGOLIA

It is necessary to implement the "Smart crop farming" policy directed at fully utilizing the available resources and promoting an environment-friendly production of healthy, diverse, quality, and organic products. In other words, it is possible to conduct a sustainable, knowledge-based, risk-free, wide-scale production based on mechanization, automation, electronization and information technology. Based on the needs and demands of adaptation to climate change in the Mongolian crop farming sector, it is of foremost importance to address the following fundamental issues through comprehensive step-by-step approaches *(19)*:

- **Soil protection agrotechnology;** (fertilization technology of crop plants; production and use of biological fertilizers; integrated soil cultivation technology; no mechanical tilling technology; covered cultivation)
- **Irrigated crop farming;** (selection of irrigated crops and varieties, cultivation of valuable crops in irrigated farming, protect and improve soil fertility, increase investment, improve soil fertility by cultivating annual and perennial crops such as soybeans, peas, and alfalfa along with other valuable commercial crops, plant high production capacity crops such as corn, Sudan grass, rye in order to decrease adverse impacts of irrigation on soil salinity and leaching, and increase soil fertility and yields)
- **Protected soil cultivation technology;** (in order to develop and introduce new varieties and hybrids of early-, mid-, and late-ripening, high-yielding, disease and pest resistant greenhouse crops)

As mentioned above, it is time to take a serious step of acclimatizing the following smart crop farming technologies in Mongolia that are already in use in the developed countries of the world *(19)*:

1. Develop a plant factory: automatically adjust fertility, air exchange, moisture, water and heat required for crop growth in specially equipped facilities to protect crops from risks; ensure stable, year-round harvest and use the opportunity to provide consumers with fresh vegetables throughout the year;
2. Develop automatic sensors to monitor and control the environment required for crop growth based on the achievements of information technology and electronics;
3. Develop vertical farming: install vertical shelves on the roofs of large food markets of major urban centers to conduct hydroponic and aeroponic soil-less cultivations of leafy vegetables throughout the year and increase the food supply to the population;

4. Establish remote monitoring of soil fertility, nutrient deficiencies, and spread of pests and diseases, introduce technologies for accurate application of nutrients and crop protection substances in the right place, establish, promote, and gradually expand the use of smart farming models;
5. Develop information systems for transmitting an information database that is regularly updated and released for the monitoring of changes in natural resources from the hydrometeorological and environmental research institute to assist herders and farmers in a timely manner with contents like heavy snow fall, summer weather condition, drought, biomass of pasture plants, soil surface temperature, and forest fires.

6.2. SOIL CULTIVATION AND MAINTENANCE TECHNIQUES AND TECHNOLOGICAL INNOVATIONS

In order to adapt crop production to the changing climate, countries around the world are testing and implementing farming technologies that are eco-friendly and rationally use biological resources. For example, the following advanced farming technologies have been intensively used in Russia, Canada, Japan, Germany and France in recent years: cultivation system that is adapted to the characteristics and climate conditions of the region; direct cultivation for soil protection or zero-tillage cultivation system; crop farming involving the efficient use of energy, water, soil and other resources; and programmable crop farming based on accurate calculations.

The successful implementation of the "Virgin land 3" campaign by the Government of Mongolia, which increased production to fully cover the domestic demand for grains and potatoes, not only strengthens food safety and economic independence, but also creates the opportunity for exporting food to other countries suffering from food shortage.

Today, machinery and equipment in the crop farming sector of Mongolia have improved so that about 1,800 high- and mid-powered tractors and over 1,200 combines implement a mechanization of 100 % in grain production, 60 % in potato production and more than 30 % in vegetable production *(11, 12)*.

Innovations in crop farming techniques and technologies are specifically important for reducing the risk of crop loss, increasing productivity, producing sustainable crops, and developing an export-oriented production.

According to a 2014 study by the MoFALI, the number of entities cultivating grain crops on fewer than 800 hectares accounted for 78 % of the total entities, but the volume of their harvested crop was just over 30 % of the total yield. On the other hand, the number of entities cultivating an area of more than 1,500 hectares accounted for 12 % of the total entities and almost 50 % of the total yield. This is partly due to the fact that small farming entities do not implement production technologies sufficiently well and are not able to update their technologies and equipment that are out of date *(11, 12)*.

6.3. INTRODUCTION OF INTEGRATED AND ZERO-TECHNOLOGY MACHINES AND EQUIPMENT FOR SOIL PROTECTION

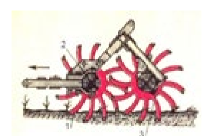
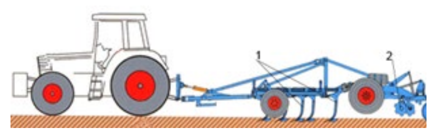
With the development of machines and techniques that allow crop production to integrate technological processes such as tillage, cultivation, sowing, fertilizer application and preservation of soil moisture, a reduced technology is widely used as a resource saving solution. Thus, the shift to direct cultivation or zero-tillage cultivation to meet the

requirements of soil protection and adaptation to climate change has become a widely-used method around the world for reducing the effects of climate change. Article 18.3 of the "Law on Crop Farming" approved by the State Parliament in 2015 states that "Crop production technologies must protect the soil from erosion and damage, preserve soil fertility, reduce evaporation of moisture, save resources, create a convenient working environment, and maintain ecological balance," which is an expression of the policy on crop farming adaptation to climate change.

Therefore, the main condition to reduce the risk, increase productivity, and improve efficiency of crop production in Mongolia is the implementation of technologies and activities that are adapted to climate change by a comprehensive consideration of agroecological, agro-landscape, and production (economic) issues. The following issues must be comprehensively implemented while criteria such as eco-friendly, intensive, ecological, environment-friendly and resource-saving have to be satisfied *(58)*:

- Widely use tractors, tilling and sowing machines, and combine harvesters that are eco-friendly, resource-saving, economical, and meet the requirements on mechanized technology;
- Introduce crop farming systems suitable for the characteristics of each region using reduced technologies to mitigate the effects of wind, drought, and dryness;
- Implement a comprehensive resolution of arable land management that meets requirements of the agro-ecological balance with the proper combination and localization of crop and livestock farming activities.

According to Professor Byambadorj Ch. et al, an ecological, resource-saving, and environmentally friendly development of tilling technology in Mongolia can be viewed in the following stages *(12)*.

Type of soil cultivating equipment	Soil tilling technology	Implementation period
 Moldboard plough	Technology of soil ploughing and overturning by tilling	1959-1976 As a result of the "Virgin land 1" campaign, cultivated lands reached 437.1 thousand hectares *(16, 53)*.
 Arrowhead blade tiller  Teeth harrow	Technology to protect soil from wind erosion	1976-1990 Soil protection technology was implemented on 80% of crop farming land *(16)*.
 1-Tiller, 2-double disk, 3- double roller	Reduced technology	First tested in 1980; widely used today, since 2000 *(12, 45)*.

 Sprayer  Straw cutting and spreading combine harvester	Zero-tillage technology	First tested in 1998 for fallow cultivation within the TACIS program; and widely used in production today, since 2013. According to the MoFALI, fields using chemical cultivation of fallow had reached 108 thousand hectares in 2016 *(45)*.

Table 2: The stages of development of soil cultivation techniques and technologies used in Mongolia.

Although crop farming in Mongolia has been developed using the basic tilling technologies mentioned above, there is a need today to acclimatize reduced, zero-tillage technologies.

Since the introduction of reduced technologies in grain production, the yearly crop yields under regular weather and rainfall conditions have increased compared to the yield harvested before 1990. According to Byambadorj Ch. et al's research, the average yield of wheat from 1970 to 1989 was 9.7 ce/ha, while the average yield from 2010-2016 was 13.2 ce/ha, which is 3.4 ce/ha more than before due to technological innovations *(12)*.

Technological innovations with parameters and structures suitable for the ecological and production conditions of crop farming in Mongolia aim to solve the following tasks:

1. Reduce the frequency of soil tilling and cover the fields to protect the soil from erosion, reduce soil moisture loss, and improve soil fertility and, thus, provide a basis for shifting to zero-tillage cultivation technologies. For example: For grain production, in any case, direct sowing should be conducted; while for potatoes and vegetables, it is nessecary to widely use machinery equipped with a combination of various tools with rotors carrying out multiple field activities in one procedure such as sowing potato seeds in a wide row while cultivating the soil in the wide row.
2. Leave as much grain straws as possible on the surface of the field and spread straws back over the field to create a mulch cover.
3. Till grain fields with combined chemical and mechanical methods and gradually shift towards chemical and biological tilling.

A policy on the differentiated use of techniques with optimum parameters and operating modes, specifically during soil cultivation, sowing and harvesting activities, in the small, medium and large crop farming entities has been pursued with irrigated and

non-irrigated grain production practices.

According to the information provided by the MoFALI, the composition of crop farming machinery was comprised of 55 % for reduced technologies and 25 % for zero-tillage technologies in 2016. Zero-tillage technology is only being used for the cultivation of fallow and implemented on 100,000 hectares per year.

Non-irrigated farming techniques using reduced technology. Most of the soil cultivation machinery currently used in Mongolian crop production meets the requirements of efficiently performing multiple tasks in one procedure; in other words, machinery which is designed to disturb the soil as few times as possible. It includes the Russian-made Leader-4 (6) and Stepnyak cultivators as well as equipment by Canadian brands like Flexi-Coil, Morris, and Bourgault.

Figure 1: Tiller with arrowhead blade, the most widely used crop farming equipment in Mongolia in recent years.

The sowing machinery currently used in the crop farming industry is designed with arrowhead blade tiller or seed drill to sow seeds in strips and mechanical or pneumatically powered seed dispensers. In addition, if the bunker is placed intact on top of the carriage, it is at least 2 meters wide, and if positioned separately from the carriage, it is at least 10 meters wide allowing for a direct embedding of the seeds into the soil. This provides opportunities for soil protection and development of eco-friendly crop production. The need for further expansion is of foremost importance.

As a result of intense technical innovations in the crop farming sector of Mongolia in recent years, the usage of machinery that is suitable for adaptation to climate change,

K-700 A tractor+SKP-2.1 "Omichka"

JD 9430 tractor+MAXIM II sowing machine+7240 bunker

Figure 2: Mechanical and pneumatic cultivation in crop farming in Mongolia.

reduced technology, resource-saving and zero-tillage technology is increasing year by year. Consequently, production costs are decreasing, and productivity and efficiency are increasing.

According to the research of Byambadorj Ch. et al on the use of high-power tractors in two shifts for cultivating and sowing seeds, their performances are 3.0-4.5 times better at soil cultivating, 3.5 times better at seed sowing, and 1.5-2.0 times better at direct harvesting with superior technological quality indicators when compared with performances of the widely-used Belarus 1221 tractor with required assemblies of soil cultivator Leader-4 and seed sowing machine SKP-2.1 "Omichka" and the combine harvester SK-5 "Niva-Effect" *(11)*.

Due to the requirements of harvesting more yields, use of fewer machinery and low processing costs after seed harvest, the sorting method for grain harvest accounts for a high percentage in crop harvesting technology. This method requires a 6-10 m-wide row trailer and self-propelled swather, a bunker with a capacity of 4-6 m³ or 5-6 kg/sec (150-160 hp), and a mid-sized combine harvester with tools to shred and spread straws.

Trailer JVP-6.4 swather

Self-propelled Macdon swather
100 hp wide row

Figure 3. Trailer and self-propelled swathers are commonly used for sorted harvesting.

According to the results of researches and studies, the prevailing tractor for the upcoming years in crop farming should have a power of 90-125 kW (120-170 hp) with a traction power of 30-40 kN, or a power of 60-70 kW (80-100 hp) with a traction power of 14-20 kN and 4WD tires that could be double mounted, when necessary. In addition, the use of tractors with a power of 180-260 kW (250-350 hp) is recommended for highly intensive farming with an area of more than 3,000 hectares. However, their impact on soil and economic benefits need to be further studied *(11, 53)*.

6.4. THE NEED TO ENSURE THE AVAILABILITY OF MACHINES AND MACHINERY SUPPLIES AND TO BRING REPAIR AND MAINTENANCE TO A NEW LEVEL

The first objective of the National Crop Farming Recovery Program of the "Virgin land 3" campaign was to equip entities with commonly used machinery that had been updated with modern technology. This has already been implemented in over 50% of grain production entities along with the introduction of new techniques according to the reduced cultivation technology.

In addition to consulting research institutions and scientists on selecting reduced cultivation techniques that are suitable for the soil, climate and production conditions of

Mongolia, farmers also consider recommendations published by research institutions.

Powerful machinery and equipment produced by Canadian technology are destined for being introduced in larger entities. The MoFALI has informed that more than 60% of power generating techniques in the crop farming sector has been updated as a result of measures taken to improve machinery and technologies.

The manufacturers implement their agricultural machinery services through the respective distributor or sales company to provide their customers with competitive technical services to maintain a market presence, to improve the quality of their technical production and to ensure the normal operation of the machinery and equipment supplied.

One of the main issues in implementing machinery supply in recent years has been the import tender process in which the lowest bidders as well as non-professional organizations are selected. Based on this procedure, during the past 15 years, over 30 types of tractors from more than 10 countries around the world and about 10 types of combine harvesters from 6-7 different manufacturers were imported. As a result, one farming entity today has 3-4 types of tractors and 2-3 types of combine harvesters, which in some cases has led to dead-end situations in which organizations responsible for maintenance and repair cannot be found. In the future, there is a need to strictly adhere to the requirement that organizations importing agricultural machinery and equipment must have a service center which is responsible for the repair and maintenance of their supplies *(28)*.

As of 2017, there were about 1,400 entities engaged in agricultural production throughout Mongolia. Without improving the maintenance and storage services, a sustainable development of crop production is not possible. Since 100 % of the agricultural machinery and equipment are imported, there are more than 20 import companies with service centers such as Gatsuurt, Wagner Asia, Insada Tractron, MSM, and Agromachtech, etc.

Agricultural machinery services include a complete set of services such as supplying machines, tools, spare parts and materials used during operation, training operators, promoting new products, providing preventive maintenance services, restoring the functionality of main parts and replacing damaged parts. Large dealer companies have started setting up agricultural machinery service centers to sell spare parts straight from the warehouses as well as conducting maintenance in specially equipped shops. Most companies use the form of mobile laboratories to conduct on-site services for their supplied equipment such as carrying out maintenance work during the warranty service period, conducting on-site diagnostics of defective machinery, and replacing broken parts and joints. However, there are many dealer companies that are still operating without agricultural machinery service centers or even without qualified equipment storage areas prior to sale.

Therefore, it is important to establish a repair and maintenance center after technical equipment supply for example by:

- Supporting dealer companies aiming at developing and implementing projects with the setup of agricultural maintenance services and spare parts supply centers in remote locations such as Erdenet and Darkhan;
- Supporting and assisting foreign agricultural machinery manufacturers and

suppliers interested in supplying agricultural machinery and establishing service centers for their maintenance work;
- Ensuring that entities supplying the machinery are solely or jointly responsible, in cooperation with the manufacturer, for the warranty services required, and expanding dealer companies to provide mobile on-site services *(28)*;
- Organizing trainings and seminars on machinery repair and maintenance, adjustments, storage and safety;
- Supporting entities to establish their own small workshops equipped with lathes, stationary drilling machines, and stationary and mobile welding equipment used for tractor and combine harvester maintenance, and small repairs on trailers and hitch coupling machinery.

6.5. TENDENCY OF THE POLICY REFORM ON AGRICULTURAL MACHINERY AND PROBLEM-SOLVING SOLUTIONS AND OPPORTUNITIES

It is necessary to make customers acquainted with resource-saving techniques that are suitable for Mongolian soil and climatic features and production technologies, to establish operating systems, and to expand the production and assembly process of some machines and tools.

An important issue facing the development of the crop farming sector is to change over large-scale potato and vegetable productions to fully mechanized processes by providing farmers with reduced and zero-tillage technologies equipped with resource-saving, modern operation and control devices.

Therefore, it is recommended to focus on implementing the following solutions and opportunities to solve this issue:

1. Intensify the production of small crop production entities by uniting their labor and assets;
2. Increase the operating load of agricultural machinery and reduce production costs by increasing crop rotation through irrigated technology, acclimatization of new crops and development of agro-techniques;
3. Revise the requirements for machinery and equipment used in crop production and submit them for state approval to provide companies and banks which offer leasing services with guidelines;
4. Establish a network and database to provide consumers with information such as price, design, and operational features of agricultural equipment on the Mongolian market;
5. Provide state support to entities and farmers in terms of technological updates on agricultural machinery and equipment;
6. Support agricultural machinery suppliers in the establishment of their own service centers.

SUMMARY

Mongolia, as a country that is physically experiencing the impacts of global warming and climate change, urgently needs to develop and implement a technology to adapt the crop farming sector to climate change.

The main focus of climate-adapted crop farming technology for the sustainable production of healthy and safe foods is on the development of crop varieties through: (i) creation of drought tolerant, disease and pest resistant and early ripening crop varieties; (ii) development of high quality seed production systems for acclimatized varieties; (iii) introduction of reduced or zero tillage, resource-saving technologies; (iv) systematic usage of mineral and organic fertilizers; (v) application of proper crop rotation systems to improve soil fertility and crop yield; and (vi) development and implementation of crop irrigation technologies.

In oder to be able to carry out this requiredresearch, we used the results and reports of previously conducted experiments and research to compile the following analysis and conclusions:

1. In order to closely integrate plant breeding research with the sciences, such as physiology, genetics, biotechnology, chemistry, plant disease research, molecular biology and soil science, the consideration of increasing crop yields, improving quality, increasing resistance to the external environment, and fully utilizing the genetic potential of crops should be integrated into research and development (R&D) works. In addition, there is a need to reach global levels in the fields of (i) using modern biotechnological techniques for crop selection, (ii) enhancing selection efficiency by diagnosing with molecular marker techniques, (iii) transferring beneficial genes through genetic engineering, (iv) producing donor plants with disease, pest, drought and frost resistant genes through remote hybridization for being used as genetic resource material, and (v) improving crops using nuclear technology.
2. Researchers have found that crop yields of varieties that are adapted to the region may be increased by up to 25-30 % and then up to 50% by using the soil climate capacities without any additional costs. When selecting varieties for cultivation, it is important to cultivate early, mid, and mid-late ripening varieties in a specific ratio and to correctly determine the composition while considering the environmental and climatic impacts in order to reduce the risk of drought and increase the likelihood of harvesting a constant yield.
3. Accelerating the production of new elite seeds that are drought resistant, adaptive and proven to be acclimatized allows for the replacement of varieties and seed renewals within a short period, which is a key condition for the restoration and sustainable operation of crop production.
4. The soil cultivation system, which is the basis of crop farming technology, must be adjusted to the soil and climate characteristics of each region prior to agricultural production. Failure to do so can lead to many adverse consequences, such as soil compacting, loss of structure, dust creation, soil erosion, and intense mineral degradation, causing a sharp reduction of soil fertility which has been increasingly noticeable in Mongolian crop farming. Furthermore, many years of research show that the fertility of soil used for crop farming has significantly degraded.

5. The introduction of advanced soil protection technologies not only increases the ability of crop production to adapt to climate change by conserving soil fertility and reducing erosion, but also mitigates climate change by reducing the amount of greenhouse gas emissions from the soil. If the appropriate technical solutions are implemented, this will also reduce fuel and labor costs as well as crop production costs.
6. In order to reduce organic carbon emissions in response to changing climate factors, it is necessary to introduce soil protection techniques and technologies, such as strip farming, crop rotation, cover crop cultivation, establishment of windbreaks, and soil fertilization. With cover crop cultivation it is possible to reduce bare fallows, reduce humus decomposition and protect soil fertility, change sowing norm and sowing depth, cultivate crops other than wheat, and completely stop soil erosion.
7. In the future, there is a need to expand research on varieties with economical and health benefits and to hybridize and breed foreign and domestic crop varieties. Such crops may include: buckwheat, millet, quinoa, oat, camelina, common flax, soybean, peas, and beans. There is a need to increase the types of varieties in crop rotation.
8. For crop rotation, the combination of using (i) no-till cultivation technology on soil and establishing straw covers on field surfaces, and (ii) introducing perennial grasses and legumes, and annual legumes into crop rotation to improve soil fertility will reduce the climate dependence and ensure the agro-ecological stability of the prevailing crop rotational system.
9. The basic technology for ensuring that the soil surface is resistant to wind and water, retains soil moisture, mitigates the growth of weed species, regulates soil microflora activation, restores soil fertility, and stabilizes and increases crop yields, which is reached partly by soil coverage, is the “no-till” method which has already been introduced in most parts of the world. This technology saves energy, soil resources and time, reduces costs, mitigates the mineralization and degradation of soil organic matter, creates an ecological farm by preventing further degradation, and improves climate change adaptation abilities and increases yields.
10. Changing the currently used mono-crop rotation and prolonging the rotational cycles as well as amplifying the types of varieties cultivated can reduce the tillage frequency, improve biological activity and physical, chemical and biological properties of the soil, and promote soil nutrient circulation for soil rehabilitation.
11. Soil respiration is low in chemically cultivated fallow and relatively high in ploughed and tilled fallow. High soil respiration is an important indicator of the negative impact of improved microbiological activity and intensive decomposition of organic matter.
12. With increasing aridness and frequency of droughts, irrigation is of utmost importance; however, it should not be forgotten that irrigation is also followed by drought. In addition to cultivating the valuable farming crops, some beneficial crops must also be cultivated to increase irrigation efficiency; these crops may include: fertility enhancing perennials and annuals such as soybeans, peas and alfalfa, and salinity and leaching reducing crops such as corn, Sudan grass, and rye, which also improve soil fertility and increase yields.
13. Irrigated farming can reduce the risk of agricultural production and increase the productivity of meat and dairy producing cattle, pigs and poultry by growing the required high-protein, acidic and succulent feeds such as rapeseed, peas, corn, Sudan grass, soybean and alfalfa to develop a settled and semi-settled livestock farming. In addition to growing grain crops on irrigated fields, increasing the proportion of economically viable crops by cultivating mid- and early-ripening varieties that are hyper-sensitive to water and fertilizers and are disease and pest resistant is one of the key factors in improving irrigation efficiency.
14. It is time to take a serious step towards acclimatizing smart crop farming technologies in Mongolia that are already being used in the developed countries of the world, such as plant factory and vertical farming. In other words, it is possible to conduct a sustainable, knowledge-based, risk-free, wide-scale production based on mechanized, automated, and electronic information technology. It is of foremost importance to implement smart technologies in crop production that meet the demands of adaptation to climate change.
15. With the development of machines and techniques that allow crop production to integrate technological processes such as tillage, cultivation, sowing, fertilizer application and prevention of soil moisture, reduced technology is widely used as a resource saving solution. Thus, the shift to direct cultivation or zero-tillage cultivation to meet the requirements of soil protection and adaptation to climate change has become a widely-used method around the world for reducing the effects of climate change. Although this shift has been made to a certain extent in Mongolia, there is a need to increase and expand its effect.
16. For grain production, direct sowing machinery should be used, while for potatoes and vegetables, it is nessecary to widely use machinery equipped with a combination of various tools with rotors that provide multiple field activities in one operation, such as sowing potato seeds in a wide row while cultivating the soil in the wide row. Grain straws should be left as much as possible on the surface of the field, as straws are re-spread into the field to create a mulch cover. In addition, it has been found appropriate to till grain fields with combined chemical and mechanical methods and then gradually change over to chemical and biological tilling.
17. An important issue facing the development of the crop farming sector is providing farmers with reduced and zero-tillage technologies equipped with resource-saving, modern operation and control devices, which is also the direction for the policies and activities of technical innovation.

REFERENCES

1. Avaandorj D. 2014. Soil Science. Ulaanbaatar, Admon publishing.
2. Altansukh N. Use of Genetic Resources in Mongolian Spring Wheat Selection. Doctoral Thesis. 2000.
3. Ariungerel M. et al. Results of studies on some local wheat varieties using ISBP, ISSR, RAPD. School of Agro-ecology, Crop Farming magazine 2017.
4. Baasandorj Ya., Munkhzul M. Mongolian arable land soil erosion, damage and changes. UB. 2006.
5. Baast B., Effect of test mutagenesis on spring wheat heredity. Work 5 of the PSARI, 1980.
6. Baljinnyam G., Nambar J., 2012. Climate change – Cover crop cultivation. The work of PSARI.
7. Baranchuluun Sh., Choijamts A., Davaajamts Sh., Dugarmaa M. et al, 2011. Irrigated cultivation management. Ulaanbaatar, Munkhiin useg.
8. Bayarsaikhan B. 2019. Impact of fertilizer on soil fertility, spring wheat yield, and seed quality. Dissertation, 128 p.
9. Bayarsukh N., Dolgor Ts. Final report on the improvement of wheat productivity through mutation breeding

in Mongolia for 2012-2015, IAEA/RCA Final Project Review Meeting on RAS/5/056, Nay Pyi Taw, Myanmar.
10. Bayarsukh N., Byambasuren M., Nyamsuren O., 2017. Sustainable development of the crop farming sector and results of science, technology and innovation. Agricultural Sciences and Technology Innovation Conference 2017.
11. Byambadorj Ch., Mungun J., Gankhulug B. The results of new technical operation indicators in the crop farming sector. Agricultural Sciences. 2015. No. 1, p. 177-182.
12. Byambadorj Ch., Yesunerdene D. The immense step from 50 horsepowers to 500 horsepowers. The current situation and the future goals of grain production. New Farmer. 2014. No. 5, p. 57-59.
13. Galt L., Davaa L., Solongo G., Grain cultivation technology, and its current level and future trends, p. 80-87, 2012.
14. Ganbaatar B., Study on the parameters of new varieties of spring wheat. // Doctoral thesis in Agriculture. UB. 2009.
15. Ganbaatar B., Myagmarsuren Ya., //Seed cultivation technology and acclimatized varieties// book. Darkhan-Uul 2015, p. 61-67.
16. Gungaadorj Sh., 90 years of the Ministry of Agriculture of Mongolia – Crop development. // New Farmer. No. 5, 2014, p. 11-16.
17. Gunaanyam G., Impact of straw covers on the moisture supply and abrasion resistance of tilled fallow in the central region, Doctoral thesis in Agriculture, Darkhan-Uul, 1998.
18. Gantulga G., Otgonbaatar I., 2018. "Traditional and Improved crop rotation technology of grain cultivation in Mongolia" /comparison, analysis, conclusions and recommendations/.
19. Gantulga G., Kheruuga T., Bayarsukh N. et al. Problems in agricultural development and the impact of the 4th Industrial Revolution. "Development level and further goals of agricultural sciences", booklet. Ulaanbaatar. 2019. p. 146-155.
20. Davaa L. Impact of soil cultivation and rotation on biological activity, Doctoral thesis in Agriculture. UB. 2005.
21. Davaa L. Baatartsol B., Munkhjargal O., and Nambar J., 2015. Features of cultivation technology in Mongolia and their impact on soil structure and fertility.
22. Dolgor Ts., Results of mutation selection research and future goals, Work of PSARI 27, p. 73-81, 2009.
23. Dolgor Ts., Results of the use of chemical mutagens in mutational selection, Agricultural Sciences magazine, p. 51-53. 2012.
24. Dolgor Ts., Myagmarsuren Ya., Current status and future goals of grain selection in Mongolia. "Current status and future goals of Mongolian crop cultivation technology, crop farming, plant protection". Proceedings from the International Conference. 2010.
25. Dorj B. 2018. Adaptation technology of wheat farming. Ulaanbaatar, Soyombo printing, p. 8-9.
26. Dorj B., Davaadorj G., Gungaadorj Sh. et al, 2018. Soyobo encyclopedia on Mongolian Crop Farming. Ulaanbaatar, Soyombo printing, p. 25-27, 65.
27. Zandraagombo D., Baljinnyam G., Sunjidmaa O., Otgon J., 2015. Trial results of cover crop cultivation technology. Agricultural Sciences magazine No. 14 (01), p. 119-124.
28. Lkhagvasuren L., Justification for building an optimum system for maintenance and repair of agricultural machinery, Technical Intelligence Doctoral (PhD) thesis, Ulaanbaatar. 2019.
29. Mijiddorj J., 2012. Soil protecting crop farming. Darkhan.
30. Mijiddorj R. "Global warming desert call" UB. 2008.
31. Mijiddorj J. Soil protecting zero-tillage technology. Darkhan. 2012.
32. Mijiddorj J., Baatartsol B., Nambar J. et al, "The proper technology to prevent erosion and degradation of crop farming soils" Science and Technology project report 2007-2009.
33. Mijiddorj J., Baljinnyam G., Adilbish G., Sunjidmaa O., Khishigsuren D., Report on the "Comparative study of changes in the basic physical, chemical, and biological properties of soils under traditional and zero-tillage technologies". 2013-2015.
34. Mijiddorj J., Basis for crop ecology and adaptability improving technology. Book. Darkhan 2010, p. 101-117.
35. Mongolian farmer's scripture. Collaboration, Ulaanbaatar 2009. Munkhiin Useg Group, p. 20.
36. Mongolian Agricultural sector: Developmental properties, MULS, Agricultural Economy and Development Research Center, 2018, p. 22.
37. Munkhjargal O., 2013. Scientific basis for oil crop cultivation in Mongolia. Ulaanbaatar.
38. Munkhjargal O., 2013. Spring rapeseed cultivation technology. Ulaanbaatar
39. Munkhjargal O., 2014. Irrigation cultivation. UB. Soyombo Printing.
40. Myagmarsuren Ya., Ganbaatar B. et al, 2015. Seed cultivation technology and acclimatized varieties. Darkhan-Uul.
41. Myagmarbayar D., Use straw covers to protect soil from wind erosion in the Eastern crop farming region of Mongolia. Doctoral thesis in Agricultural Education, Choibalsan-UB. 1996.
42. Nambar J., Baljinnyam G., 2016. Current state and prospects of crop rotation in Mongolia. Plant Sciences and Agricultural Research Institute work.
43. Natsagdorj L., Dagvadorj D., "Adaptation to climate change" UB. 2010.
44. Odgerel B. et al, Genetic research on salinity resistance of wheat /triticum aestivum L./ varieties and its opportunity for selection. Agricultural Sciences magazine, No. 18/02, p. 101-103. 2016.
45. Odonkhuu B., The current status and further goals of grain production. New Farmer magazine. 2014. No. 5, p. 51-53.
46. Otgonbaatar I., 1997. Impact on soil fertility and spring wheat yield in the central crop farming region. Doctoral thesis in Agriculture. Ulaanbaatar.
47. Otgonbaatar I., Batmunkh B., Reports on crop rotation system and structure improvements in the central crop farming region.
48. Sarantsetseg M., Reports on mutational selection. 1987-1988.
49. Saikhantsetseg C., Possibility of using cover crop cultivation and zero-tillage technology in fallow and grain crop rotation /Central crop farming region/ Doctoral thesis in Agriculture. UB. 2014.
50. Sunjidmaa O., Study of changes in soil microorganisms during climate warming// Masters degree thesis work. Darkhan-Uul. 2013.
51. Tovuu L. 2004. Crop farming. Ulaanbaatar. p. 7.
52. Tungulag M. et al. Varietal identification study of six wheat varieties using ISSR markers. Mongolian Journal of Agricultural Sciences, 23(01), p. 14-17, 2018.
53. Tumen J. Technification of Mongolian agriculture. New Farmer magazine. 2014. No. 5. p. 30-36.
54. Umberto Blanco Rattan Lal. "Soil protection management principles" UB. 2011.
55. Uugantsetseg B. Results of the study on the dose of chemical and physical mutagens on rapeseed. Masters degree thesis in Agricultural sciences. 2016.
56. Khishigsuren Kh. et al. Results of selected spring wheat mutant varieties for fodder and food purposes. Proceedings of the Scientific Conference in honor of Ulzii M. and Zunduijantsan Kh., p. 53-57.
57. "Cover crop cultivation rotation" Science and Technology project report, 2016-2018.
58. Chandmani D., Adiyabazar D. 2005. Irrigation amelioration. Ulaanbaatar.
59. Byambadorj Ch., Munkhbat B. Current status of supply of agricultural technology in Mongolia. Mongolian journal of agricultutal sciences. Special issue. 2015. Volume 2. p. 127-132.
60. Shu. Q. Y et al, Plant Mutation Breeding and Biotechnology, 2012, www.cabi.org
61. "The Impact of Minerals and Fertilizers on Sustainable Improvement of Crop Soil Fertility and Products". Research project report implemented 2015-2017. Darkhan. 2018.
62. Report on soil analysis of fallow land (as part of the Virgin Land 3 campaign). PSARI Soil agrochemical laboratory. 2008-2010

OPTIMIZING HUMUS, WATER, AND NUTRIENT MANAGEMENT IN MONGOLIA IN CHANGING CLIMATE CONDITIONS

Authored by:

***Prof. Dr.* Guggenberger G.**
Institute of Soil Science
Leibniz Universität Hannover
e-mail: guggenberger@ifbk.uni-hannover.de

CONTENTS

INTRODUCTION

Temperate grasslands with their fertile Chernozems and Kastanozems have been almost completely converted into arable land during the last centuries. Alone in the 20th century about 400 million hectares of steppe have been cultivated to mostly arable land *(Foley, 2005)*. While in northern America the conversion was primarily carried out in the late 19th century and the early 20th century, in the southern Siberian, Kazakh and Mongolian steppes most of the native steppe has been cultivated after 1950. This Virgin Lands Campaign (1954-1963) in the former Soviet Union, called tselina, affected even larger areas of temperate grasslands than had been cultivated in the USA. In Mongolia, large-scale agriculture, with wheat as the only major crop, started in the 1960s with the introduction of techniques and equipment from the Soviet Union. The converted steppe soils are nowadays hotspots for agricultural production, primarily with rainfed crops.

But the conversion of native land into arable land led also to soil degradation with a loss of soil fertility and concomitant decline in yields. Caused by a series of several dry years, this was exemplified as the Dust Bowl Syndrome in the 1930s in the Great Plain region of the USA *(Hornbeck, 2012)*. This catastrophic event initiated the development of more resource saving agricultural techniques, and particularly mini-till and no-till soil management techniques have been developed. Large programmes have been developed in the USA and in Canada investigating the impact of conservation agriculture on soil humus, soil aggregate stability and resistance to soil erosion, on soil nutrient cycling and nutrient efficiency, but also on crop yield and economic issues. There are numerous publications on the results of these studies. The most extensive one on that topic is likely the book published by Paul et al. (1996) who compiled the results of 34 long-term agricultural field experiments in North American steppe soils. A key finding of this comparative study was that the presence - or loss - of humus is of utmost importance for agricultural productivity. Hence, the authors concluded that decisions on soil and crop management should be performed into the direction of keeping or building up the humus contents in soil. Results also revealed that the positive aspects of mini-till or no-till are becoming more relevant with a drier climate. Due to this extensive research, leading to very region-specific recommendations on soil and crop management, and also due to well available financial resources, most of the North American farms are nowadays applying resource conserving agricultural techniques.

Also, in the former Soviet Union the dramatic soil degradation after tselina led to the development of resource conserving agricultural techniques such as mini-till, e. g. at the Baraev Institute in Kazakhstan. But this was not fully implemented, and after the collapse of the Soviet Union a mosaic of farms emerged in the Russian Federation and Kazakhstan, which are partly working with modern western resource conserving agricultural equipment and agronomic techniques or still using the old Soviet equipment. Plowing and bare fallow still is in practice on most of the latter ones, with accelerating humus losses. Likewise, fertilization is lacking in most cases and wheat is mostly grown in monoculture. The situation is not better in Mongolia, even though the negative impact of bare fallow - spring wheat rotation for instance on soil humus depletion and soil erosion is well known.

In this report, the soil humus is in focus, as this is likely the most important variable defining and assuring soil fertility. First, I present some basics on the definition, function and composition of humus or soil organic matter and discuss some principles in humus management. In the next chapter, I report on the results of some previous research on humus, water, and nutrient management in steppe soils of southwestern Siberia and Kazakhstan. This is followed by a brief outline of the conditions of rainfed agriculture in Mongolia, before I finally discuss some options on how to improve humus, water, and nutrient management in rainfed agricultural soils of Mongolia.

1. HUMUS AS THE KEY COMPONENT FOR SUSTAINABLE AGRICULTURE

1.1. DEFINITION AND QUANTIFICATION OF HUMUS

In literature, there is no common definition of humus. Humus is a term that is widely used in agriculture. Scientists in contrast prefer the term soil organic matter, as the term humus is not well and not consistently defined. According to Baldock and Nelson (2000), soil organic matter is all biologically produced dead organic matter on or in the soil, independently of its degree of decomposition, including plant residues, residues of microorganisms and soil animals, humified organic matter, and pyrogenic carbon. Humus in its narrow sense (i. e. humified organic matter) strictly does not include plant residues in the soil, although they do play an important role in soil fertility. In this report, I therefore will use the word humus, as most of the agronomists are familiar with this term, but I will follow a holistic definition of humus which addresses the same as soil organic matter, i. e. all dead organic material in soil.

The humus content is difficult to measure directly. It is usually done by dry ashing. But this leads to errors, particularly in soils containing clay minerals. A more standardized procedure is to measure the organic carbon (OC) content of the soil with an elemental analyzer. In this case, carbonates need to be measured separately. Quite often, the soil humus is calculated by use of conversion factors, e. g. 1.74 or 2.0 But since the carbon content of the organic soil substances is not uniform, but varies depending on climate, vegetation, soil type and soil use *(Baldock and Nelson, 2000)*, the use of a defined conversion factor usually leads to incorrect values. In conclusion, it is advisable to measure the organic carbon contents directly and to refrain from using conversion factors.

1.2. FUNCTIONS OF SOIL HUMUS

Soil humus influences or controls almost all biological, physical and chemical properties and processes in soil (**Table 1**). It is the primary energy source for the heterotrophic material cycle and at the same time represents a temporary sink and source of plant nutrients. Humus influences the aggregation and poring of soils and is therefore important for the infiltration and storage of water, the exchange of soil air, and it reduces the erosion susceptibility of soils *(Gregorich et al. 1994)*. Microbial transformation of the organic matter leads to a higher net charge and thus to an increased chelation of multivalent metal cations *(Zech et al., 1997)*. This in turn stabilizes the soil structure and finally reduces the degradability of the organic substances *(Oades, 1984)*. Interventions in the humus balance of soils therefore always influence an entire network of soil properties and soil functions. Humus also controls the effectiveness and degradation behaviour of pesticides *(Gregorich et al. 1994)*. Over longer periods of time, most xenobiotics can be mineralized or humified with natural organic compounds via partly co-metabolic degradation *(Haider and Schäffer, 2000)*. With respect to nitrogen, but also to phosphorus and sulfur, humus can perform both a sink function (e. g. microbial N immobilisation) and a source function (e. g. N mineralization).

Soil organic matter property	Soil organic matter function
Biological properties	
Reservoir of metabolic energy	Soil organic matter provides metabolic energy for most biological processes in soil.
Source of nutrients	The mineralization of soil organic matter influences the pools of plant available macro nutrients (N, P, S) in soil (mostly releases the nutrients, but there can be also microbial immobilization).
Ecosystem elasticity	A significant pool of organic matter and the associated nutrients can increase the ability of agricultural ecosystems to increase their resilience towards natural or anthropogenic disturbance.
Influencing enzyme activities as well as plant and microbial growth	Specific components of the soil organic matter can stimulate or inhibit enzyme activities and plant and microbial growth.
Physical properties	
Stabilization of the soil structure	Because of the microbially promoted binding to reactive surfaces, organic matter binds primary soil particles and small aggregates to water-stable larger aggregates.
Water and air balance	Soil organic matter improves the soil water balance directly due to its high porosity and indirectly due to its effect on the soil structure and pore geometry.
Soil color	The dark color of the soil organic matter influences the thermal properties of soils.
Chemical properties	
Cation exchange	High net negative charge of organic compounds increases the supply of exchangeable cations like Ca^{2+}, Mg^{2+}, K^{+}, NH^{4+}, Fe^{3+} and of cationic micronutrients.
pH buffer capacity	In weakly acid to alkaline soils, the organic substance acts as a proton buffer and keeps soil in a favorable pH range
Chelation of metals	The formation of stable complexes with metals and micro-elements increases the weathering of soil minerals and increases the availability of phosphorus and micronutrients.
Interactions with xenobiotics	Soil organic matter influences the activity and persistence of pesticides and hydrophobic organic pollutants in soil.

Table 1: Impact of organic matter on important biological, physical, and chemical soil parameters.

Since the Kyoto Protocol at the latest, organic matter in agricultural soils has also been the focus of many discussions on the cycle of climate-relevant trace gases. For example, degraded agricultural soils can represent an effective carbon sink when humus-accumulating techniques are applied, and contribute to reducing the increase in atmospheric CO_2 *(Flach et al., 1997)*.

1.3. COMPOSITION AND TURNOVER OF SOIL ORGANIC MATTER

The functions of soil humus are closely related to its composition. In general, soil organic matter consists of plant and microbial residues (mainly polysaccharides, lignin, fats/waxes) and their transformation products *(Waksman, 1938; Kögel-Knabner, 1993)*. In the course of microbial degradation processes, degradation-resistant biomolecules accumulate selectively *(Hedges et al., 2000)*. Plant-derived polysaccharides and most proteins are rapidly mineralized and serve as sources of energy, carbon and nutrients for microorganisms. In recent years, there was a change in paradigm that organic compounds do not accumulate, because they are per se stable against microbial decomposition, e. g. compounds such as lignin or cutin. Rather the soil environmental conditions are decisive for the accumulation of organic matter in soil *(Schmidt et al., 2011)*.

Chemisorption of organic substances on particles of the clay fraction leads to the formation of primary organo-mineral complexes *(Christensen, 1992)*. This effectively protects the organic compounds against degradation. This fraction therefore comes very close to the well-known term “permanent humus (Dauerhumus)”. Secondary organo-mineral complexes characterize biogenous aggregates and are characteristic for intensively rooted soils of high microbial activity. The living root network links primary soil particles and microaggregates (< 250 m) to macroaggregates (> 250 m) (sticky string bag; Oades, 1993). After the death of the plant roots, they serve the microorganisms together with the other plant litter as substrate and produce a hotspot of microbial activity. The fungal hyphae or excreted microbial mucus formed in the process cause a loose binding of mineral particles around this so-called particulate organic substance (*Golchin et al., 1994*). This biogenic aggregation promotes the soil structure and leads to a temporary stabilization of the organic substance contained in the aggregates (**Figure 1**). Fresh plant litter and the particulate organic matter temporarily enclosed in aggregates and the microbial compounds associated with it correspond approximately to the “nutrition humus (Nährhumus)”. This type of humus strongly depends on a regular input of fresh plant residues.

Physical disturbance of soil organic matter, e. g. by soil tillage, destroys macroaggregates (> 250 µm diameter) and large microaggregates (50-250 µm diameter) and releases the physically protected organic substance. With regard to soil humus management, this fraction probably plays a key role as it (1) represents about 50 % of the soil organic carbon, (2) is decisive for soil fertility due to its turnover rates at time scale of decades, (3) reacts sensitively to land use changes, and (4) has a decisive influence on soil physical factors *(Elliott et al., 1996)*. Soil cultivation is always accompanied by a disproportionate decrease of the organic matter occluded within macroaggregates and microaggregates. In contrast to that, organic matter being chemically bound to clay minerals and particularly to Fe and Al oxides and occluded within small microaggregates (< 50 µm diameter) is effectively protected from degradation *(Kaiser and Guggenberger, 2000)* and is believed to be less affected by agricultural management *(Elliott et al., 1996)*.

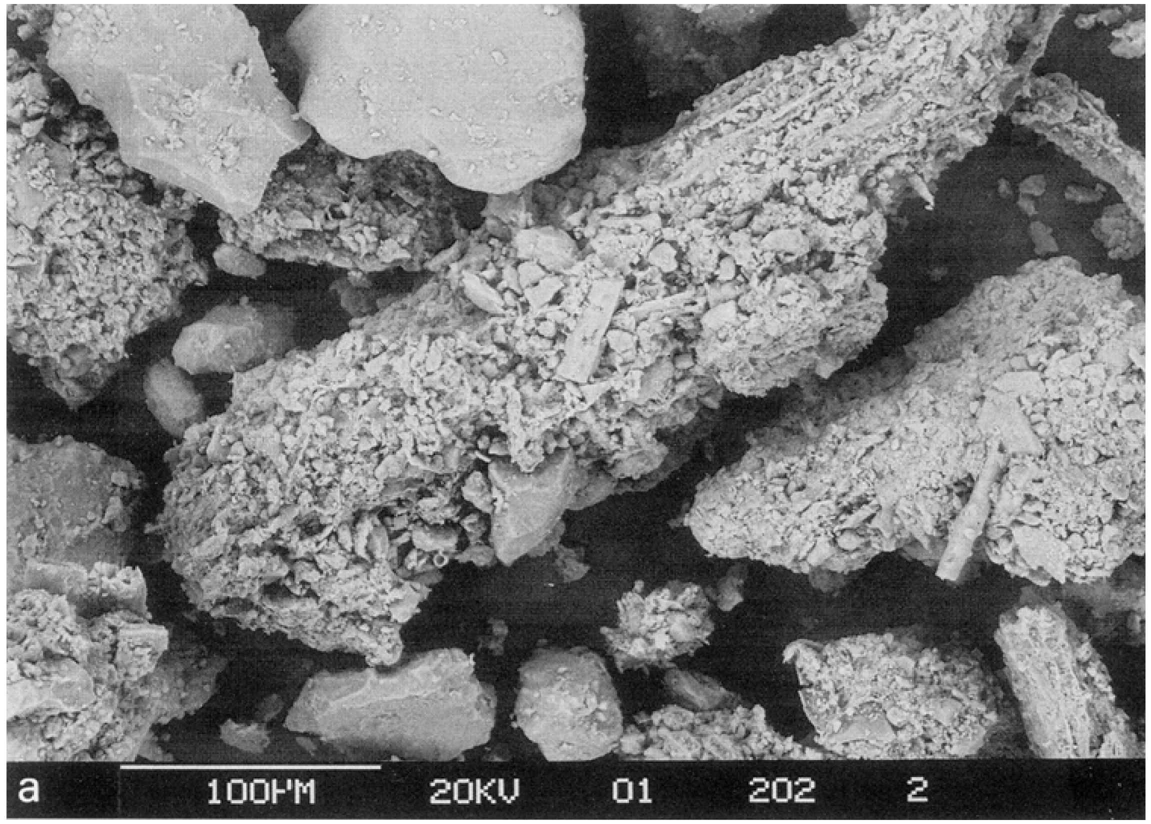


Figure 1: Scanning electron micrograph of encrusted particulate organic matter within water-stable aggregates of diameter 90-250 µm *(Source: Oades, 1993)*.

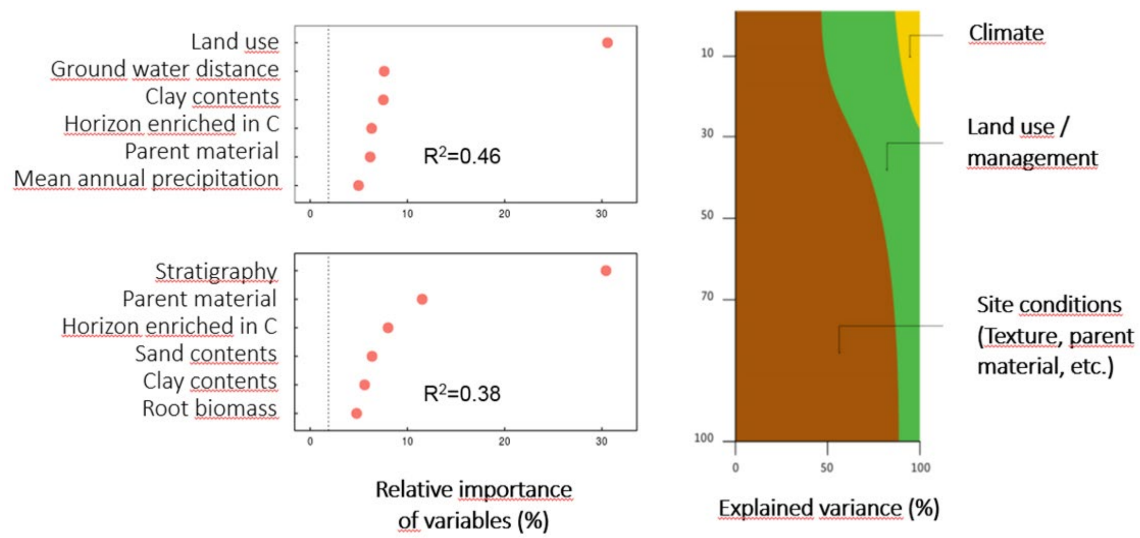


Figure 2: Left side: Effects of different soil parameters on soil organic carbon contents in agricultural soils (top) and grassland soils (bottom). Note the huge impact of land use in agricultural soils. Right side: Effect of site conditions, land use / soil management, and climate on soil organic carbon contents within the soil profile *(Source: data from the German soil carbon survey, Jacobs et al., 2018)*.

Environmental parameters that influence the soil organic carbon contents include site conditions (incl. parent material and texture), land use/soil management, and climatic conditions. The Thünen Report on the German soil survey concerning soil organic carbon storage *(Jacobs et al., 2018)* revealed the prominent role of land use/soil management on the organic carbon contents, particularly in the upper part of the soil profile (**Figure 2**). However, also climatic effects are becoming increasingly important.

1.4. PRINCIPLES OF SUSTAINABLE SOIL ORGANIC MATTER MANAGEMENT

In order to define the optimum soil organic carbon content and to approach it by sustainable management, it is first important to have a solid comparison of the arable soils with their natural counterparts. Unfortunately, for many regions in the world, there is not a solid database of soil organic carbon contents and stocks. This holds also true for Mongolia. From studies in the USA and Canada it can be seen that agricultural land use reduces the stock of organic carbon to about half of the original stock and that a new equilibrium of carbon flow (i. e. carbon input vs. output) occurs after about 50-100 years (**Figure 3**).

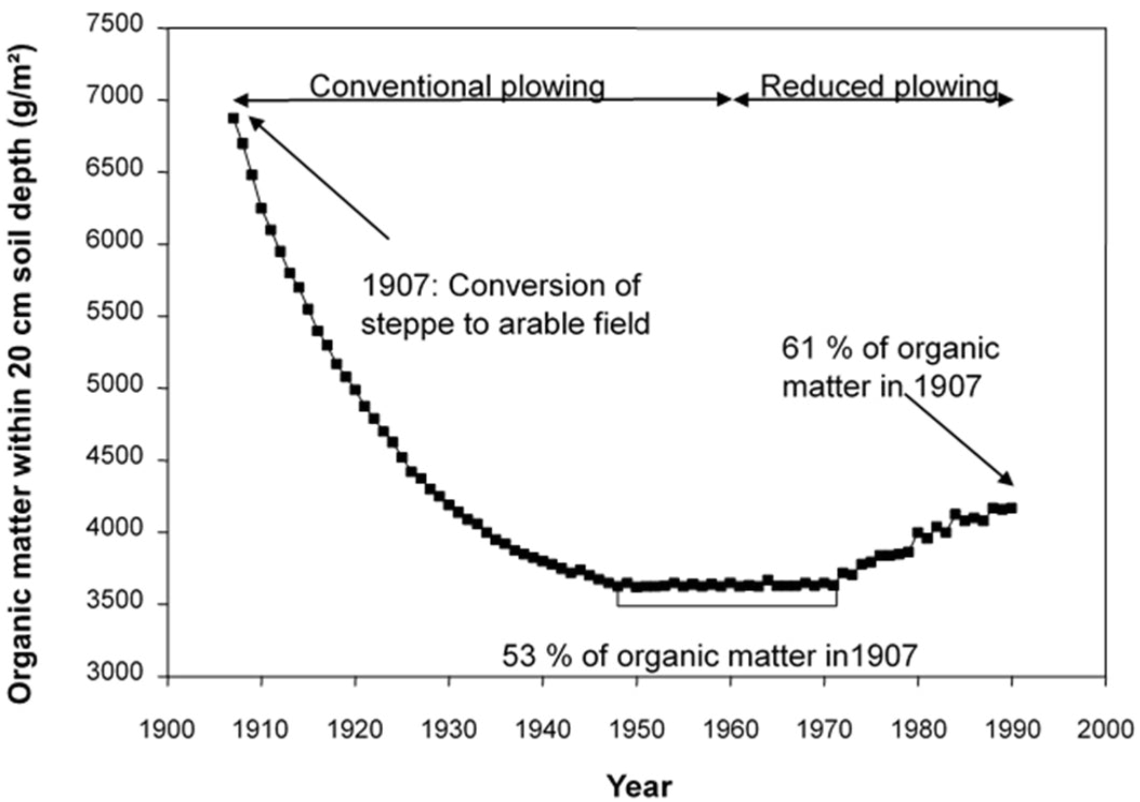


Figure 3: Simulated carbon stocks in surface soils under agricultural use by time (mean values of 27 regions in the Great Plains of North America) *(Source: Flach et al., 1997)*.

It is clear that the original soil organic carbon contents of native soil cannot be achieved without enormous input of residues into the soil. This is in most cases not possible and where it is possible, it is economically not feasible. However, under the aspect of protecting the natural body of soil and preserving or improving its functions (its habitat and regulatory functions), in addition to the production function, the closest

possible approximation to the natural soil condition and thus to the natural humus body in quantity and quality is required. For agricultural soils, it is in particular important to increase the easily turning over soil organic matter, i. e. the nutrient humus. For that, it is essential to have a high input of crop residues, mulch, and/or cover crops and to reduce fast microbial mineralization by avoiding soil tillage. From the point of view of the global carbon balance, agricultural soils are suitable as significant carbon sinks under humus-conserving management *(Flach et al., 1997)*.

In Germany, there has been a discussion that soil organic carbon contents in agricultural soils can also be too high *(Körschens, 1998)*. Non synchronized mineralization of soil organic matter and nitrogen uptake by plants can lead to nitrate contamination of groundwater. Also high input of easily decomposable organic substrates into the soil may increase N_2O emissions to the atmosphere *(Flessa and Beese, 1995)*. However, both is not likely to happen in dry soils of low nitrogen availability in Mongolia.

Fertilization is not only necessary for assuring a proper crop yield, but also for maintaining and increasing the soil organic carbon contents. Many continuous fertilization experiments prove that fertilization increases soil organic carbon contents directly by organic matter input (organic fertilizer) and indirectly by a larger return of crop residues (organic and inorganic fertilizer). A combination of mineral and organic fertilization results in a slightly higher yield and ensures higher soil organic carbon contents in the soil than a pure mineral fertilization *(Merbach and Körschens, 1999)*. This is especially true for sandy soils. In these light soils, the property of organic fertilizers as a slowly flowing nutrient source is important. In loess soils, no influence from the fertilization type could be determined on soil organic carbon content and crop yield *(Körschens and Pfefferkorn, 1998)*.

Destruction of the soil structure by cultivation measures leads to a loss of soil organic matter which is protected in macroaggregates and large microaggregates *(Six et al., 1998)*. This fraction corresponds in its size (approx. 50 % of the total soil organic carbon) and in its turnover rates (approx. 50 years) exactly to the carbon which is lost when the soil is cultivated in the first 5 decades. Vice versa, a reduction of the intensity of soil tillage leads to an increase of this fraction, because the turnover of the aggregates and thus the turnover of the organic soil substance present in the aggregates slows down *(Six et al., 1998)*.

Hence, a high soil humus content depends on a sufficient supply of organic matter with crop residues, animal manure and green manure on the other hand, and on the use of conserving soil cultivation methods. The basics of how this influences the humus balance are explained in the next section.

1.5. MANAGEMENT EFFECTS ON CARBON AND NUTRIENT CYCLING

Different agricultural management influences the biological processes in the soil through a multitude of interactions. In addition to the direct effects such as introduction of harvest residues on microbial activity, litter incorporation changes important soil physical parameters (**Figure 4**). For instance, a higher content of particulate organic matter causes, among other things, a stronger aggregation. This has consequences for the pore system of the soils, thus for the oxygen and water balance as well as the accessibility of the substrate for the microorganisms and their protection against grazing by the microfauna.

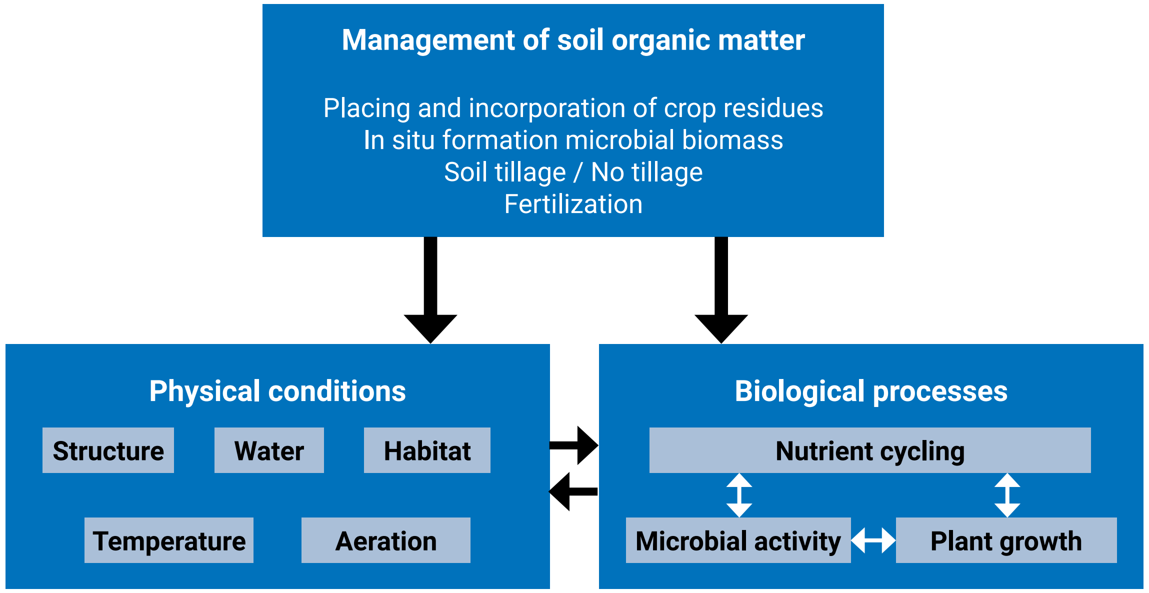


Figure 4: Relationship between soil organic matter management, physical soil properties and soil biological processes *(Source: according to Doran and Smith, 1987).*

1.5.1. INPUT OF SOIL ORGANIC MATTER

The input of crop residues is to a large extent controlled by the farmer and a function of the selection of crop, level of productivity (influenced by fertilization measures), management of crop residues and type and amount of organic fertilization. A number of field trials demonstrate the theoretical proportionality between input of organic substrates and soil organic carbon content (**Figure 5**). Since NPK fertilization leads to an increased net primary production, the organic carbon content of exclusively inorganically fertilized soils in long-term agricultural trials is also higher than that of unfertilized control *(Merbach and Körschens, 1999)*. However, the direct fertilizing effect of different organic fertilizer forms differs considerably depending on the nitrogen content and form *(Sauerbeck, 1992)*. With regard to the release of nitrogen, liquid manure is superior to solid manure, but

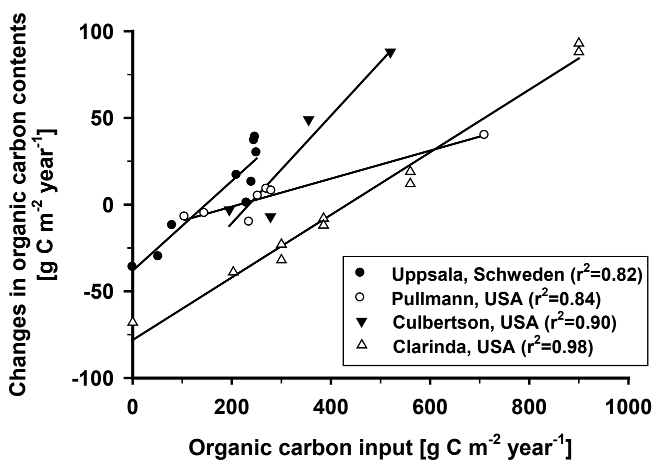


Figure 5: Linearity between the yearly changes in the stocks of OC in the soil and the yearly OC input *(Source: Paustian et al. 1997)*.

the classic manure forms have a better long-term effect. The situation is similar with various harvest residues. While legume litter is a fast nitrogen source and hardly causes an increase of the humus supply in well fertilized European and North American soils, the same biomass of harvest residues with a wide lignin to nitrogen ratio releases less nitrogen and leads to a stronger increase of the humus supply *(Paustian et al., 1997; Fig. 5)*. Under these circumstances, however, nitrogen deficiency can also lead to a reduced efficiency of C stabilization, as the microorganisms have to use more carbon for energy metabolism (CO_2 production) under these conditions, instead of the build-up of microbial biomass and the formation of stable soil organic matter from microbial residues *(Cotrufo et al., 2015)*. Hence, in soils that are depleted of organic carbon and nitrogen, rather legumes are useful for increasing the organic carbon contents in soil.

In addition to keeping the harvest residues in the field as completely as possible and reducing so-called "humus eaters (Humuszehrer)" such as potatoes and silage maize in crop rotation, the cultivation of catch crops leads to a higher input of organic matter. Intercrops also directly serve nitrogen management which is closely linked to humus management. Legumes are nitrogen fixers, while a number of non-leguminous plants temporarily bind nitrogen and make it available to subsequent crops after nitrogen mineralization of the residues *(Willumsen and Thorup-Kristensen, 2001)*. Though it is not likely that in dry steppe soils of Mongolia significant nitrogen loss is occurring. To my knowledge there is no data on it.

1.5.2. SOIL TILLAGE

Soil tillage is used, among other reasons, to increase the rate at which nutrients are released. But this is precisely what has led to physical, chemical and biological soil degradation in many soils of many regions worldwide. The aim of soil-friendly cultivation methods is to reduce erosion and humus depletion and even to increase humus reserves. Soil tillage influences the carbon and nutrient balance of the soil by physical disturbance and mixing of the soil with the creation of new surfaces on the one hand and by controlling how plant residues are incorporated into the soil on the other hand *(Paustian et al., 1997)*. The two extremes of tillage are conventional ploughing and no tillage with direct seeding.

With a decreasing degree of tillage, the aggregate stability and thus the physical protection of the organic matter against microbial degradation increases *(Six et al., 1998)*. In addition, water-stable aggregates are formed with direct seeding or mulch seeding with minium tillage. The omission of the incorporation of harvest residues into the soil leads to a shift of the microbial decomposer community towards fungi *(Beare, 1997)*. Through the formation of hyphae, fungi promote aggregation and incorporate the organic residues in the aggregates better than bacteria. A positive feedback between the stabilization of aggregates by dead fungal hyphae and the physical protection of organic matter inside aggregates could be demonstrated *(Guggenberger et al., 1999)*. The evaluation of American long-term experimental sites showed that the combination of increased biogenic aggregate formation and reduced physical destruction of the aggregates by minimal tillage leads in most cases to higher organic carbon stocks than with conventional tillage (**Figure 6**).

In the US, ploughless tillage is propagated primarily because of its potential for carbon sequestration in agricultural soils. Its agronomical success has been shown to be best in drier areas *(Paul et al., 1996)*. Hence, conservation agriculture is supposed to be successful also in dry steppe soils of the former Soviet Union and Mongolia.

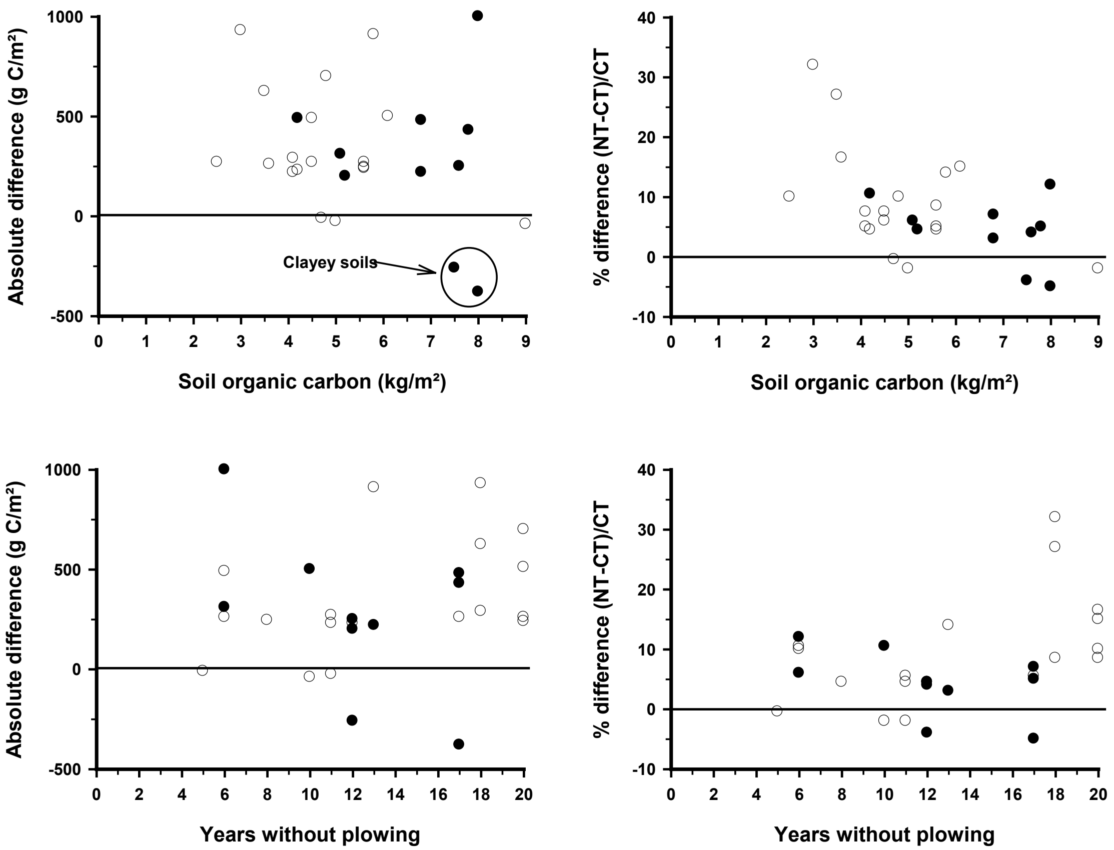


Figure 6: Soil carbon levels in pair-wise comparisons of conventional tillage (CT) and no tillage long-term experiments in N-America. Shown are (upper left) absolute difference (NT-CT) and (upper right) relative difference ((NT-CT)/CT) as a function of soil C under conventional tillage and (lower left) absolute and (lower right) relative differences as a function of time under no till. Values are for total C to depths at or below depth of plowing and adjusted for differences in bulk density. Filled circles are for clay and clay loam soils, all other textures shown as open circles *(Source: Paustian et al., 1997)*.

2. LESSONS LEARNED FROM THE KULUNDA AND REKKS PROJECTS IN SOUTHWESTERN SIBERIA AND KAZAKHSTAN

In this chapter, main results will be reported from two interdisciplinary research projects in southwestern Siberia and northern Kazakhstan, funded by the German Federal Ministry of Education and Research (BMBF). The research project **KULUNDA** "How to Prevent the Next Global Dust Bowl?" targeted on the identification of ecological and economic strategies for sustainable land management in the Siberian Kulunda steppe of the Altai Krai, Russia, within the framework of the **FONA** funding programme. The follow-up project **ReKKS** "Innovations for Sustainable Agricultural Resource Utilization and Climate Adaption in Dry Steppes of Kazakhstan and Southwestern Siberia", funded within the CLIENT II initiative of the BMBF, currently extends the research activities further to the dry steppes.

The Virgin Lands Campaign (tselina) in the former Soviet Union initiated by the general secretary Nikita Khrushchev was the largest ecosystem conversion in the 20th

century. From 1954 to 1963 areas of 255,000 km² in northern Kazakhstan and 62,000 km² in southwestern Siberia, respectively, were converted from native steppe into arable soil (**Figure 7**). This tselina area stretches from forest steppes in the north via typical steppe in central parts to dry steppes in the most southwestern parts of the Altai Krai (Kulunda steppe) and northern Kazakhstan. The annual precipitation decreases in the same direction from about 400 mm to less than 250 mm. Climatic conditions are severe, including high evaporation, high variability of precipitation, droughts, risk of early and late frosts, and strong winds. Soils are mostly typical Chernozems in the north, while in the more arid steppe regions in the southwestern part of the Kulunda steppe and in Kazakhstan southern Chernozems and Kastanozems prevail.

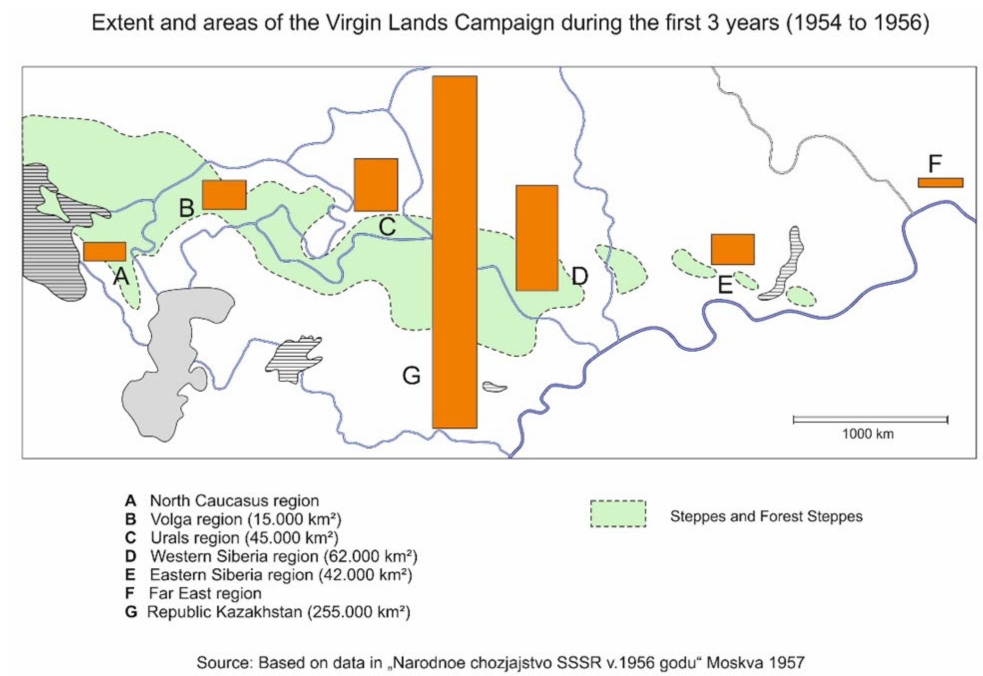


Figure 7: Extent and areas of the Virgin Lands Campaign (tselina) *(Source: Frühauf et al., 2020 as taken from Narodnoe khoziaistvo SSSR, 1957, and modified by Meinel, 2002)*.

After tselina, a few successful years, promoted by a favourable climate, were followed by a series of dry years. These led not only to very low yields (e. g. in the converted Kazakh regions the average yield in 1963 was 3.1 dt ha^{-1}, Kazstat, 2003), but also to a severe soil degradation, particularly soil erosion. In the territory of today's Kazakhstan, more than 80 % of the converted land was damaged by wind erosion by 1963 *(Frühauf et al., 2020)*. Thereafter, measures were taken in order to reduce soil degradation, such as by planting tree lines, replacing deep tillage by flat cultivation and increasing soil fertilization. However, with the collapse of the Soviet Union, lack of alternatives regarding herbicides, fertilizers, and machinery as well as short-sighted, profit-oriented management resulted in the fallback to outdated, stressful and yield-reducing soil management methods *(Frühauf et al., 2020)*. Only in recent years, a better financial situation of the farmers, the importation of western technology and equipment and their adaptation to the situation of the tselina area brought about a change in this development. Yields are increasing and soil degradation could be stopped in many areas.

2.1. SOIL ORGANIC MATTER DEPENDING ON CLIMATE AND LAND USE

So far, there were not many detailed studies dealing with the loss of soil organic carbon in the tselina region. For the Kulunda steppe in western Siberia, Bischoff et al. (2016) assessed the impact of conversion of native steppe to arable land use in the forest steppe, the typical steppe, and the dry steppe (**Figure 8**). Soils in the forest steppe and in the typical steppe were mostly Chernozems, while in the dry steppe Kastonozems dominated. Also, sodic and saline soils (Solonetz, Solonchak) were identified within the study area.

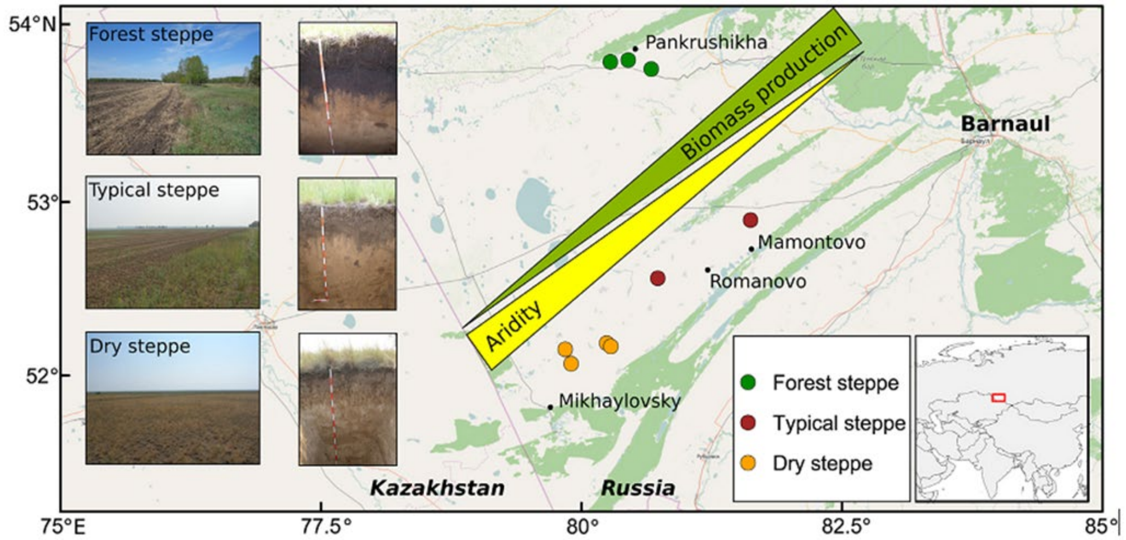


Figure 8: Map of the Kulunda steppe with sampling sites at forest steppe, typical steppe and dry steppe, along with a representative landscape picture and soil profile. Biomass and aridity gradients are shown schematically *(Source: Bischoff et al., 2016)*.

The measured soil organic carbon stocks down to 60 cm soil depth ranged from about 10 to 250 Mg ha^{-1} (10 to 25 kg m^{-2}) and generally decreased from forest steppe to typical steppe to dry steppe *(Bischoff et al., 2016;* **Figure 9**). Conversion of grassland to arable land use lowered the SOC stocks by about 20 % to 35 %. Chronosequence data from the forest steppe showed that by far most of the organic carbon was lost within the first five years after ploughing the grassland, thus corroborating the results of Poeplau et al. (2011) and emphasizing the fast response of soil organic matter on land use change in a degrading system. The climosequence study also enabled us to assess the impact of climate on the soil organic carbon losses by converting native soils to arable soils, which is discussed controversially in literature *(Guo and Gifford, 2002; Poeplau et al., 2011)*. The proportional decline in the soil organic carbon stocks was similar for forest steppe and dry steppe, while the typical steppe tended to have larger proportional organic carbon losses, though not statistically different *(Bischoff et al., 2016;* **Figure 9**). This indicates that the proportional decline of the organic carbon stock is independent of climate. However, the smaller soil organic carbon stocks in the dry steppe than in the typical steppe and particularly in the forest steppe must be considered when investigating land use change - climate change interactions. Hence, the predicted drier climate in the semi-arid steppes of southwestern Siberia and Kazakhstan will likely lead to a pronounced loss of organic

carbon in both grasslands and arable soils due to decreasing biomass input under drier conditions *(Bischoff et al., 2016)*.

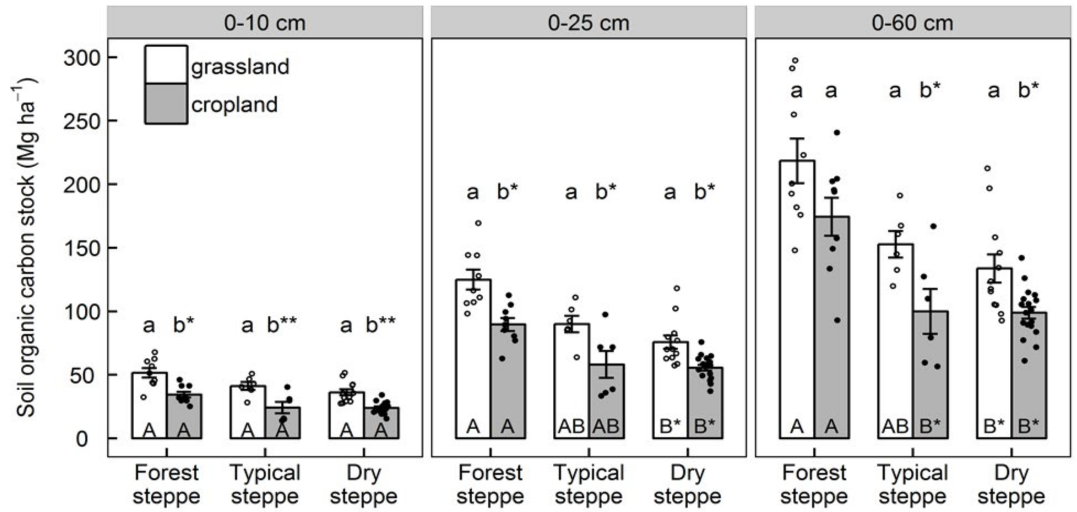


Figure 9: Soil organic carbon stocks (Mg or tonnes ha^{-1}) depending on land-use type for 0-10 cm, 0-25 cm, and 0-60 cm in different steppe types. Values are given as arithmetic mean ± standard error of the mean. Points show individual measurements and lowercase letters indicate significant differences between land-use types, tested within steppe type and depth increment (p-value, 0 < *** < 0.001 < ** < 0.01 < * < 0.05). Numbers above bars indicate the relative SOC stock decline due to grassland to cropland conversion *(Source: Bischoff et al., 2016)*.

Interestingly, it was not the “nutritional humus (Nährhumus)” that was lost the most. In all three steppe biomes, the organic carbon loss with cultivation of native soils was mostly due to losses of the so-called “permanent humus (Dauerhumus)” (**Figure 10**). This shows that the cultivation of native soils leads to losses of organic matter within a few decades that had been accumulated during decades to millenia. Hence, the loss of organic matter does not only negatively affect the release of mineral nitrogen, phosphorus, and sulfur by mineralization of organic matter. It also decreases the cation exchange capacity, as the “permanent humus (Dauerhumus)” is rich in carboxylic functional groups. The organic matter can provide up to half of the soil’s cation exchange capacity in native steppe soils *(estimated from the clay and organic carbon content according to Ad-hoc-Arbeitsgruppe Boden, 2005)*.

For the analysis of the future development of the soil organic carbon storage in the Kulunda steppe, the model Lund-Potsdam-Jena managed Land (LPJmL) was employed by Müller et al. (unpublished), based on reconstructed land use with local official statistics on agricultural productivity, inputs and sown crops and remote sensing estimates of recent land-use changes. All model runs showed a drastic decrease in the soil organic carbon storage from ca. 1950 onwards (**Figure 11**). While in the 20th century this decrease was primarily driven by the conversion of steppe, in the 21st century the increasing rates of soil organic carbon losses are driven by climate and largely associated with the decreasing production of plant biomass in a drier climate *(Guggenberger et al., 2020)*. Hence, the model exercise corroborates the results of the space-for-time approach by Bischoff et al. (2016). This trend definitively causes a challenge to agriculture in these arable steppe ecosystems and increases the pressure to move to a humus conserving agriculture.

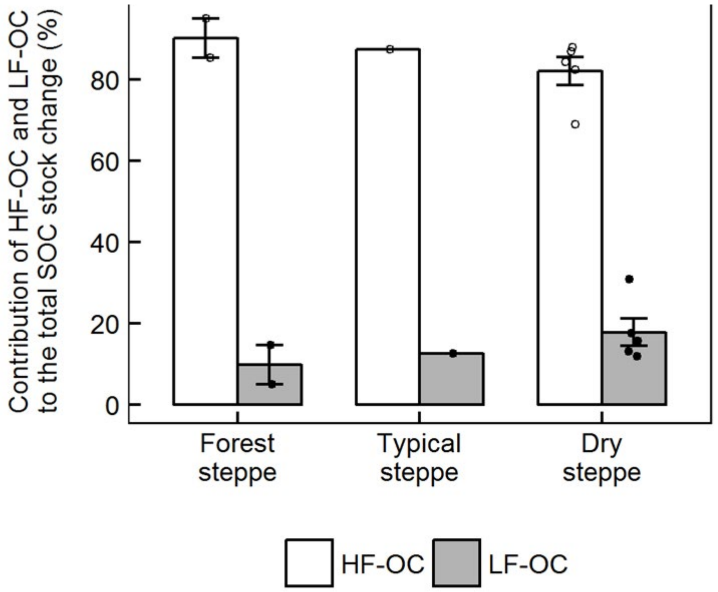


Figure 10: Relative contribution of "permanent humus (Dauerhumus)" and "nutritional humus (Nährhumus)" to the soil organic carbon losses with cultivation of steppe soils in the Kulunda steppe. The two different forms of humus were separated by density fractionation in a polytungstate solution with a density of 1.6 g cm³. Light fraction organic carbon, LF-OC (i. e., plant residues), floating on the solution has a turnover time of several months to a few years and is considered as "nutritional humus", while the heavy fraction organic carbon, HF-OC (i. e., organic matter associated with soil minerals), has a turnover time of decades to millennia and is considered as "permanent humus" *(Source: Bischoff et al., 2016)*.

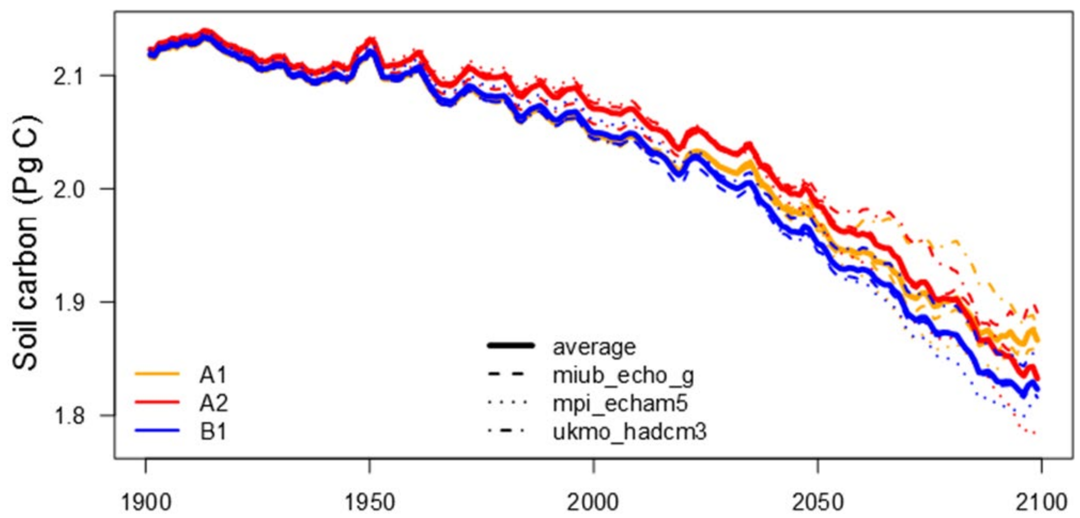


Figure 11: Simulation results of organic carbon in vegetation (top) and soil organic carbon (bottom) (1 Pg C = 1,000,000,000 tons) in the Kulunda region from 1900 to 2100 for the GLUES scenarios A1, A2, and B1 for different climatic models *(Source: Guggenberger et al., 2020)*.

The loss of soil organic carbon with cultivation is strongly related to a decline in the aggregate stability (**Figure 12**). Besides bare fallow, this is the second major reason for the high vulnerability of arable steppe soils for erosion. This concurrent loss of soil organic carbon and the decline in aggregate stability is due to two reasons. First, mechanical destruction of the aggregates releases organic matter that had been occluded before within the aggregates and thus protected against fast decomposition by soil microorganisms *(Elliott., 1986)*. Second, a smaller input of surface and root litter to arable soil than in steppe soil leads to a lower microbial activity and an associated less pronounced build-up of stable soil aggregates *(Six et al., 2002)*. However, **Figure 12** also shows that the concurrent losses of soil organic carbon and aggregate stability is smaller with a decreasing tillage intensity. This bears a chance of counteracting.

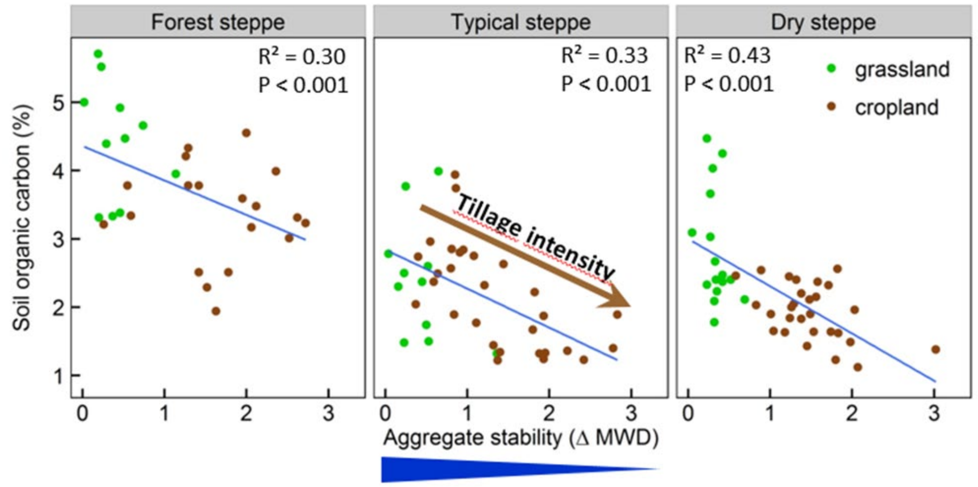


Figure 12: Relation between the aggregate stability and the soil organic carbon contents. The aggregate stability (Δ MWD, mean weight diameter) was calculated as the difference of the mean weight diameter between dry and wet sieving aggregates through a stack of sieves with 4, 2, 1, 0.5, and 0.2 mm mesh size *(Source: Bischoff et al., 2016)*.

As shown above, long-term agricultural management, particularly with high tillage intensity, leads to the depletion of soil organic carbon. This provides the chance to restore the soil organic carbon stocks *(Paustian et al., 2016)*, either by conversion of arable land to grassland or forest *(Laganière et al., 2010)*, by practices that increase organic matter inputs *(Burney et al., 2010)*, or by transformation to conservation tillage practices that decrease soil organic carbon mineralization *(Ogle et al., 2005)*.

After the collapse of the Soviet collective farming system in the early 1990s, about 25 million ha of arable land were abandoned in western Siberian and Kazakh steppes *(Kamp et al., 2015)*. In a meta-analysis, Kurganova et al. (2014) calculated an average carbon accumulation rate of 0.96 t carbon ha^{-1} yr^{-1} in 0-20 cm depth of abandoned Russian soils, though data vary widely between -0.23 and 3.70 t carbon ha^{-1} yr^{-1}. Parts of this variation are due to different soil types. Hence, the potential of storing more soil carbon in southwestern Siberia is high. But land-use conversions towards rehabilitated steppe are in conflict with agricultural production and food security worldwide and particularly in Russia and in Kazakhstan. However, there are many soils in this region that are severely degraded and cannot be used anymore as arable soils. Those soils, being strongly depleted of soil organic matter, bear a high potential of a future carbon sink when transferred to grassland with the help of optimized seeding technologies and choice of seeds *(Silanteva and Meinel, unpublished)*. Even though these soils may then be set aside from agricultural production, they may provide income to the farmer with carbon emission trading.

As discussed before, for many northern American soils it has been shown that a less intensive tillage, particularly zero tillage, leads to an increasing soil organic carbon storage *(Paul et al., 1996)*. Also, Kämpf et al. (2016) identified 3 % and 14 % larger soil organic carbon stocks in temperate soils under reduced and zero tillage management, respectively, as compared to their conventionally tilled counterparts. In the soils of the Kulunda steppe, Bischoff et al. (2016) revealed slightly larger organic soil organic carbon stocks along with a higher aggregate stability with decreasing tillage intensity (**Figure 12**). However, the results are not significantly different. In summary, it appears that minimum or zero tillage may provide an option to increase the organic carbon storage in western Siberian and Kazakhstan steppe soils.

2.2.WATER MANAGEMENT IN RAINFED AGRICULTURE

Soil moisture is the most limiting factor in agricultural production in the Altay Krai and in northern Kazakhstan, despite the situation in many places is not as severe as in Mongolia. Since irrigation is not feasible on most areas due to ecological constraints and economic reasons, most of the crops are produced in rainfed agriculture. Water management in rainfed agriculture is directly connected with the soil tillage system. In the Soviet Union, in the late 1960s soil protective farming strategies were developed for the Kulunda steppe, including preservation of the stubble on the soil surface during soil treatment *(Baraev, 1988)*. During the 1990s, development of minimum tillage came about out in conjunction with effective herbicides and fertilizers. In the years after 2000, disadvantages of deep tillage were being more and more recognized and mini-till or no-till technologies were introduced at a larger scale, primarily due to energy savings *(Belayev et al., 2014)*. With this large-scale utilization of mini-till and no-till technologies, the application of glyphosate is mandatory. In the framework of the **KULUNDA** project and already before, V.I. Belyaev and co-workers carried out several studies on the effects of soil tillage on the water contents and stocks in arable soils. It is important to mention that these experiments were done directly in the field, hence, under practical conditions.

Belyaev et al. (2020a) compared the temporal dynamics of water stocks in soils of the dry steppe in the southern part of the Kulunda steppe under deep autumn tillage with chisel plow PG-3-5 (depth 20-22 cm) without pre-sowing tillage and with bare fallow, mini-till with chisel plow KPSH-9 (14-16 cm), and no-till technology without autumn tillage. In late April, the soil water reserves were very similar among all techniques with around 180 mm (**Table 2**). During the vegetation period, decreases in soil water reserves were slightly larger for the mini-till and no-till than for the deep tillage. The authors attributed this to the fallow fields in the deep tillage system. More important, however, is the water use efficiency, i. e. the amount of water used for the production of a unit of crop. Here, the mini-till was superior to no-till and to deep tillage. In another experiment, Belyaev et al. (2020b) showed that deep tillage and associated bare fallow led to larger soil moisture reserves in early spring. However, also water losses (77 mm) were larger during the growing period. Here, mini-till technologies keeping mulch on the surface lose much less water (52 mm) due to the protection against evaporation from the soil surface.

Soil tillage	Late April, mm	Mid June, mm	Difference, mm	Late Aug., mm	Difference, mm	Yield,	Efficiency, mm/t
Deep tillage	180.3	165.8	14.5	104.3	61.5	1.28	59
Mini-till	179.4	154.5	24.9	98.3	56.3	1.64	49
No-till	179.1	162.4	16.8	97.5	64.9	1.41	58

Table 2: Temporal dynamics during the cropping season of the soil moisture stocks along with crop yields and water use efficiency for three different soil tillage systems; mean values for the years 2013-2016 are given. Deep autumn tillage with chisel plow PG-3-5 (depth 20-22 cm) without pre-sowing tillage and with bare fallow; Mini-till with chisel plow KPSH-9 (14-16 cm); No-till technology without autumn tillage *(Source: Belyaev et al., 2020a)*.

Also Bondarovich et al. (2020) investigated into the effects of different tillage systems on the soil moisture contents. In their comparison of deep plowing (chisel plow PG-3-5, depth 20-22 cm) with no-till, in the deep plowing treatment a bare fallow was included in the year 2014. The soil moisture was lower in the deep plow treatment than in the no-till treatment in all three soil depths investigated in the following year 2015 (**Table 3**). And also in 2016, the no-till treatment mostly showed higher soil moisture contents. These results suggest that bare fallow does not provide an advantage for the water supply of the succeeding crop. In contrast, no-till and mini-till technologies keeping the stubbles and the crop residues on the soil surface are superior. This can be partly explained by the mulch effect on evaporation, by reducing the wind speed due to the higher surface roughness and thus reducing the water vapour deficit directly on the soil surface, and by reducing the soil temperature. The installation and use of large weighable lysimeters revealed another process to be also responsible for the better water supply in no-till and mini-till systems. For the first time, the weighable lysimeters enabled the measurement of the water fluxes with dew in steppe agroecosystems. Despite the dry climate, dew formation in the Kulunda steppe is obviously an important contributor to the overall water budget *(Meißner, unpublished)*. As the surface roughness is higher at no-till and mini-till than under plowing and with bare soil, water harvesting is higher with the conservation treatments. The water flux with dew in dry steppe ecosystems and how this can be efficiently used in rainfed agriculture definitively deserves more attention in the future.

Year (Mean May-Sept.)	Soil moisture to 30 cm (Vol-%)		Soil moisture to 60 cm (Vol-%)		Soil moisture to 90 cm (Vol-%)	
	Deep tillage	No-till	Deep tillage	No-till	Deep tillage	No-till
2015	12.0	14.8	13.7	17.7	13.7	16.0
2016	15.6	17.0	16.8	18.5	18.2	16.5

Table 3: Average of the soil moisture in 30, 60, and 90 cm soil depth during the vegetation period from May to September in 2015 and 2016 with deep tillage with chisel plow KPSH-9 and no-till technology *(Source: Bondarovich et al., 2020)*.

2.3. ORGANIC MATTER MINING AND NUTRIENT DEPLETION

Besides the climatic conditions and the loss of organic matter with high tillage intensity agriculture, soil nutrient depletion is a major limiting factor in crop production in western Siberia and northern Kazakhstan. During Soviet times, the effectiveness of farming was strongly improved by the use of mineral fertilizer which stabilized and increased the crop yield in the Kulunda steppe *(Ivanova and Nosov, 2008)*. After the collapse of the Soviet Union, the use of mineral fertilizer strongly decreased, a situation which is also true for Mongolia. In consequence, the soils of the Kulunda steppe and also in northern Kazakhstan suffer from a serious nutrient deficiency. Some fields have not received any fertilizer for the last 30 years, and farmers need to rely on the supply of soil nutrients from weathering (e. g. potassium, phosphorus) and from mineralization of soil organic matter (mostly nitrogen, but also phosphorus and sulfur). The latter process is also one of the reasons for the incorporation of bare fallow into the crop rotation; organic matter continues to be mineralized by microorganisms and nutrients released may stay in the soil and can be used by the following crop. In addition to the direct effects of bare fallow on organic carbon depletion, also this nutrient mining by organic matter mineralization decreases the soil organic carbon. As nitrogen (and phosphorus and sulfur) is not only insufficient for plants but also for microorganisms, the temporary immobilization of these nutrients in microbial biomass competes with the plants for nutrients and further decreases the nutrient availability for the crops. A survey in the Kulunda steppe revealed much higher crop yields on those farms which are applying a proper fertilization. But since these farms are also working with an optimized soil tillage, it is not possible to relate the higher yields exclusively to higher fertilization rates.

In the **KULUNDA** project, unfortunately there has been no subproject focusing on the nutritional status of the soils. Due to frequent complaints by many farmers that they do not know the nutritional status of their soils, in the **ReKKS** project a nutrient survey was carried out for the Kazakh oblasts Akmolinsk and North Kazakhstan. The results showed that those arable soils which are receiving mineral nitrogen fertilizers have partly a modest nitrogen supply (**Figure 13**). In contrast, not a single one of the soils having not received mineral fertilizer exceeded a Nmin content of 12 mg kg^{-1}. Interestingly, this holds also true for the native steppe soils. This is likely due to the fact that during the time of sampling (end of May) the well growing steppe vegetation had already taken up most of the available nitrogen.

The situation is worse with other nutrients, like phosphorus, as in many cases farmers are exclusively fertilizing with nitrogen. According to **Figure 14**, most of the P_2O_5 contents in the northern Kazakh soils are in class A indicating a strong depletion of available phosphorus. This holds also true for micronutrients. In soils of high pH that are commonly found in the steppe and particularly in the dry steppe, metal cations such as copper, zinc, and manganese are quite frequently at a minimum, since they are strongly bound to soil minerals under these conditions. In contrast, molybdenum is well available at such pH values. However, the data base for micronutrients is even worse. The lack of knowledge on the soil nutrient contents calls for an initiative for an extensive soil analysis with respect to macro- and micronutrients, along with the analysis of soil physical parameters such as soil texture and bulk density/penetration resistance. Just with the knowledge of these basic soil parameters at a relatively high spatial resolution, precision agriculture will make sense. Currently, such initiatives are established in Kazakhstan, and also in

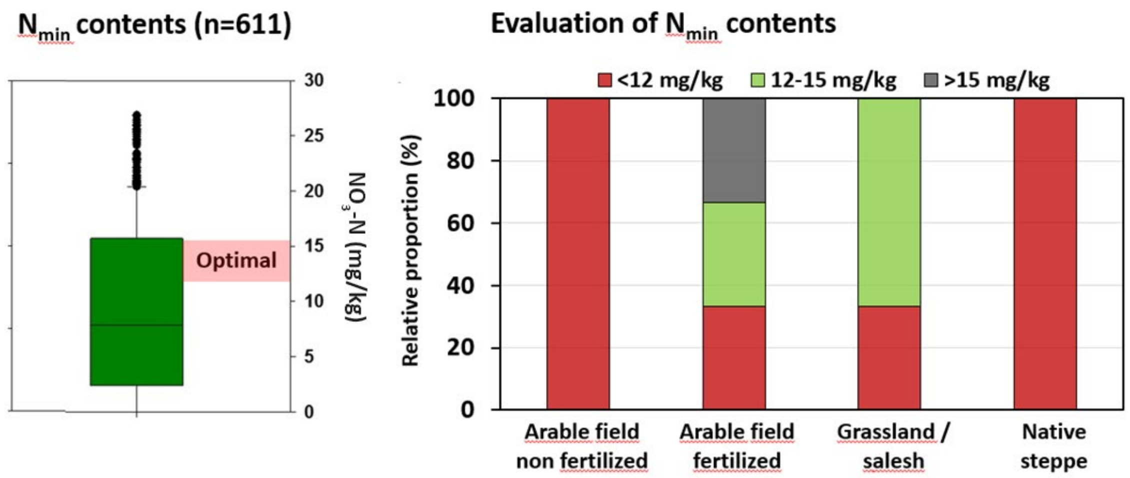


Figure 13: Left: Whisker plot of the NO_3^--N contents (NH_4^+ was most often below the detection limit) in representative soils of the Kazakh oblasts Akmolinsk and North Kazakhstan. Right: Relative proportion of NO_3^--N contents in soils of different land use *(Source: Koch et al., unpublished)*.

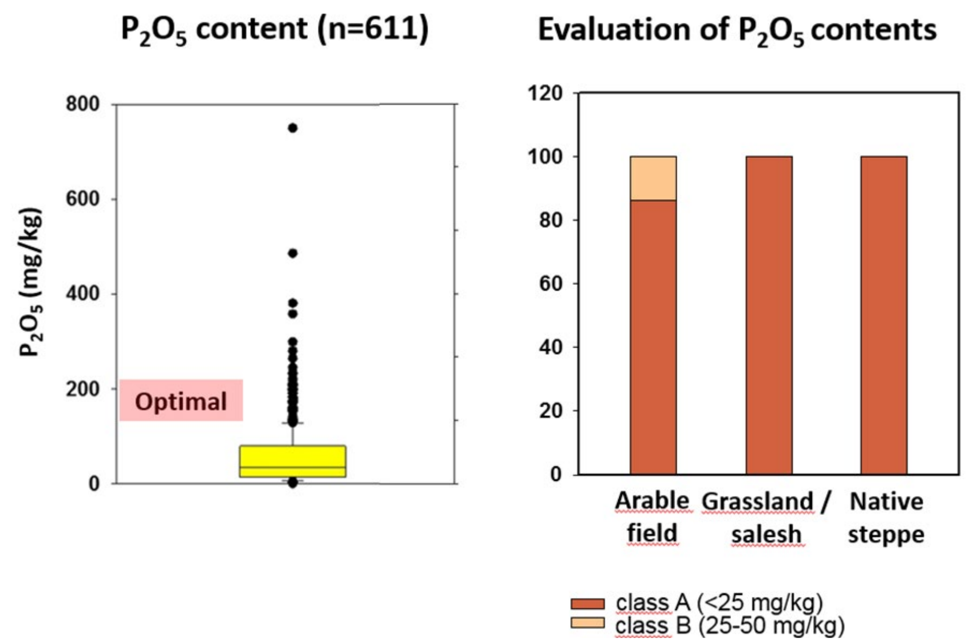


Figure 14: Left: Whisker plot of the P_2O_5 contents in representative soils of the Kazakh oblasts Akmolinsk and North Kazakhstan. Right: Relative proportion of P_2O_5 contents in soils of different land use with respect to nutrient classes *(Source: Koch et al., unpublished)*.

the framework of **ReKKS** a joint Kazakh-German laboratory on soil testing has been established at Seifullin Agrotechnical University in Nur-Sultan.

Another challenge with fertilization is the way how the fertilizer is added to the soil. Simply spreading the fertilizer on the soil surface, as it is usually done in Europe, does not work in the dry climate of the steppe. During dry periods, the granular fertilizers cannot be dissolved and thus cannot enter the rooting zone of the crops. Hence, a common practice is that the fertilizer is added to the soil with a seeder into the furrow directly with the seeds. However, this bears the risk of burning the seeds and limiting the dose of nitrogen supply to a maximum of 30 kg ha^{-1} *(Akshalov et al., 2013)*. Besides adding granular fertilizer to the soil, a relatively new development is the application of liquid fertilizer. As the fertilizer is already dissolved, it can easier reach the whole rooting zone of the crops. At present, experiments are running in the ReKKS project, investigating into the nitrogen uptake efficiency depending on soil tillage and on the physical status of the fertilizer (solid vs. liquid). In addition, with liquid fertilization a cocktail of nutrients can be mixed for the specific nutrient demands of the plant-soil system. However, the implementation of liquid fertilizer technology needs quite a high investment.

As an alternative to mineral fertilization, also the inclusion of legumes in the crop rotation may increase the soil nutrient levels and thus the crop yield. Belyaev et al. (2020a) compared the crop yield under different cropping systems: wheat/complete fallow - wheat/chemical fallow (with deep plowing), pea - wheat - wheat - rape seed (mini-till), and pea - wheat - wheat - rape seed (no-till). The average crop yield for the years 2013-2016 was highest under crop rotation including the pea with mini-till (1.64 t ha^{-1}) and lowest under wheat monoculture with deep plowing (1.28 t ha^{-1}). Despite, due to the experimental design the effects of soil tillage and crop rotation cannot be clearly disentangled. This shows the advantage of including the legume into the crop rotation.

3. CONDITIONS FOR RAINFED AGRICULTURE IN MONGOLIA

3.1. ABIOTIC CONDITIONS

The climate of Mongolia is characterized by strongly continental conditions with a mean annual temperature between 8.5 °C in the southern desert and -7.8 °C in the northern and western areas *(Baast, 2016; Baast and Bartseren, 2019)*. The amplitude of the temperature is very high between -31.1 °C and -55.3 °C in January and 28.5 °C and 44.0 °C in July. Due to the continental climate and the high elevation of Mongolia (on average 1,580 m), the vegetation period is short with 70 to 120 days between late April / early May and September. Frost is sometimes also possible in May and in August.

As compiled by Baast (2016) and Baast and Bartseren (2019), the mean annual precipitation is 110 to 140 mm in the south and west, 200 to 230 mm in the east, and 220 to about 350 mm in the north and central regions, barely exceeding 400 mm (**Figure 15**). The distribution of precipitation is uneven, with 5-10 % during winter and spring (November to April), 60 % during summer (Mai to August), and 20 % during autumn *(Illies, 2012)*. Mountain ranges in the west, southwest and northwest prevent the influence of westerlies in Mongolia. Instead, particularly during winter Mongolia is under the influence of the Siberian high-pressure system. Precipitation maxima are in July and August with an extension of the East Asian summer monsoon. In contrast to Kazakhstan, which receives still a pretty good winter precipitation with snow, the soil moisture conditions in Mongolia are often critical in springtime.

As in many post-Soviet countries, also in Mongolia the weather conditions for plant growth, particularly in agriculture, are evaluated by the hydrothermal coefficient (HTC) which relates the sum of precipitation in periods of a temperature of >10 °C to the temperature sum during these periods. During the last years, the HTC was mostly between 0.7 and 1.0 (**Figure 16**) which categorizes dryness. In rainfed agriculture, there

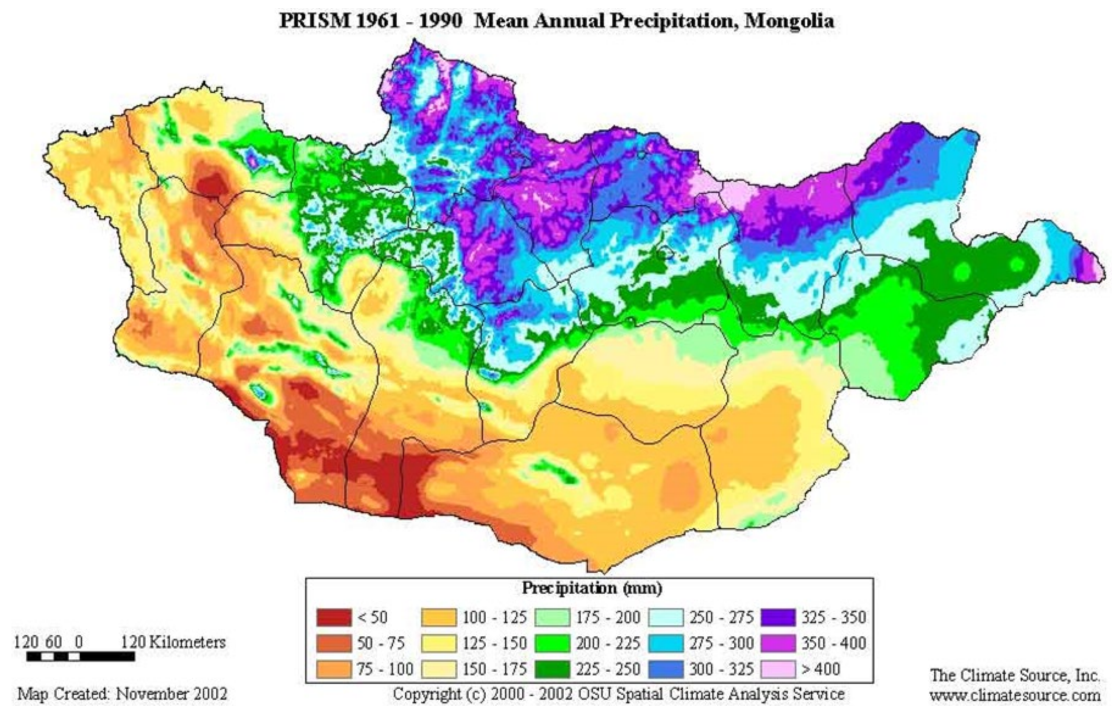


Figure 15: Mean annual precipitation in Mongolia *(Source: www.climatesource.com)*.

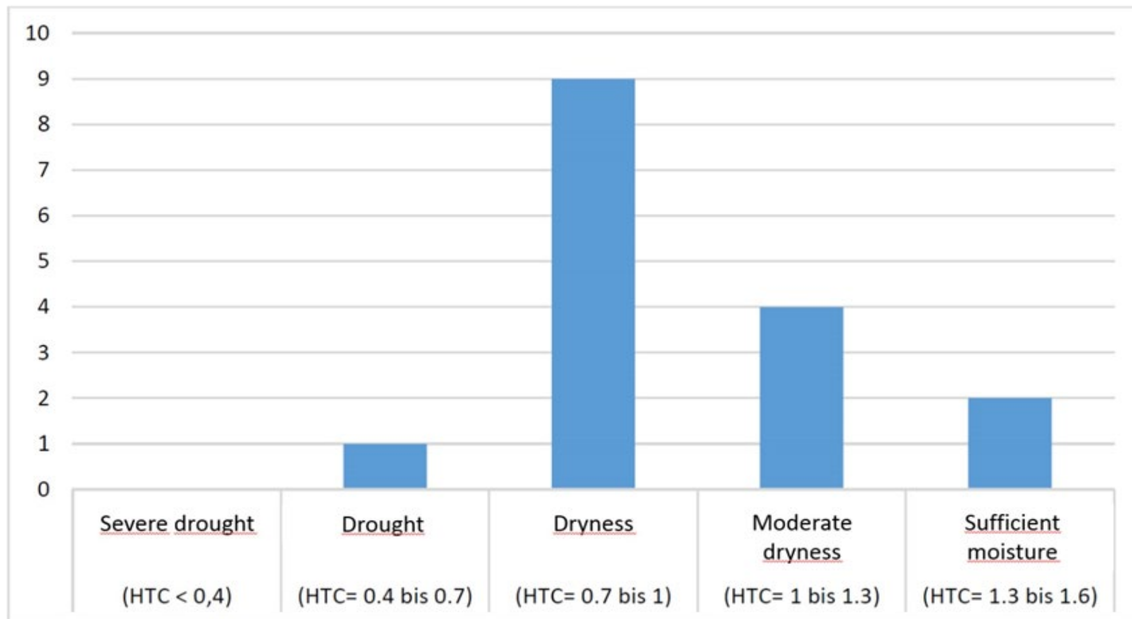


Figure 16: Frequency distribution of the hydrothermal coefficient during the period 2000 to 2015 *(Source: Baast and Bartseren, 2019)*.

is a strong relation between the HTC and the crop yield. So, in 2012 with a HTC of 1.39 the average yield of spring wheat was 15.7 dt ha^{-1}, while in 2015, with a HTC of 0.91, the yield was 5.6 dt ha^{-1} only *(Baast and Bartseren, 2019)*.

The geological situation of Mongolia is very complex. It is composed of various microcontinents and island chains that experienced pronounced tectonics during the past 500 million years. Parent material for soil development includes highly weathered magmatic and metamorphic silicate rocks, partly of basic and ultrabasic as well as carbonate rocks. In the valley systems Quaternary sediments accumulated. In large areas, Mongolia is dominated by mountains and is characterized by a rolling topography with slopes of different inclinations. Plain areas in river basins are limited.

3.2. SOIL CONDITIONS

Soils developed under these conditions are characterized by intensively physically weathered parent material. Rocks are worked up and the thickness of soils should be sufficient, given that the slope is not too steep. Best locations for agriculture should be in river basins where alluvial material accumulated.

Chemical weathering of the minerals, and thus nutrient release, is often limited due to a low soil moisture. The pH values are mostly neutral to alkaline, thus many macronutrients such as calcium and magnesium are well available. However, at such a high pH the nutrient availability of phosphorus, potassium and many cationic micronutrients can be low.

Agriculture is mostly limited to the central and northern steppe and forest steppe zones. This is where soils are dominated by Kastanozems (chestnut soils, kastanienbraune Böden) which are considered to be suitable for agriculture *(Baast and Bartseren, 2019)*. According to the authors, the more fertile dark Kastanozems are located in the northern and central agricultural regions, whereas typical and light Kastanozems occur in the western and eastern agricultural regions.

Such soils have been used for arable agriculture since the 1960s. Choijamts et al. (2015) compiled data on the status of the fertility of arable soils in Mongolia, which was summarized by Baast and Bartseren (2019). A major finding of this study was that in the central agricultural region, only 5.1 % of the soils are not or only slightly eroded, while 59.7 % are severely eroded. In 1996, the proportion of eroded soils was much less, showing the high rate of erosion.

Another sign of soil degradation is the loss of humus. About 50 % of the overall arable soils in the agricultural regions have a humus content of < 2 % (i. e., < ~1 % soil organic carbon). These soils are considered as poor and very poor in humus *(Ad-hoc-Arbeitsgruppe Boden, 2005)*, and they can barely fulfil the different soil functions. Particularly, strongly eroded soils show low humus contents. These soils have been a strong source of atmospheric CO_2 during the past 30 years. However, this bears also the chance to gain humus again with conservation soil and land management, and thus to make the soils carbon sinks again in the future.

Along with the humus depletion and as a result of a limited fertilization, also the contents of available nutrients decreased strongly during the last decades. So only 40.3 % of the arable soils have sufficient contents of nitrate, and only 23.0 % and 11.5 % have sufficient contents of available phosphorus and potassium, respectively. In a case study in the Kharaa river basin, Hofmann et al. (2016) identified an average deficit of approximately 20 kg of nitrogen ha^{-1} yr^{-1} and 4 kg of phosphorus ha^{-1} yr^{-1} (potassium was not studied). As a consequence of this nutrient depletion, many arable fields have already been set aside.

3.3. CLIMATE CHANGE

The Hydrometeorology Institute of Mongolia has estimated that the mean annual temperature of Mongolia has already increased by 2.14 °C over the last 65 years *(Dagvadorj et al., 2009)*. This is considerably more than the global average.

The mean of different ensembles for projection of future climate change indicates that in the near future until 2035 the temperature is expected to increase by 2.0-2.3 °C, and until the end of the century the temperature increase is projected to be as high as 2.4-6.3 °C, depending on each RCP scenario *(Zamba et al., 2018)*. Likely all seasons will be affected by this temperature increase, though the interannual variability will be high.

Concerning precipitation change, winter snow is expected to increase and summer rainfall shows no significant change, there is only a slight increase of less than 10 % for all scenarios. Winter snow will be increased by 10.1-14.0 %, depending on each scenario in the near future, and by 15.5-50.2 % in the far future *(Zamba et al. 2018)*.

In a study on the trends of temperature and precipitation-based aridity in Mongolia by using climate change scenarios, Nyamtseren et al. (2018) concluded that the aridity level is likely to increase in the 21st century in central parts of Mongolia. This can have an adverse impact on crop (and grassland) productivity. Consequently, under the conditions that wheat variety and soil fertility remain unchanged, wheat yield is expected to decrease in the next decades *(Zamba et al., 2018)*. This shows the challenge that agricultural management has to deal with.

4. POSSIBLE OPTIONS FOR OPTIMIZING HUMUS, WATER AND NUTRIENT MANAGEMENT IN RAINFED AGRICULTURE IN MONGOLIA

This chapter discusses possible options to sustainably improve soil fertility. As the report of Tobias Meinel discusses in detail technical aspects with respect to agricultural equipment, i. e. minimal tillage, direct seeding, strip tilling including the technological solutions offered for seeding, fertilization and harvesting, this aspect will not be covered here.

4.1. REDUCTION OF BARE FALLOW

A major characteristic of Mongolian crop production is that it is largely based on wheat monoculture with a bare fallow - wheat rotation, with the contribution of bare fallow being 33 % or even 50 %. There are three reasons given for the bare fallow: **(1)** water conservation for the following crop, **(2)** increase of nitrogen (also phosphorus and sulfur) supply for the following crop by soil organic matter mineralization (i. e. soil mining), and **(3)** weed control. But at the same time, bare fallow is responsible for many aspects of soil degradation. Open soil is per se vulnerable to soil erosion. At first, this addresses wind erosion, but occasional torrential rain events during the summer monsoon in Mongolia also lead to a severe water erosion even in the dry steppe of Mongolia. The risk of soil erosion is increased by the loss of soil organic matter which acts as a gluing agent to form water stable macroaggregates and large microaggregates (see also **Chapter 2.1**). Loss of aggregate stability increases the vulnerability both against wind and water erosion. The use of bare fallow for nutrient mining finally leads to a deprivation of soil nutrients, which in turn will lead to a lower soil fertility in the long run. After all, a degraded soil also does not store as much water as a healthy soil, due to the selective loss of fine particles with wind erosion, a decrease in the soil thickness, and the loss of water-storing humus.

Hence, there is a large agreement to omit bare fallow also in Mongolia. And there are also good arguments for that. As was shown in the **KULUNDA** project (and also previously e. g. by Belyaev and Volnov, 2010), water saving by bare fallow is very limited if it works at all. Tillage breaks the capillary continuum and thus should theoretically reduce evaporation. However, the frequent tillage on bare fallow counteracts this effect. Also, the direct exposure of the soil to the dry wind increases the water vapour deficit and therefore increases evaporation. An alternative to bare fallow can be legumes and green manure. Of course, there is the argument that e. g. green manure will consume much water with transpiration; thus, the soil will provide less water to the following main crop. Also in Germany, there is a similar concern with the establishment of catch crops after the harvest of the main crop. Farmers are afraid that the water consumption by the catch crops is too high.

However, own studies investigating into the effects of catch crops on nutrient cycling, organic matter storage, physical soil properties, and soil water contents show the opposite. In a long-term experiment with several monoculture catch crops and two mixtures of catch crops of different diversity, at the end of the growth period of the catch crops, the soil moisture exceeded in all cases (except mustard) the soil moisture of the bare fallow

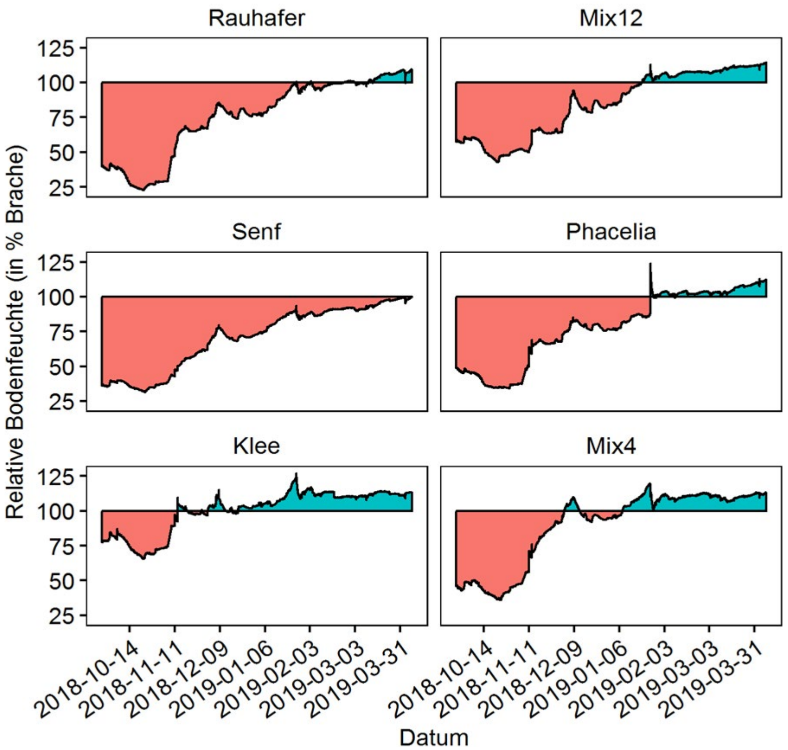


Figure 17: Relative soil moisture contents during the growing periods of different intercrops as compared to that under bare fallow (=100 %). Translations: Rauhafer (bristle oats), Senf (mustard), Phacelia (phacelia), Klee (clover); Mix 4 represents a mixture of four intermediate crops, Mix 12 (TerraLife) represents a mixture of twelve intermediate crops *(Source: Gentsch and Guggenberger, unpublished)*.

which served as the basis for the check (**Figure 17**). At early stages the soil moisture was much lower under the catch crops due to the build-up of biomass and transpiration losses. However, the situation reversed at later stages. Then, the transpiration by plants was minor and was outcompeted by the evaporation loss from the bare soil. In the planted soil, vegetation and residue cover obviously strongly reduced evaporation losses. Even though this observation cannot be translated one-to-one to the situation in the dry steppe of Mongolia, it shows that a vegetated soil does not necessarily lose more water than a bare soil.

4.2. PROMOTION OF INTERMEDIATE CROPS, PARTICULARLY OF LEGUMES

There are several further advantages of intermediate crops or green manure. One of the main reasons of the use of catch crops in Europe is catching the nitrate in autumn in order to decrease nitrate leaching into the groundwater and to provide nitrogen to be taken up by the following crop *(Thorup-Kristensen et al., 2003)*. While this does not appear important in the dry steppe of Mongolia, the inclusion of legumes in intercrops and also fostering non-symbiotic N_2 fixing microorganisms improve the nitrogen supply for the following crop. As can be seen from **Figure 18**, particularly intermediate crop mixtures containing legumes provide a slowly flowing nitrogen source with their decomposition in the soil. The total release of nitrogen is much higher than that from the bare fallow after wheat, and the decomposing intermediate crops provide also a nitrogen supply for longer periods of time. In total, the intercrops released between 40 and 60 kg N ha^{-1} with their decomposition (**Figure 19**). Here again, the release would be much less in Mongolian soils, but nevertheless it can be high enough to cover a large part of the estimated crop demand of about 20 kg N ha^{-1}. Of interest is also the release of potassium

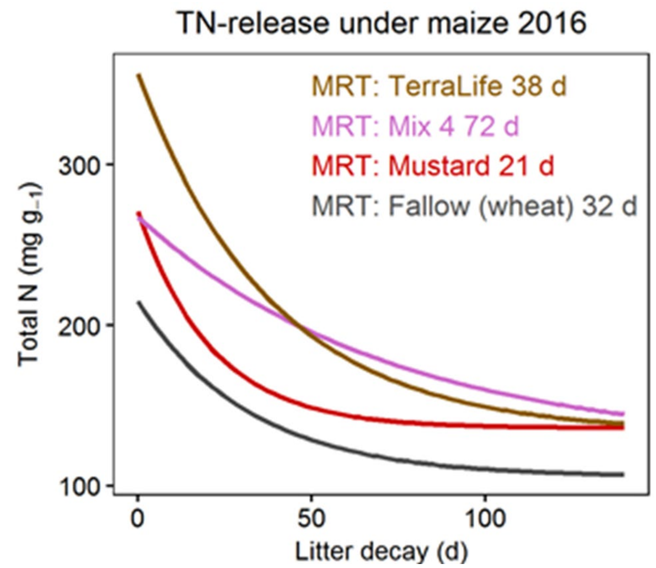


Figure 18: Temporal course of the release of total nitrogen in soil under maize during decomposition of litter from mustard, and two intermediate crops of different diversity (Mix 4 and Mix 12 (TerraLife)) as compared to nitrogen release under maize after bare fallow *(Source: Gentsch and Guggenberger, unpublished)*.

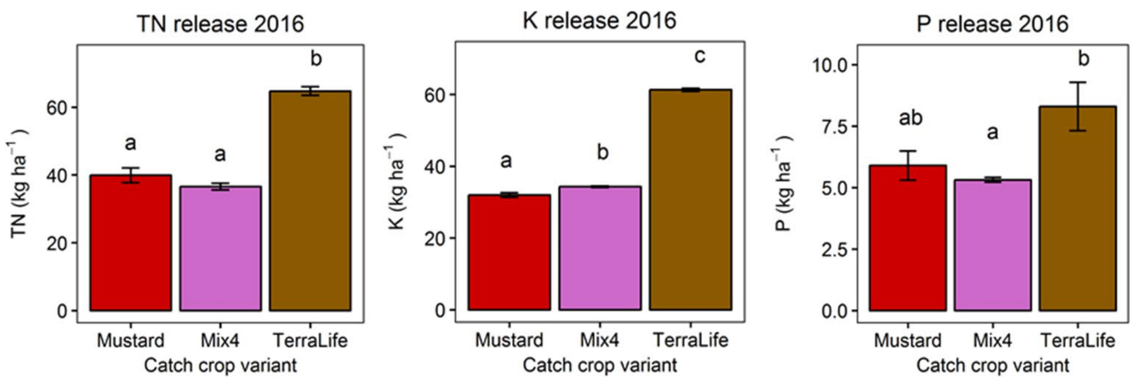


Figure 19: Total release of total nitrogen (left), potassium (center), and phosphorous (right) in soil under maize during decomposition of litter from mustard, and two intercrops of different diversity (Mix 4 and Mix 12 (TerraLife)) *(Source: Gentsch and Guggenberger, unpublished)*.

and phosphorus to the soil during the decomposition of the catch crops (**Figure 19**), as also those two nutrients are mostly deficient in high-pH steppe soils, despite the usually fairly high total contents of these elements in the soil. There are further indications that the soil microbiome is modified by the intermediate crops *(Reinhold-Hurek, unpublished)*. Mycorrhization of the intermediate crops can help to mobilize phosphorus from barely soluble phosphorus forms (e. g., apatite, phosphate bound to Fe-oxides) and potassium by promoting mineral weathering.

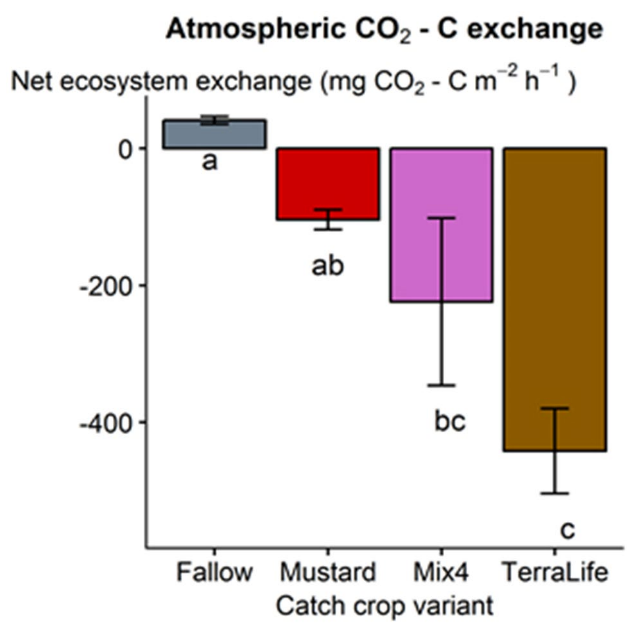


Figure 20: Net ecosystem exchange of CO_2 in bare fallow compared with intermediate crop plant-soil systems with mustard, and two intercrops of different diversity (Mix 4 and Mix 12 (TerraLife)). Note, positive values indicate net CO_2 emission and negative values net CO_2 uptake as organic carbon *(Source: Gentsch and Guggenberger, unpublished)*.

Intermediate crops are also promoted in Europe because they produce biomass that provides organic input material for the soil. Indeed, CO_2 flux measurements (net ecosystem exchange) carried out on bare fallow and in different intercrop systems showed that bare fallow is a source of CO_2 (thus losing carbon), while intercrop systems serve as a sink of CO_2 (thus gaining carbon) (**Figure 20**). Parts of this carbon will end up as humus. One may expect that this positive effect of intermediate crops on the soil organic carbon contents will be particularly pronounced in degraded and organic matter-depleted arable soils. Along with the increasing soil organic carbon contents, the overall fertility and productivity of soils will increase, as can be seen in our test fields in Germany (**Figure 21**).

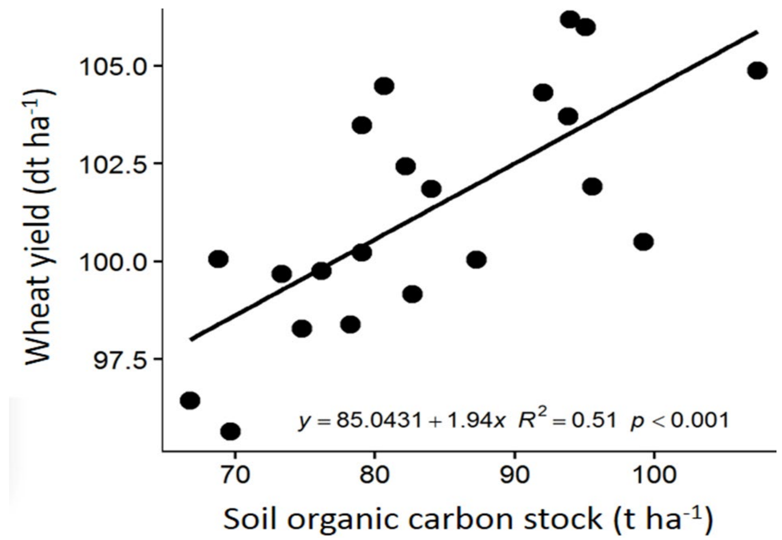


Figure 21: Wheat yield related to soil organic carbon stocks in arable fields including different intermediate crops in the crop rotation *(Source: Gentsch and Guggenberger, unpublished)*.

In Mongolia, preference should be given for legumes as intermediate crops, taken into account the consequences of long-term nitrogen mining in the usual bare fallow - wheat rotation. Even soils that have lost most of their organic matter or where the topsoil has been eroded can theoretically be rehabilitated by the cultivation of intermediate crops. This is obvious from studies on deposited calcareous loess after the reclamation of a former open-cast lignite mining region. In this case, the intermediate crops are cultivated for several years. After seven years of alfalfa cropping as pioneering plant, soils are ready for arable use *(Pihlap et al, 2019)*. An additional organic matter input further improves chemical, physical, and biological soil characteristics.

These statements were all based on research in warm temperate climate with an average temperature of about 9 °C and a mean annual precipitation of about 600 mm. In principle, intermediate crops provide also an opportunity in much drier and colder Mongolia, but only a few crops can be considered. In the following, some optional crops to be used as intermediate crops or also in general to be included in the crop rotation will be discussed.

4.3. POSSIBLE INTERMEDIATE CROPS AND ALTERNATIVE CROPS TO WHEAT TO BE USED IN MONGOLIA

4.3.1. LEGUMES

Alfalfa *(Medico sativa)*

Alfalfa is one of the few perennial legumes and thus provides the soil with nitrogen. It can be used in the rehabilitation of degraded soils and plays an important role in many regions of the world in animal husbandry, incl. dry and cold regions such as Inner Mongolia and Canada. So it may contribute to satisfy the rising demand for fodder crop production, helping to limit the negative impact of the frequently occurring dzud. But it is getting also increasingly important in sustainable agriculture and organic production. Besides adding available nitrogen and carbon to the soil, it provides a good soil structure and helps to control weeds.

Alfalfa has a relatively high transpiration coefficient of > 700 L H_2O kg^{-1}, but is considered to be drought resistant. It is grown in Mongolia in small amounts only, but quite frequently in neighbouring Inner Mongolia also under non-irrigated conditions *(Mao et al., 2018)*. Also in Canada, alfalfa is grown successfully, rather often in grass-legume mixtures such as bromegrass *(Bromus inermis)* and wheatgrass *(Agropyron inetermedium)*. Jefferson et al. (2007) reported for semi-arid Saskatchewan a higher grass forage production when they are grown together with alfalfa. Also Foster et al. (2013), working as well in Saskatchewan, showed that the inclusion of alfalfa not only increases the protein content of the forage but, when grown in unfertilized soil, also the dry matter yield.

Currently, climatic conditions in Mongolia are a challenge for alfalfa production. But improving thermal conditions in Mongolia together with some success in breeding new lines of alfalfa by crossing alfalfa wild relatives *(M. sativa subspecies falcata)* with their domesticated counterpart *(foodtank.com/news/2018/12/alfalfa-queen-of-forages-reconquering-the-grasslands-of-inner-mongolia/)* that better tolerate colder temperatures and dry soils may increase the chances to successfully include alfalfa in agricultural production in Mongolia. But it has to be kept in mind that alfalfa must be inoculated with rhizobium. And also legumes would need at least a basic nitrogen availability at the earliest growth stages, before, together with their symbionts, they can provide their own nitrogen for growth.

Phacelia *(Phacelia tanacetifiolia)*

Phacelia is a quick growing annual green manure that germinates already at low temperature and has low nutrient requirements. It consumes less water than alfalfa, and is well able to harvest water from dew (own observation during the dry autumn of 2018). To my knowledge, it has not been tested yet in Mongolia.

Pea *(Pisum sativum)*

Like alfalfa, pea is a legume, but it is an annual crop and can thus be well included in the crop rotation. And just like other legumes, pea mobilizes phosphorus from soil much better than cereal crops. Thus, it improves not only the nitrogen availability in the soil, but also that of other nutrients. A general problem of legumes is that the nitrogen fixation is quite an energy demanding process, and thus legumes need to deliver large amounts of their photosynthates to their roots. Therefore, legumes generally require relatively much water. Nevertheless, field pea plays an important role in crop rotations on the Canadian prairies *(Johnston et al., 2002)*, particularly in conservation tillage *(Lafond et al., 2006)*. According

to own observations, peas are growing well in the dry steppe of Kazakhstan and southwestern Siberia. As the drought sensitivity of peas is not as high at early vegetative stages as at the reproductive phase, the precipitation maximum in Mongolia in July and in September is quite favourable for pea cultivation, despite the generally dry climate.

Lentil *(Lens culinaris)*

To my knowledge, lentils are currently not grown in Mongolia. However, in the dry steppes of Kazakhstan and southwestern Siberia lentils are grown successfully (own observation), while Canada is the major producer of lentils *(Bueckert and Clarke, 2013)*. The major climate constraints of lentil production are a short growing season and cool, wet end-of-season conditions, which can delay maturity in this crop. However, in Canada cultivars have been released that show a shift to medium (105 d) and medium-late (105 to 110 d) maturity for a higher yield potential via a slightly longer reproductive duration, along with an improvement in yield for small-seeded lentil *(Bueckert and Clarke, 2013)*. This might be long enough at least for some agricultural areas in Mongolia. Further, there are several lentil genotypes that have been identified as promising drought-tolerant genotypes *(Biju et al., 2018)*. Gan et al. (2017) compared the agroecosystem productivity of a wheat - lentil - durum system with that of a wheat - summer fallow - durum system in semi-arid Saskatchewan. The lentil system increased the total grain production over the summer fallow system through the access of residual soil water and biological fixed nitrogen. Often, lentils are planted with other crops that provide a supporting function.

4.3.2. CONVENTIONAL CROPS

Wheat *(Triticum aestivum)*

Wheat is dominating the arable production in Mongolia, with occupying almost 70 % of arable land *(Baast and Bartseren, 2019)*. Due to harsh winters, in Mongolia exclusively spring wheat is grown. First successful attempts have already been made with winter wheat in southern Siberia, and it is regarded as a promising option in Kazakhstan *(Broka et al., 2016)*, due to significantly warmer and shorter winters with a higher snow pack. Since in Mongolia the winters are much drier with no or only very thin snow pack, even in the future with a predicted higher winter precipitation, winter wheat will continue to be no option.

Canola *(Brassica sp.)*

The Brassica napus canola production strongly increased in recent years (Baast and Bartseren, 2019) to satisfy the local vegetable oil demand. This is a trend that can be seen all over the world and also in Canada, which is partly due to the increasing global demand for biofuels. B. napus is grown pretty well in Mongolia, though it must be considered that the nitrogen demand of this crop is quite high and a compensation fertilization is necessary in the long run.

In Canada, B. juncea canola has recently been introduced. This species is well-suited to a short vegetation season and dry climate. A longer flowering duration enables the crop to set successive flushes of flowers, a strategy that a crop uses to abort flowers in adverse weather and set yield when weather conditions improve *(Berger et al., 2006)*. This matched phenology to water availability likely causes a greater drought tolerance of B. juncea. Even though the yield potential of B. juncea is not as uniform as that of B. napus over different sets of environmental conditions *(Gan et al., 2007)*, this strategy appears to be advantageous in the Mongolian climate.

Barley *(Hordeum vulgare)*

Spring barley is grown in Mongolia, albeit only on a limited area. It is one of the most suitable crops in Mongolia and cultivation has increased in the past *(Bachmann and Friedrich, 2003)*. Spring barley is more resistant to drought than wheat and also gives a high yield. According to Bachmann and Friedrich (2003), there is a need for locally produced malting barley for the relatively large local brewing industry. Spring barley is less demanding than spring wheat with regard to the site conditions, but it cannot be grown as monoculture with the same success.

Durum *(Triticum durum)*

Durum is also barely cultivated in Mongolia, despite of its great drought resistance. In Kazakhstan, durum is quite frequently grown on the border of the agricultural zone towards the semi-desert with annual precipitations of 200-250 mm. In these areas (e. g. in the south of Kostanay Oblast) the annual harvest of durum of approx. 6-8 dt ha^{-1} is very small. But the quality is extraordinarily good, so that according to the information of the local enterprises very high prices can be achieved. Due to the low crop yields, the soils' nutrient supply in this area is stable even without fertilization.

In Canada, modern cultivars such as Strongfield appear to be particularly competitive crops under dry conditions. This cultivar is well adapted to the driest areas of the Canadian prairies, the Brown and dry Brown soil zones, areas that had for a long time been considered to be not suitable for arable land use *(Bueckert and Clarke, 2013)*. In addition to its superior performance in water stress, its grain quality meets strict protein and quality criteria *(Clarke et al., 2006)*. This crop is worth testing in Mongolia.

Other crops

Other alternative crops to be cultivated in Mongolia are flax, maize, sunflower, and buckwheat. Since they have already been discussed in the report of Tobias Meinel, they are not presented again here.

Alternative crop rotations

The establishment of a more complex crop rotation in Mongolian agriculture than bare fallow – wheat or bare fallow – canola – wheat is of utmost importance to stop humus depletion and soil degradation. Although it is challenging under the climatic conditions of Mongolia, the incorporation of legumes, either as cash crop (pea, lentil) or as intermediate crop and for livestock feed (pea/lentil including underplanting as supporting crops, alfalfa in pure stand or in mixtures with grasses), is a prerequisite for improving the soil structure, the soil nutrient contents and the humus status of the soil.
Depending on the climatic conditions, agronomic structure of the farm and surrounding area, and the market situation, the following crop rotations may be possible:

a) Cash crops

Pea / lentil - spring wheat - spring barley
Pea / lentil - spring wheat - durum
Pea / lentil - spring wheat - flax - spring wheat / spring barley / durum

Also buckwheat, and if climatic conditions allow, millet can be grown as subsequent crop of spring wheat.

b) Inclusion of potato for the local market

Pea / lentil - potato - spring wheat

c) Crop production on farms with livestock

Intermediate crops [incl. legumes, annual or perennial (alfalfa)] - potato - spring wheat
Intermediate crops [incl. legumes, annual or perennial (alfalfa)] - spring wheat - spring barley
Pea - maize - spring wheat (strong focus on feed production)

With the omission of bare fallow, control of weeds is more challenging. A chemical treatment with glyphosate is necessary. However, weeds are also suppressed by intermediate crops and oilseeds.

4.4. FERTILIZATION

Besides the low precipitation and the short vegetation period, low nutrient supply may limit agricultural production in Mongolia. As is described by Baast (2016) and Baast and Bartseren (2019), Mongolian arable soils suffer from multiple nutrient deficiencies. Nitrogen is sufficient in 40 % of the arable soils, and for phosphorus and potassium the numbers are 23 % and 12 % only. The potassium deficiency in 88 % of the soils is particularly relevant, as potassium improves the water uptake of the roots by specifically transporting the water into the central cylinder and plays a decisive role in the distribution of nutrients within the plant *(Marschner, 1986)*. In addition, most of the soils are depleted of soil organic matter and, therefore, the capacity to provide available nutrients by microbial mineralization of the organic matter is limited.

Interestingly, not nitrogen appears to be the most problematic nutrient, but phosphorus and potassium. I do not know whether farmers focus on a fertilization with nitrogen only and do not consider the other elements to that extent. But one reason for the problems with the low availability of phosphorus and potassium is the high soil pH, with 42 % being neutral and 55 % being slightly to strongly alkaline. In such pH conditions, the availability of phosphorus is low due to the formation of Ca-phosphates. Likewise, available potassium is low due to the very low silicate weathering and associated small release of potassium at neutral and slightly alkaline pH values. No information is obtainable on the micronutrient content. However, metals like copper, zinc, and manganese are barely soluble at this high pH, and even stronger deficiencies in Mongolian soils than in Kazakh soils can be expected due to the higher mean pH values of the former ones. If available, farmers should therefore use physiologically acidic fertilizers, e. g. urea and ammonia fertilizers. Ammonium sulfate fertilizers are particularly efficient, and they provide also sulfate, an element which is also likely to be deficient.

A problem with fertilization is that - like in Kazakhstan - most of the farmers do not know about the nutritional status of their soils. But this is a prerequisite for the identification of the elements with which fertilization has to be performed and of the fertilizer rates. Hence, a survey of the nutritional status of the farmers' fields is necessary. This can be done at three levels, each with different costs, investment of time, and accuracy of the result. For the analysis of nitrate, the easiest option is a hand-held reflectometer using test strips or test disks. Several types are available on the market; e. g. Hach nitrate-nitrite test kit model NI-12, RQflex® 20 Reflectoquant® which provides quite useful results. More demanding in terms of investment and skills by the farmer, but also more accurate in terms of the results, is an instrument based on capillary electrophoresis on a microfluidic chip (such as iMETOS MobiLab). But these instruments mostly focus on the different nitrogen forms NO_3-, NO_2- and NH_4+ (only NO_3- is relevant in these high pH soils). For an accurate analysis of these ions, the other macronutrients, and particularly the micronutrients, well equipped soil test laboratories are necessary with trained staff who works according to standardized procedures.

The next problem then is the translation of the measured nutrient contents and the calculated nutrient stocks into a recommendation for the rate of fertilization. Unfortunately, due to the completely different climatic conditions, the recommendations given by the German Landwirtschaftliche Untersuchungs- und Forschungsanstalten (**LUFA**) might not work in Mongolia. Instead, recommendations developed for Canadian dry and cold areas are suggested, as provided by the Government of Saskatchewan *(https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients)*.

But even the best soil analysis can only be as good as the sampling. In contrast to the flat and homogenous landscapes of the Kulunda steppe and in large areas of northern Kazakhstan, most arable soils in Mongolia are located in a hilly landscape. Often parts of a field are located in upslope positions, while others are located at the bottom of the slope. From own investigations in the Khakassian steppe (southern Krasnoyarsk Krai in Russia) I know that under such conditions the soil variability can be very large. Hence, soil sampling for nutrient analysis must comply with this heterogeneity. Meanwhile we know that the subsoil is also important for the nutrient acquisition of arable plants *(Kautz et al., 2013)*, so it is advisable to sample and analyze the soil down to a depth of at least 60 cm.

Though an increasing nutrient availability can be achieved by mineral fertilization only, it is advisable to use also intermediate crops for improving the soil fertility and to include them into crop rotation. As outlined in chapter 4.2, particularly legumes or mixtures containing legumes are well suited to increase the soils' content in plant-available nitrogen, phosphorus, and potassium (and likely also other elements), which will be available for the following crop and will reduce the need of mineral fertilization. Together with the conservation technologies in soil tillage, seeding, fertilization, and harvesting, the introduction of intermediate crops and the adjusted fertilization are expected to increase not only the crop yield but also the soil organic carbon content by a higher crop residue input to the soil and a reduced soil organic matter mineralization.

As beneficial as this is, there is one disadvantage associated with the build-up of the humus stock. In a degrading soil, organic matter is net mineralized and the mined nutrients are provided to the crops. In contrast, in an aggrading soil, the build-up of soil organic matter requires additional nitrogen. Let us consider the following intellectual game: If the transformation of a conventional cropping system into conservation cropping increases the soil organic carbon stocks from 50 t ha^{-1} by 20 % to 60 t ha^{-1}, not only carbon is sequestered in the soil organic matter but also nitrogen (and phosphorus and sulfur). At a typical carbon-to-nitrogen ratio in arable soils of 12, these additional 10 t of carbon ha^{-1} translate to 833 kg nitrogen ha^{-1} which must be immobilized by soil microorganisms and stored in the soil as organic nitrogen. Thus, the transformation into a fertile and organic matter accumulating soil definitively needs a high investment into fertilizers, as even the legumes in intermediate crops cannot account for that completely. It is also clear that for a certain period of time the nitrogen uptake efficiency will decrease after the transformation to conservation agriculture. But once a new steady state equilibrium of the soil organic matter contents is reached, the annual net mineralization rate of nitrogen (and of phosphorous and sulfur) will be higher than before as more organic matter is in the soil, which is turning over.

CONCLUDING REMARKS

The largest challenge in Mongolian arable land use is the reduction of bare fallow. Bare fallow has been used in the past for nutrient mining, particularly for nitrogen. As this is the main reason for humus depletion and soil degradation, the bare fallow regime is not sustainable. Another reason for bare fallow is water harvesting. However, in many areas worldwide, bare fallow does not have an advantage with respect to water saving, even if that still has to be tested in Mongolia. Phytosanitary control is easier to handle when bare fallow is included in crop rotation. But even under this aspect, involving legumes as cash crops or as intermediate crops in crop rotation will help to control pests. It is clear that growing these legumes in Mongolia is challenging due to the low water supply and the short vegetation period. As the main rainy period in Mongolia is pretty late (July, August), those crops and varieties are advantageous as they can respond flexibly to a varying water supply or have their highest water needs at later stages of the vegetation period. This holds also true for other crops. The inclusion of legumes and alternative grain crops to spring wheat, such as spring barley and durum, provide a chance of a more diversified crop rotation. Also flax, sunflower, and buckwheat are options. In recent years, there has been success in breeding many crops to be more drought-tolerant and more adapted to the growing conditions in Mongolia. Climate change will increase the vegetation period, but it is not clear whether summer will become moister in Mongolia, like in large areas of the neighbouring Kazakhstan, or not.

Shifting towards conservation agriculture is mandatory for water-saving agriculture. This is important with respect to keeping the crop residues as mulch on the soil, which is enabled, for instance, by direct seeding or strip tillage techniques. This is thoroughly discussed in the report of Tobias Meinel, as well as optimum seeding and harvesting technologies.

The third measure of optimization concerns fertilization. A good nutrient supply of plants is, together with the water supply, mandatory for a high productivity of the crops. This increases the yield, but also the return of crop residues to the soil is larger. Along with a decreasing nutrient mining by microorganisms, this, in turn, increases the soil humus contents with all the positive aspects linked to that. In the long run, the nutrient losses with the crop export must be compensated for with mineral fertilization. Nitrogen fixation by legumes and non-symbiotic nitrogen-fixing bacteria as well as the nutrient flow with mineral weathering should be considered. But knowledge of the soils' nutrient status is without alternative.

Finally, it would be wise to overcome the separation of crop and livestock production. While intermediate crops (legumes) can significantly contribute to the diet of livestock, a nutrient return with the farmyard manure will increase soil fertility. However, suitable storage, handling, and application methods need to be introduced.
The transformation towards conservation agriculture considering all these issues needs activities and investments, at the farm level but also at the administrative / state level.

The following points seem to be important:

a) Education and further education of farmers

Farmers need to get educated in new agricultural technologies, including equipment and arable farming techniques. Fundamental information about it is important. Workshops offered by extension service providers on site are advantageous. In Kazahkstan, good experiences have been made with Deutsches Agrarzentrum Kasachstan (**DAZ**).

Farmers often do not trust scientists and people from administration. With this respect, positive examples are very useful. In the framework of the **KULUNDA** and **ReKKS** projects, field days were organized at farms which are very successful in practicing conservation agriculture and producing high yields. Such lighthouse farms can be a perfect nucleus for spreading knowledge.

b) Soil test laboratories

Farmers do need to have access to fast, reliable, and affordable analysis facilities for their soils and crops. The State University of Agriculture in Darkhan and the Mongolian University of Life Sciences cannot fulfil this task. At best, a state-owned or state-controlled network of laboratories in the agronomic core areas of Mongolia should be established. It is mandatory that the staff receives a proper training.

c) Performance of long-term agricultural experiments on new crop rations and fertilization

Long-running agricultural experiments may be carefully transformed to comply with sustainable concepts of crop rotation, fertilization, and modern agricultural equipment, and potentially new experiments can be established in the different crop growing areas. From our experience in southwestern Siberia and Kazakhstan, also innovative local farmers are interested in such experiments and perform them on their own fields. This saves costs, provides equipment, and such on-site agricultural experiments are often more realistic than those on experimental stations.

d) Political actions

Mongolian policy has already addressed a clear goal towards conservation agriculture. But it needs to be considered that this requires huge investments by the farmer for agricultural equipment, fertilizers, herbicides and seeds. An easy credit system with affordable interest rates can help, but likely also subventions are necessary. Successful farmers who can show that they increase the carbon stocks in their soil may participate in the local and global emission trading and establish a second source of income. It is very likely that carbon trading will get more important in the future.

REFERENCES

Ad-hoc-Arbeitsgruppe Boden (2005) Bodenkundliche Kartieranleitung, 5. Auflage. Bundesanstalt für Geowissenschaften und Rohstoffe (ed.) Schweizerbart, Stuttgart.

Akshalov KA et al (2013) Tekhnologiia priamogo poseva kul'tury rapsa effektivnost' preimushchestva [The technology of direct seeding of rapeseed crops efficiency advantages]. In: Conference 01.08.-01.08.2013: Diversification of crops and zero technologies in arid regions. Scientific and Production Center of Grain Farming A.I. Baraeva, Shortandy. [in Russian]

Baast E. (2016) Beschreibung und Bewertung des mongolischen Agrarsektors unter besonderer Berücksichtigung der Schwerpunktthemen des DMKNL. Deutsch-Mongolisches Kooperationsprojekt Nachhaltige Landwirtschaft, unpublished.

Baast E., Bartseren N. (2019) Der mongolische Ackerbau im Überblick – natürliche, agrarpolitische und institutionelle Rahmenbedingungen. Deutsch-Mongolisches Kooperationsprojekt Nachhaltige Landwirtschaft, unpublished.

Bachmann T.L., Friedrich T. (2003) Conservation agriculture in Mongolia. Working paper.

Baldock J.A., Nelson P.N. (2000) Soil organic matter. In: Sumner ME (ed) Handbook of Soil Science. CRC Press, Boca Raton, p. B-25-B-84.

Baraev A.I. (1988) Selected works. Soil-protective agriculture. Moscow. (in Russian).

Belyayev V.I. (2014) Ecologic, economic and technological bases of sustainable agriculture in the Kulunda Steppe of the Altai region. In: Digest of the International scientific-practical conference Environmental and Economic Strategies for Sustainable Land Use in the Steppes of Eurasia under the Conditions of Global Climate Change. Barnaul, p. 65-67.

Belyaev V.I. et al. (2020a) Modernization of current agricultural technologies of grain production under the conditions of a steppe zone of the Altai region. In: Frühauf et al. (eds.) Kulunda: Climate Smart Agriculture. Springer Nature Switzerland, p. 341-354.

Belyaev V.I. et al. (2020b) Autumn tillage, soil moisture content, and crop yields. In: Frühauf et al. (eds.) Kulunda: Climate Smart Agriculture. Springer Nature Switzerland, p. 355-366.

Belaev V.I., Volnov V.V. (2010) Resursosberegaiushchie tekhnologii vozdelyvaniia zernovykh kul'tur v Altaiskom Krae [Resource-saving technologies of cultivation of grain crops in the Altai Territory]. Barnaul. [in Russian]

Berger et al. (2006) Genotype by environment studies demonstrate the critical role of phenology in adaptation of chickpea (Cicer arietinum L.) to high and low yielding environments in India. Field Crops Research 98, 230-244.

Biju S. et al. (2018) The use of infrared thermal imaging as a non-destructive screening tool for identifying drought-tolerant lentil genotypes. Plant Physiology & Biochemistry 127, 11-24.

Bischoff N. et al. (2016) Land-use change under different climatic conditions: Consequences for organic matter and microbial communities in Siberian steppe soils. Agriculture, Ecosystem & Environment 235, 253-264.

Bondarovich A.A. et al. (2020) Soil moisture and evapotranspiration. In: Frühauf et al. (eds.) Kulunda: Climate Smart Agriculture. Springer Nature Switzerland, p. 167-181.

Broka et al (2016) Kazakhstan – Agricultural sector risk assessment. World Bank Group Report Number 103076-KZ.

Bueckert R.A., Clarke J.M. (2013) Review: Annual crop adaption to abiotic stress on the Canadian prairies: Six case studies. Canadian Journal of Plant Science 93, 375-385.

Burney J.A. et al. (2010) Greenhouse gas mitigation by agricultural intensification. Proceedings of the National Academy of Sciences, USA 107, 12052-12057.

Choijamts A. et al. (2015) Stand der Fruchtbarkeit von Ackerböden in der Mongolei, Verbesserungsmöglichkeiten und Bedarf an Düngung. Beitrag zum Workshop Bodenschutz als Grundlage für nachhaltige Pflanzenproduktion, Deutsch-Mongolisches Kooperationsprojekt Nachhaltige Landwirtschaft, November 2015.

Christensen B.T. (1992) Physical separation of soil and organic matter in primary particle size and density separates. Advances in Soil Science 20, 1-90.

Clarke J.M. et al (2006) Registration of 'Strongfield' durum wheat. Crop Science 46, 2306-2307.

Cotrufo M.F. et al. (2015) Formation of soil organic matter via biochemical and physical pathways of litter mass loss. Nature Geoscience 8, 776-779.

Guo L.B., Gifford R.M. (2002) Soil organic carbon stocks and land use change: a meta analysis. Global Change Biology 8, 345-360.

Dagvadorj D. et al (2009) Mongolia Assessment Report on Climate Change 2009. Ministry of Nature, Environment and Tourism, Ulaanbaatar.

Elliott E.T. (1986) Aggregate structure and carbon, nitrogen, phosphorus in native and cultivated soils. Soil Science Society of America Journal 50, 627-633.

Elliott E.T. et al (1996): Modeling the measurable or measuring the modelable: A hierarchical approach to isolating meaningful soil organic matter fractionations. In: Powlson DS et al. (eds.) Evaluation of Soil Organic Matter Models Using Existing Long-Term Datasets. Springer, Berlin, p. 161-179.

Flach K.W. et al. (1997) Impacts of agriculture on atmospheric carbon dioxide. In: Paul EA et al. (eds.) Soil Organic Matter in Temperate Agroecosystems - Long-Term Experiments in North America. CRC Press, Boca Raton, p. 3-14.

Flessa H., Beese F. (1995) Effects of sugarbeet residues on soil redox potential and nitrous oxide emission. Soil Science Society of America Journal 59, 1044-1051.

Foley J.A. et al. (2005) Global consequences of land use. Science 309, 570-574.

Foster A. et al. (2013) Forage yield of simple and complex grass-legume mixtures under two management strategies. Canadian Journal of Plant Science 94, 41-50.

Frühauf M. et al. (2020) The Virgin Lands Campaign (1954-1963) until the breakdown of the former Soviet Union (FSU): With special focus on western Siberia. In: Frühauf et al. (eds.) Kulunda: Climate Smart

Agriculture. Springer Nature Switzerland, p. 101-118.
Gan Y. et al. (2007) Brassica juncea canola in the northern great plains: Responses to diverse environments and nitrogen fertilization. Agronomy Journal 99, 1208-1218.
Gan Y. et al. (2017) Lentil enhances agroecosystem productivity with increased residual soil water and nitrogen. Renewal Agriculture & Food Systems 32, 319-330.
Golchin A. at al. (1994) Soil structure and carbon cycling. Australian Journal of Soil Research 32, 1043-1068.
Gregorich E.G. et al. (1994) Towards a minimum data set to assess soil organic matter quality in agricultural soils. Canadian Journal of Soil Science 74, 367-385.
Guggenberger G. et al. (1999) Bacterial and fungal cell-wall residues in conventional and no-tillage agroecosystems. Soil Science Society of America Journal 63, 1188-1198.
Guggenberger G. et al. (2020) Interactive effects of land use and climate on soil organic carbon storage in western Siberian steppe soils. In: Frühauf et al. (eds.) Kulunda: Climate Smart Agriculture. Springer Nature Switzerland, p. 183-199.
Ivanova S., Nosov V. (2008) Development of agriculture in Russia and its influence on fertilizer consumption. International Plant Nutrition Institute. (http://eeca-en.ipni.net/article/EECAEN-2025).
Haider K., Schäffer A. (2000) Umwandlung und Abbau von Pflanzenschutzmitteln im Boden. Enke im Georg-Thieme-Verlag, Stuttgart.
Hedges J.I. et al. (2000) The molecularly-uncharacterized component of nonliving organic matter in natural environments. Organic Geochemistry 31, 945-958.
Hofman et al. (2016) Agriculture in Mongolia under pressure of agronomic nutrient imbalances and food security demands: A case study of stakeholder participation for future nutrient and water resource management. In: Borchardt D et al. (eds.) Integrated Water Resources Management: Concept, Research and Implementation. Springer International Publishing Switzerland, p. 471-514.
Hornbeck R. (2012) The enduring impact of the American dust bowl: short- and long-run adjustments to environmental catastrophe. American Economic Review 102, 1477-1507.
Illies T. (2012) Studie zu nachhaltigen und standortangepassten Anbauverfahren in der Mongolei in Kooperation mit der Nationalen Agraruniversität in Ulan Bator. Im Auftrag des Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz. Manuskript.
Kazstat (2003) Respublika Kazakhstan: 50 let nachala Tselinnoi kompanii (1953–2002) [Republic of Kazakhstan: 50 years of the Virgin Lands Campaign (1953–2002)]. Agency of Kazakhstan on Statistics, Almaty
Körschens M. (1998) Sustainable land use - long-term RSOM behaviour as observed in long-term field experiments. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft 87, 93-105.
Körschens M., Pfefferkorn A. (1998) Bad Lauchstädt – Der Statische Düngungsversuch und andere Dauerfeldversuche. UFZ-Umweltforschungszentrum Leipzig-Halle GmbH.
Jacobs A. et al. (2018) Landwirtschaftlich genutzte Böden in Deutschland – Ergebnisse der Bodenzustandserhebung. Johann Heinrich Thünen-Institute (ed.) Thünen Report 64.
Jefferson P.G. et al. (2007) Performance of short-lived perennial grasses grown with and without alfalfa at a semiarid location in southern Saskatchewan. Canadian Journal of Plant Science 87, 59-65.
Jin J. et al. (2015) Phosphorous application and elevated CO2 enhance drought tolerance in field pea grown in a phosphorus-deficient vertisol. Annals of Botany 116, 975-985.
Johnston A.M. et al. (2002) Field pea seeding management. Canadian Journal of Plant Science 82, 639-644.
Kaiser K., Guggenberger G. (2000) The role of DOM sorption to mineral surfaces in the preservation of organic matter in soils. Organic Geochemistry 31, 711-725.
Kamp J. et al. (2015) Agricultural development and the conservation of avian biodiversity on the Eurasian steppes: a comparison of land-sparing and land-sharing approaches. Journal of Applied Ecology 52,1578–1587.
Kämpf I. et al. (2016) Potential of temperate agricultural soils for carbon sequestration: a meta-analysis of land-use effects. Science of the Total Environment 566-567, 428-435.
Kauz et al. (2013) Nutrient acquisition from arable subsoils in temperate climates: A review. Soil Biology & Biochemistry 57, 1003-1022.
Kögel-Knabner I. (1993) Biodegradation and humification processes in forest soils. In: Bollag J-M, Stotzky G (eds.) Soil Biochemistry. Volume 8. Marcel Dekker, New York, p. 101-137.
Kurganova I. et al. (2014) Carbon cost of collective farming collapse in Russia. Global Change Biology 20, 938-947.
Lafond G.P. et al. (2006) Effects of tillage systems and rotations on crop production for a thin black Chernozem in the Canadian Prairies. Soil & Tillage Research 89, 232-245.
Laganière J. et al. (2010) Carbon accumulation in agricultural soils after afforestation: a meta-analysis. Global Change Biology 16, 439–453.
Mao X. et al. (2018) Application of molybdenum fertilizer enhanced quality and production of alfalfa in northern China under non-irrigated conditions. Journal of Plant Nutrition 41, 1009-1019.
Marschner H. (1986) Mineral Nutrition of Higher Plants. Academic Press, London.
Merbach W., Körschens M. (1999) Dauerdüngungsversuche als Grundlage für nachhaltige Landnutzung und Quantifizierung von Stoffkreisläufen. UFZ-Bericht 24/1999. UFZ - Umweltforschungszentrum Leipzig-Halle GmbH.
Myamtsere M. et al. (2018) A comparative study of temperature and precipitation-based aridity indices and their trends in Mongolia. International Journal of Environmental Research 12, 887-899.
Oades J.M. (1993) The role of biology in the formation, stabilization and degradation of soil structure. Geoderma 56, 377-400.
Oades J.M. (1984) Soil organic matter and structural stability: mechanisms and implications for management. Plant & Soil 76, 319-337.
Ogle S.M. et al. (2005) Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry 72, 87-121.
Paul et al. (eds.) (1996) Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America. CRC Press.
Paustian K. et al. (1997): Management controls on soil carbon. In: Paul EA et al. (eds.) Soil Organic Matter in Temperate Agroecosystems - Long-Term Experiments in North America. CRC Press, Boca Raton, p. 15-50.
Paustian et al. (2016) Climate-smart soils. Nature 532, 49-57.
Pihlap E. et al. (2019) Initial soil formation in an agricultural reclaimed open-cast mining area – the role of management and loess parent material. Soil & Tillage Research 191, 224-237.
Poeplau C. et al. (2011) Temporal dynamics of soil organic carbon after land-use change in the temperate zone–carbon response functions as a model approach. Global Change Biology 17, 2415-2427.
Radovic J. et al. (2009) Alfalfa – most important perennial forage legume in animal husbandry. Biotechnology in Animal Husbandry 25, 465-475.
Sauerbeck D. (1992) Die Funktionen und Bedeutung der organischen Substanzen für die Bodenfruchtbarkeit - ein Überblick. Berichte über Landwirtschaft. Band 4: Humushaushalt. Paul Parey, S. 13-29.
Schmidt M.W.I. et al. (2011) Persistence of soil organic matter as an ecosystem property. Nature 478, 49-56.
Six J. et al. (1998) Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Science Society of America Journal 62, 1367-1375.
Six J. et al. (2002) Soil organic matter, biota and aggregation in temperate and tropical soils – effects of no-tillage. Agronomie 22, 755-775.
Waksman S.A. (1938) Humus: Origin, Chemical Composition and Importance in Nature. Baillière, Tindall and Cox, London.
Willumsen J., Thorup-Kristensen K. (2001) Effects of green manure crops on soil mineral nitrogen available for organic production of onion and white cabbage in two contrasting years. Biological Agriculture & Horticulture 18, 365-384.
Zamba B. (ed.) (2018) Mongolia Third National Communication Under the United Nations Framework Convention on Climate Change. The Ministry of Environment and Tourism, Mongolia.
Zech W. et al. (1997) Chemical control of soil organic matter dynamics in the tropics. Geoderma 79, 117-161.

SUSTAINABLE FARMING ALTERNATIVES IN MONGOLIA UNDER CHANGING CLIMATE CONDITIONS

Authored by:

***Prof. Dr.* Meinel T.**
"Amazonen-Werke" LLC of Germany
Branch Director in Kazakhstan

CONTENTS

INTRODUCTION

On a global scale, the Eurasian steppe, including the Mongolian grassland, represents the largest, almost entirely coherent farmland for arable crops. The western extension with the Black-Earth areas of Russia and Ukraine are still rather similar to central Europe with regard to the crops (winter/summer crops) and the agroclimatic farming conditions. As a consequence, comparable farming systems can be found in a modified form in these regions. The Ural Mountains represent a natural barrier. With the increasing continentality towards the east, the climate conditions and, therefore, the requirements for crop farming are changing as well. Due to the low amounts of snow and harsh frosts, it is almost impossible to cultivate winter crops. The vegetation period is significantly shorter and annual precipitation continues to decrease. In addition to the decreasing precipitation at this parallel of latitude, increased dryness also occurs further towards the south due to the varying degrees of evapotranspiration. These conditions (naturally in combination with the soil-forming substrate) are reflected in the open landscapes in the form of the respective steppe types (forest steppe, typical steppe, dry steppe). There is no significant land feature between the Ural and Altai Mountains. Following the steppe structure, the land is used for agricultural purposes more or less intensively. While the forest steppe around the 55th parallel of latitude has been used for farming for 150 years already, the intensive southwards expansion of arable land did not take place until the middle of the last century as a part of the Virgin Lands campaign (see below).

The Mongolian steppe plays a special role in this context. Firstly, it is located at a much higher altitude than the grasslands of southern Siberia and Kazakhstan (200-400 m above sea level) and, secondly, the ranges of the Altai and Sayan Mountains in Russia and Mongolia cause a distinct windward-leeward effect resulting in small amounts of precipitation carried over from the west to reach central Mongolia. Therefore, the arable lands in northern Mongolia experience even less precipitation and lower accumulated temperatures than the agricultural dry steppe in Kazakhstan or southern Siberia (see Fig. 1). Moreover, the distribution of precipitation is influenced by more continental factors. This means that from the west almost no fronts carrying rain reach the land. Precipitation is almost entirely of a convective nature and therefore extremely variable.

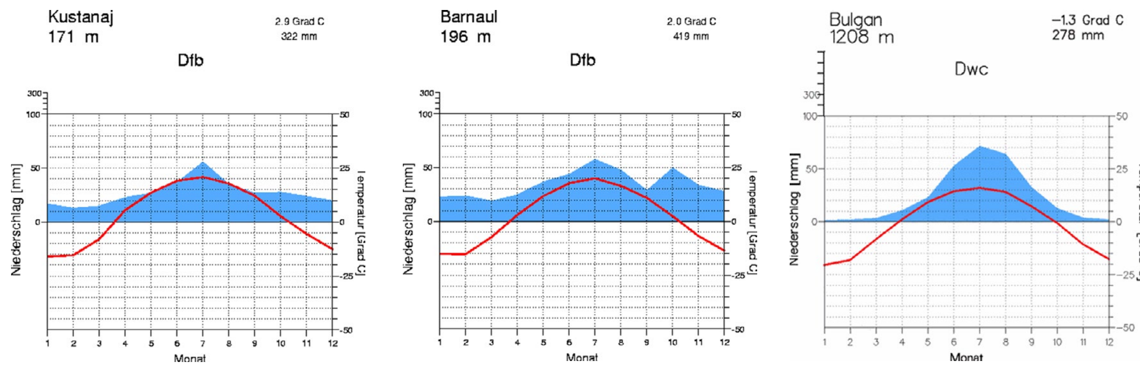


Figure 1: From left to right: Climate diagrams from Kostanay, Kazakhstan; Barnaul, southern Siberia; Bulgan, northern Mongolia. *(Source: Klimadiagramme 2019)*

Similar conditions, although not so extreme, can be found in the dry steppe of Kazakhstan and Siberia which are used for agricultural purposes as well. Since 2011, projects on sustainable crop farming funded by the German Federal Ministry of Education and Research have been conducted in these regions. **The KULUNDA** and **REKKS** projects pursue interdisciplinary approaches and are tasked with finding practical solutions for the farmers as well. This paper will introduce several methods and solutions which might possibly be applied under the agroclimatic conditions in Mongolia.

1. EFFECTS OF TILLAGE ON SOIL QUALITY AND THE SOIL MOISTURE REGIME IN SEMIARID STEPPE REGIONS

(KULUNDA and REKKS findings)

1.a Changes of the soil quality since the Virgin Lands campaign

In the years after World War II, the Soviet Union experienced a severe shortage of agricultural products, specifically grain. Aiming to solve this conundrum, the leadership of the former USSR Communist Party decided on the expansion of the grain acreage under cultivation in arid regions of the country in 1954 *(Wein, 1980)*. These activities became known as the "reclamation campaign" ("tselina"). Already in April 1954, two months after the decision of the reclamation campaign, plowing and seeding activities started. During the first year of the reclamation campaign 17.2 million hectares of so-far untouched steppe were tilled *(Geogriev, 1955)*.

Reclamation district	Area in million ha
Kazakhstan	25.5
Volga Region	1.5
Ural	4.5
West Siberia	6.2
East Siberia	4.2
Total Former USSR	**41.9**

Table 1: Distribution of the reclamation sites in former USSR. *(Source: Eule, 1962, p. 115)*.

The expansion of the acreage was continued in the steppes and dry steppes until 1960. During this period, altogether 41.8 million hectares of new acreage were plowed in southern Russia and Kazakhstan *(Eule, 1962; Wein, 1983)*. The largest portion of reclamation sites, accounting for 25.5 million hectares, is situated in Kazakhstan.

The target area of the reclamation campaign was the Eurasian steppe belt in an area of 300 mm precipitation p.a. with characteristic soil types such as southern Chernozems and Kastanozems (**Figure 2**). Typical for these dry steppe areas is not only the variability but also the lack of precipitation. Generally, precipitation mainly falls as convective rain during the summer in these high continental steppes *(Gugs, 1977)*.

During the vegetation period of the main cultivation spring wheat, only 140 mm of precipitation fall on long-term average *(Rostanowski, 1979)*. However, due to the high temperatures in the summer the potential evaporation exceeds by far the precipitation *(Gugs, 1977)*.

These basic agrometeorological data already offer an indication of the great risk with regard to the appearance of droughts and thus yield reduction. Precipitation amounts around 300 mm p.a. have been defined as drought in the Great Plains *(Späth, 1980)*, but

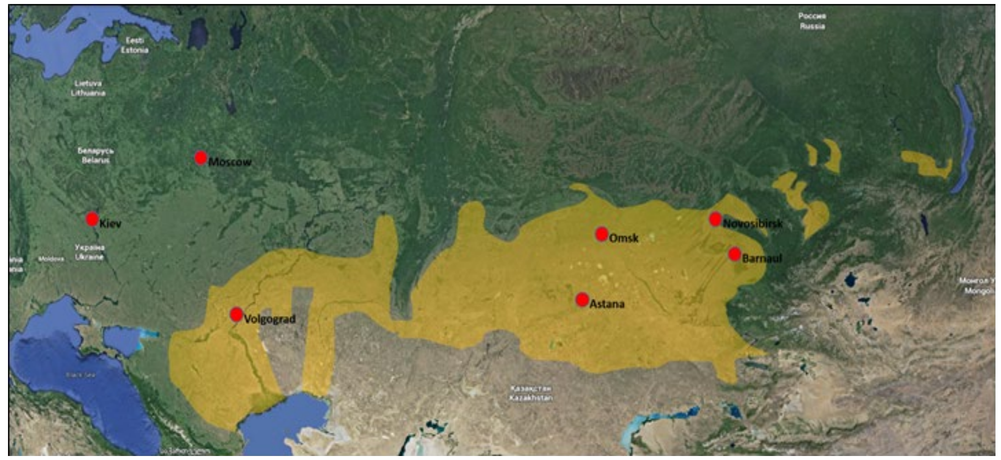


Figure 2: Target areas of the Russian site reclamation campaign. *(Source: Eule, 1962, modified)*.

these precipitation values are the long-term averages in the site reclamation areas of the former USSR.

Additionally, a further foreseeable risk at the time of the decision about the site reclamation campaign was the appearance of wind erosion. Devastating dust storms had already appeared in the reclaimed areas in 1956 *(Kostrowski, 1959)*. Every year 187.500 ha of reclaimed land were devastated by wind erosion prohibiting further agricultural cultivation of these sites. By 1963, 13 million ha, an equivalent of more than 30 percent of the total reclamation sites, were degraded by wind erosion resulting in noticeably lower soil productivity and yields *(Wein, 1983)*.

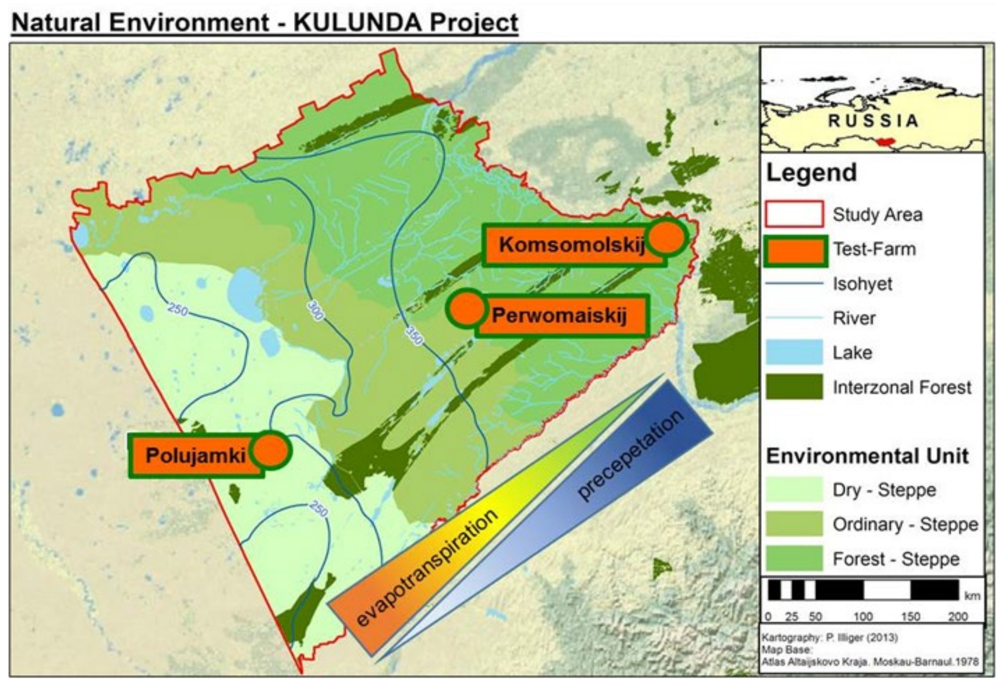


Figure 3: Natural characteristics of the Kulunda Steppe. *(Source: KULUNDA Project)*.

The Kulunda Steppe of the Altai region represents a characteristic part of the southwest Siberian steppe belt between the dominantly deciduous woodland zone as attached to the boreal coniferous forest zone and the south-east attached mountain area (**Figure 3**).

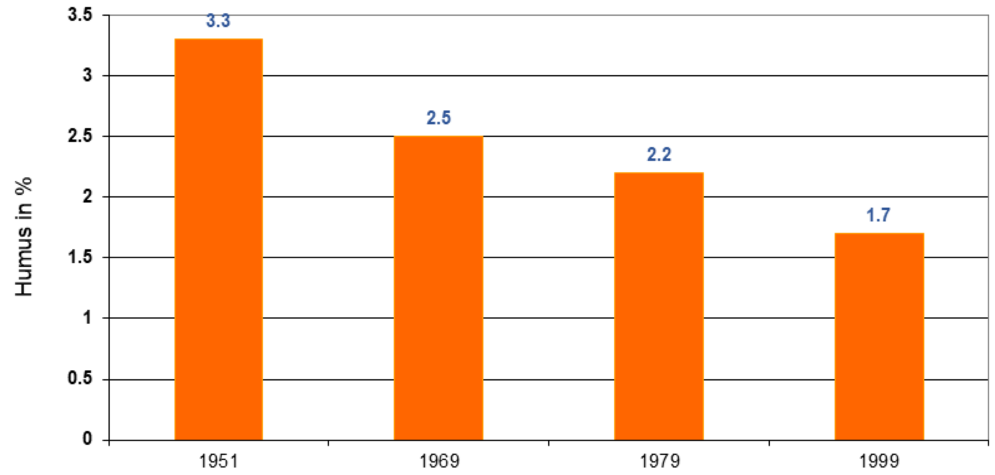


Figure 4: Average humus content in the tilled A-horizon (Kastanozem) of the Grishkovka kolkhoz. *(Sources: 1951 Investigation of the National Land Survey Office of the Altai Krai, 1969 Investigation of the GIPROSEM Institute/Barnaul, 1979 Investigation of the GIPROSEM Institute/Barnaul, 1999 author's investigations).*

Characteristics for the semi-arid and highly continental climate are great temperature amplitudes (-40 °C in winter and +35 °C in summer are not uncommon) as well as short vegetation periods. On average, the precipitation is only 250-400 mm per year. A high temporal and spatial variability is typical. Yet, during the last years, total annual precipitation revealed especially great fluctuations forming three to six-year periods of drought. Heavy convective rain occurs characteristically in the investigation region bringing up to 30-70 mm precipitation within a short time *(Gugs, 1977)*. The available water, which would be needed, evaporates relatively fast and/or can lead to corresponding opportunities for erosion processes by intense surface drainage.

Soil types in the study region follow a distinct differentiation from south-east to north-west as well as a hypsometric change of forms in the south-western direction. Southern Chernozems, attached to the typical Chernozems, are characterized by a lower humus content in the A-horizon and a generally shallower depth. In comparison to the nearby open forest steppe, precipitation and especially the occurrence of snow, are generally reduced in the central steppe leading to a lower biomass production and, hence, humus accumulation potential. This typical steppe is pedologically characterized by dark Kastanozems. Along with a further precipitation decline (approximately starting from 80° longitude) bright Kastanozems appear in the central Kulunda Steppe, holding humus content of 4 percent in the upper soil layer *(Fruehauf & Meinel, 2003)*.

According to research conducted mainly in the Great Plains of North America, the conversion of steppe to cultivated land results in an evident loss of humus and hence soil carbon within the tilled horizons *(Balesdent et al., 1988; Lal et al., 1995)*. This decline is in particular a result of enhanced mineralization of organic matter due to the change in soil

climatic conditions leading to a higher loss rate of greenhouse-relevant CO2 *(Mann, 1986)*. The reduction of soil carbon occurs principally during the initial years after cultivation. Houghton (1995) reported on a rather fast humus loss within the tilled A-horizon after cultivation, which reaches a certain steady level once the soil gains its micro-biological equilibrium again. The humus losses are quantified with values between 30-50 percent of the original natural content *(Burke et al., 1989; Lal et al., 1995)*. These estimates are in accord with our findings in the central Kulunda steppe. Organic matter content on a 50-year continuing research site (Kolkhoz Grishovka) revealed values of 1.7 percent corresponding to about 50 percent of the natural humus content in Siberian steppe soils (**Figure 4**).

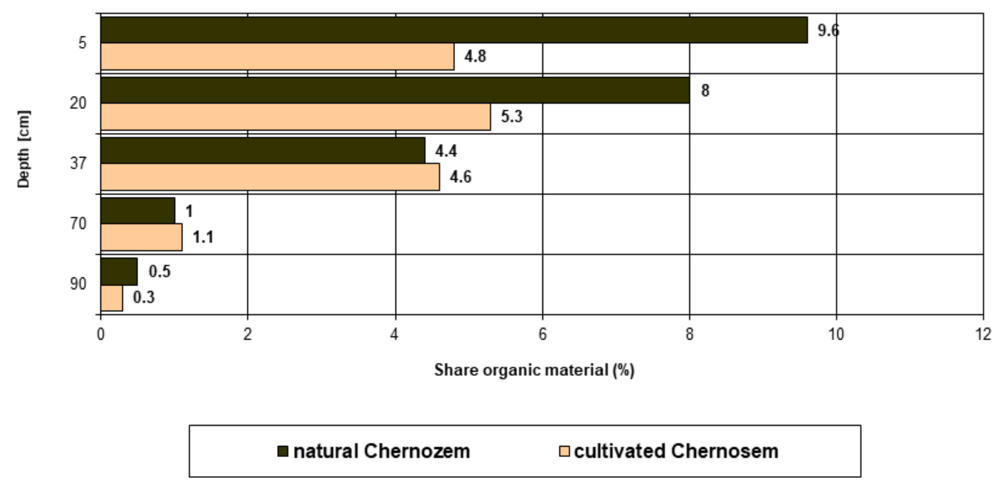


Figure 5: Comparison of the humus stocks of a "natural" and a cultivated Chernozem in the open forest steppe. *(Source: Own data)*.

Similar severe losses in humus stocks were observed on various sites of the study area comparing the natural steppe and cultivated land. Data elevation of organic matter content in the open forest steppe revealed a similar humus decline as shown for the central steppe. Yet those sites held a higher original humus content of 9.6 percent (**Figure 5**).

1.b Effects of wind erosion

Part of the humus was already lost directly due to wind erosion following soil tillage *(Burke, 1989)*. The lost material is frequently accumulated at sites near to the fields. These highly dynamic processes lead not only to soil degradation due to denudation or accumulation but also to an increasing differentiation of site-ecological parameters. The further influence of denudation and accumulation on organic matter mineralization is the subject of our current investigations.

Our field and laboratory research and the evaluation of available soil data (from the land surveying office of the Altai Krai, 1951 and Investigation of the GIPROSEM Institute/Barnaul (1969,1979)) substantiate the effects of wind erosion as a cause of the observed (irreversible) soil devastation, leading to yield decline as well as different documented on- and off-site damages in the study area. The resulting effects of the wind erosion are extremely polymorphic and show high temporal and spatial dynamics. This causes great problems in comparison to water erosion forms with respect to the collection and cartographical fixation of data *(Hassenpflug,1998)*. It was rarely possible to differentiate between spatial deflation and accumulation during the field studies. Specifically, the evidence for deflation events was already difficult for the reason of the homogenizing effect of the annual soil tillage, while soil accumulation could mostly be stated comparatively easily due to morphological methods, because dunes next to the street were observed. Air and satellite images, combined with terrestrial studies, revealed immense amounts of information about deflation-derived soil profile shortenings.

The following two examples demonstrate the characteristic effects of wind erosion on the soil:

1. Shortening of the plowed A-horizon:

Figure 6: Kastanozem damaged by deflation. *(Source: Own photo)*.

2. Accumulation in shelterbelts and at field borders:

Figure 7: Sand covering of fossil upper horizon. *(Source: Own photo)*.

The plowed horizon - especially on exposed sites with deflation - lost not only humic but also erosion-sensitive mineral soil. As demonstrated in **Figure 9**, the soil fraction between 0.01-0.05 mm (approximately coarse silt according to the German soil classification) is particularly affected. This selective deflation causes a rise in the clay and fine silt fraction as well as that of fine sand.

Furthermore, under these site-specific dry conditions different (smaller) soil fractions are affected as compared to more humid climates, where, dominantly, fine and middle sand are shifted due to wind erosion *(Morgan, 1986)*. According to present knowledge, the following factors are decisive for this circumstance:

The low precipitation and the comparatively high temperature cause a strong summer dryness up to a depth of approximately 7-10 cm. This is even more pronounced in field profiles. Caused by the form and frequency of the tillage, the drying process is more intense and far-reaching. Even under fallow conditions, the soil is tilled to an average depth of 24 cm up to four times a year. Under the comparatively dry conditions, this practice forced –the destruction of soil aggregates in many cases. An elevated risk

3. Accumulation of sand at field borders

Figure 8: Accumulation of (medium) sand after a wind erosion event May 20, 2000. *(Source: Own photo)*.

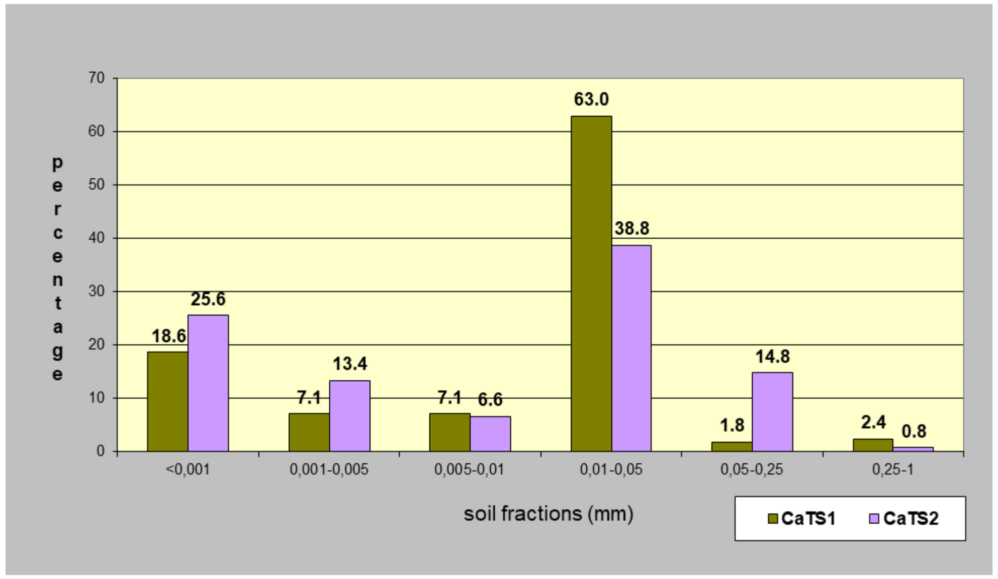


Figure 9: Selective loss in soil fractions within the plowed A-horizon of a cultivated Chernozem (CaTs2). *(Source: Own data)*.

of deflation, especially of the coarse silt fraction, is the consequence. Resulting from the changes in soil organic matter content and soil texture caused by land cultivation followed by erosion events, soil (micro-) biological, chemical and physical properties are influenced sustainably. Humic substances, together with clay minerals, form so-called „Clay-Mineral-Complexes“ which eventually lead to a decline of the soil erodibility *(Morgan, 1986)*. The loss of organic matter results in an elevated disposition of the affected sites to water and wind erosion.

The loss of organic matter influences the soil water budget and its dynamics. In this context, the utilizable field capacity can be discussed as a special parameter *(Scheffer et al., 1992)*. Under these site-specific conditions, as well as the high organic matter content in the topsoil, negative consequences can arise for deep rooting plants such as wheat. A high utilizable field capacity from spring until seeding time is, without a doubt, of great importance for the yield development as it keeps the snow-derived water in the ground and ensures the germination. On the other hand, a high water-budget capacity in the topsoil prevents precipitation from reaching beyond the topsoil to deeper soil horizons that are protected against evaporation and are thus available for a longer time (also with regard to capillary advancement).

Our data and field observations show that on natural as well as cultivated sites of semi-arid steppe, the available water budget represents the limiting factor for plant growth. Therefore, the collection of data regarding differences in the soil water budget between cultivated and natural steppe sites was of special interest. Different types and grades of degradation had to be investigated comparing natural Kastanozems and Chernozems regarding their specific budgets and the dynamics. This was achieved by using the method of soil-moisture measurement by time domain reflectometry, which was applied at different soil depths combined with precipitation quantification.

For the first time, the soil water dynamics were determined in the south Siberian steppe belt with daily data readings at different depths (20, 40, 60 and 80 cm) comparing natural and cultivated sites. The process of freezing in fall and thawing in spring could also be included in the investigation. The measurements were carried out continuously during the complete vegetation period of 2002 and 2003 (**Figure 10**), as well as by parallel recordings of the precipitation in immediate neighborhoods of the research plots.

The soil water data reveal the water budget up to 1 m deep. After the thaw up to the next greater precipitation event, a lower water content was found at natural sites overgrown with steppe grasses than on the cultivated fields. This effect can be explained by the relatively early need for water by the natural grass vegetation. This process usually begins later in the field because seeding normally takes place in the last ten days of May only. Furthermore, the fields are tilled once more right before sowing to ensure weed control. Therefore, the more intensive use of the soil water budget begins only at the end of June on the wheat cultivated sites. There are, however, already very high temperatures at that time so that a lot of water evaporates before it can be used by plants. The data show that the natural sites' water balance is positive compared to the tilled soil. Despite the water supply, the soil water content decreases faster in the cultivated area than in the natural soil. Shortly before harvest time (beginning of September), the water content of the field soil lies about 15 mm under that of the natural site. Despite the differences in the water level, it is interesting to see that both sites reach a steady state, which is not disturbed by heavy rainfall events, as occurred on September 2, 2002.

Feedback of agricultural production:

The decline of soil quality properties can also be seen in the long-term yield development, as it became clear due to the precipitation development since the site reclamation campaign started, shown here for the Grishkovka kolkhoz:

The diagram clarifies the naturally close relation (R^2 = 0.63) between precipitation and yield. Furthermore, the yield is, in tendency, negative, as the consistent precipitation trend. Considering the improvement of agricultural methods during the past 50 years, this development has to be assessed as even more dramatic. The tendency for declining yields must mainly be attributed to the decline in soil quality. Further, the influence of the political re-organization of the administrative structure since 1990/91 has to be taken

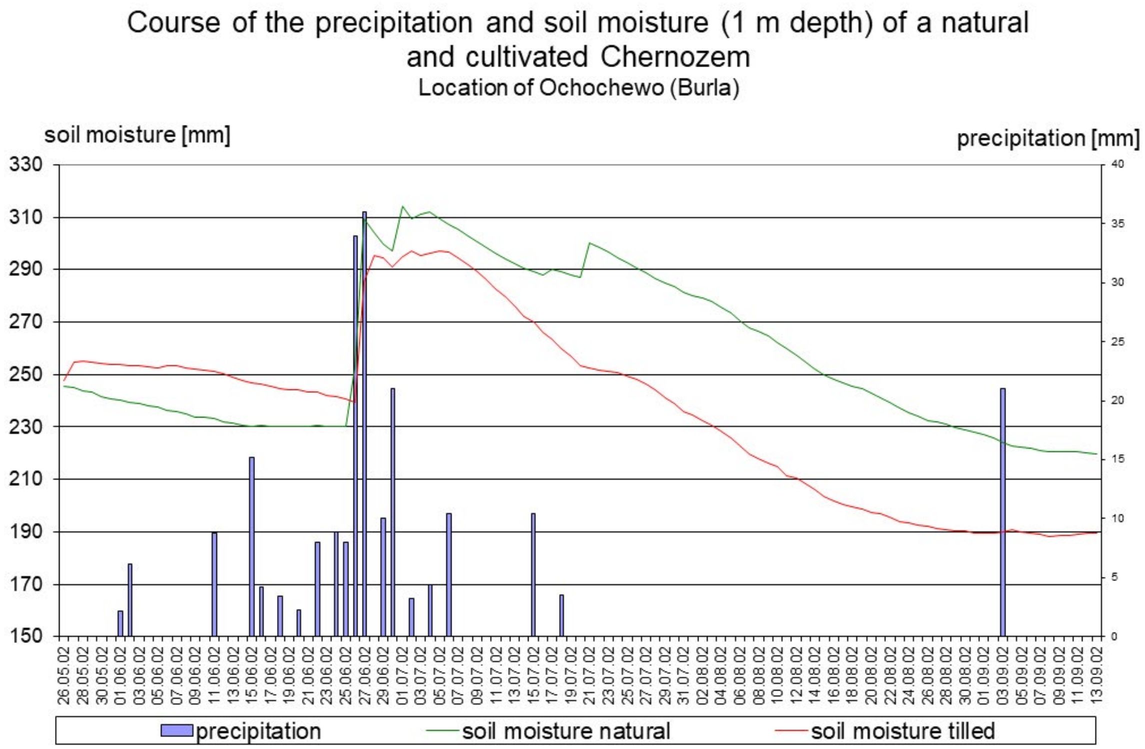


Figure 10: Soil water budget of a natural and cultivated Chernozem in summer 2002. *(Source: own data)*.

into account. The succeeding organizations of the former kolkhoz today achieve only a small financial surplus. Hence, calculating the costs of seeding and harvest, the financial resources are often depleted. Measures for stabilization or improvement of the soil quality can therefore hardly, or not at all, be carried out.

1.c Effects of black fallow

The long-term research within the framework of the **KULUNDA** project have shown that the use of black fallow represents the greatest threat to the soil in the study area. Firstly, the soil continues to be loosened so that the protective aggregates are destroyed which then leads to a high disposition of wind erosion. Secondly, the constant aeration of humus particles accelerates their mineralization. The processes were also observed in the study areas in Kazakhstan within the framework of the **REKKS** project. The challenge is now to develop a farming concept without fallow.

The farmers' frequently used argument of a fallow period being required for water conservation in the soil for the following year was disproved several times over the last few years *(Belajew, Frühauf, & Meinel 2006; Grunwald 2010)*. While water is indeed stored in the soil horizon until the next year, the amount is not as high as was previously assumed (**Figure 12**). The following figure shows that this procedure on average saves only 14 mm of precipitation annually. Obviously, this affects the yield, but it does not compensate for the crop loss during the fallow year.

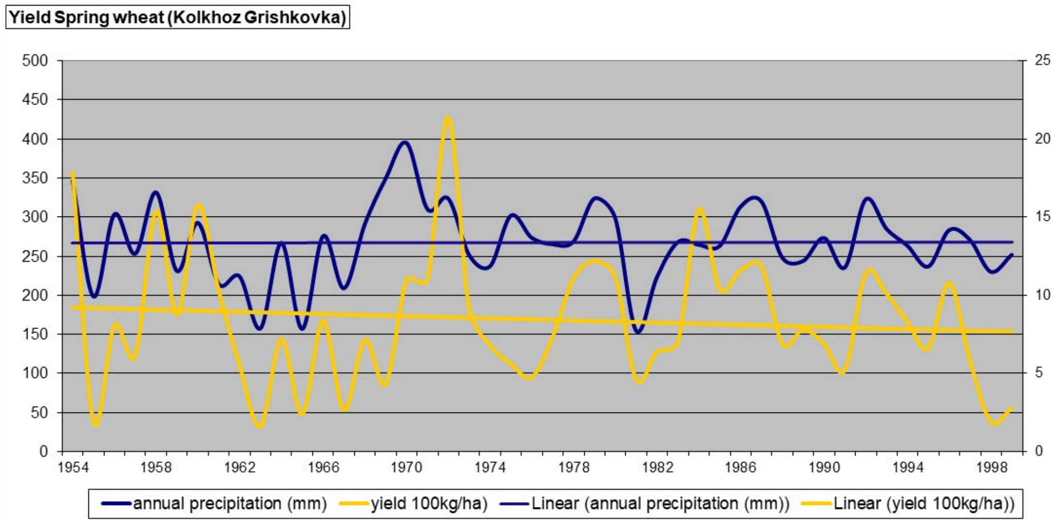


Figure 11: Yield per hectare and annual precipitation kolkhoz Grishkovka. *(Sources: Kolkhoz Grishkovka, 2000)*.

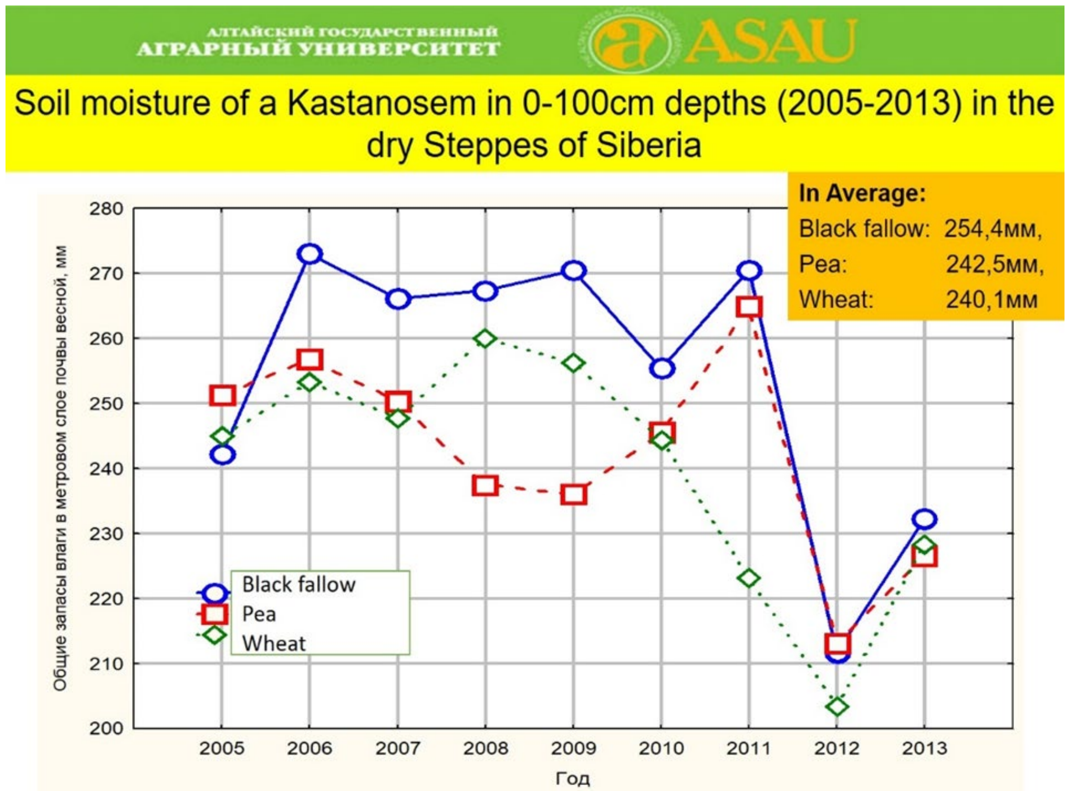


Figure 12: Soil moisture under various uses. *(Source: Belajew et al., 2014)*.

The increased yield in the year after the black fallow period is caused by other factors as well:

- Significant increase in nutrient values in the topsoil, particularly nitrogen *(Grunwald, 2010)*
- Finely worked topsoil and therefore good field emergence in the following year despite a bad seeding technology
- Less weed pressure
- Less disease infestation

All these positive effects of black fallow periods can also be achieved by using modern agronomic methods and appropriate agricultural engineering without losing a year's worth of yield and destroying the soil.

2. FUNDAMENTALS OF PROTECTION FROM SOIL DEGRADATION OF AGRICULTURAL STEPPE SOILS

2.a Protection from wind erosion

The protection from wind erosion in temperate grasslands follows relatively simple principles:

1. The more crop residue in the topsoil, the lower the erosion disposition
2. The more aggregated the soil structure, the lower the proneness to erosion
3. The smaller the field, the lower the threat of wind erosion

The first two points underline that black fallow periods bear an extremely high risk of wind erosion. The soil structure is characterized by fine crumbs and there is hardly any crop residue in the topsoil.

Examinations conducted for the **REKKS** project which used a specially developed wind generator have shown that wind erosion can be contained when using shallow tillage as well; for instance in fall (**Figure 13**). If tillage is considered to be expedient for agronomical reasons, the work should be executed in fall and as shallow as possible *(e.g. to fight perennial weeds)*.

Figure 13: Mobile wind generator to measure wind erosion. *(Source: G. Schmidt, 2019)*.

The results from the **KULUNDA** project show that erosion protection can be achieved by using shallow tillage. It is not mandatory to forgo tillage altogether and apply direct seeding.

The aforementioned third principle of the smallest possible field size is hardly applicable in the Asian steppe due to the massive areas involved. If the fields are smaller, the "soil avalanche" (saltation) is stopped and cannot achieve high speeds and, consequently causes only minor soil degradation.

The frequently recommended wind protection strips should be viewed critically. While they reduce wind speed at the soil surface, this effect is limited to a distance equal to seven times the height of the wind protection system at most *(Frank, 2005)*. With an average tree height of approximately 7 m, the field would only be protected for 50 m behind the system. For the significantly larger fields in the project region, this kind of protection is therefore insufficient.

On the contrary, the wind protection strips in the temperate grasslands also have a negative effect. The snow is very fine-grained because of the low temperatures. The constant wind carries it across the fields where it accumulates in and behind the protection systems. In spring, these accumulations of snow, which are up to 5 m in height, thaw so late that the respective location must be excluded from seeding. The melting water is missing from the areas between the wind protection strips and thus cannot be transformed into biomass (**Figure 14**).

Figure 14: Snow accumulation in May 2013. *(Source: G. Schmidt).*

Therefore, it is absolutely essential to introduce wind erosion control on the open fields. As described above, crop residue coverage, preferably with high standing stubble, offers the most effective protection and retains snow in the winter.

2.b Retention and increase of humus content

As described in the introduction, the soils of the Eurasian steppe have lost significant amounts of humus as a consequence of intensive crop farming. The reasons were

determined to be wind erosion, accelerated mineralization of the soils caused by intensive tillage, particularly by black fallow periods. In North America, this intensive tillage was referred to as "mining the soils". The studies conducted in the Eurasian steppe over the last few years proved that this expression was apt. The humus content decreases rapidly in the first few years of crop farming after cultivation. Subsequently, the decrease does not progress as fast but constantly occurs. This development can only be stopped by changing the farming method.

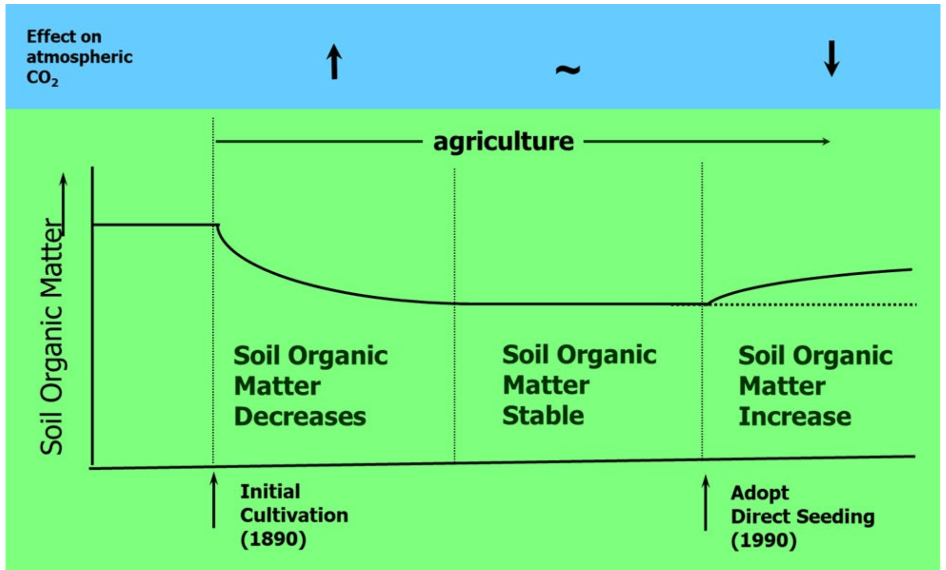


Figure 15: Development of soil organic matter. *(Source: B. Cambell et al., 2002).*

Abolishing black fallow periods altogether is essential for the stabilization of the humus content as well. Moreover, straw must not be burned under any circumstances. Crop residue must remain in the topsoil or worked in slightly. Further, a crop rotation resulting in different types of straw is beneficial for retaining and/or accumulating organic matter.

Even under ideal conditions, the humus content increases only very slowly. The natural conditions of the dry steppe produced only Kastanozem soils with a relatively low humus content of less than three percent. The main reason is low precipitation in this region, leading to very limited biomass production. There is simply not enough biomass available to create higher humus contents. Even under ideal circumstances of agricultural use, the humus content is expected to increase extremely slow. Therefore, paying attention to retaining the humus in the soils is absolutely vital for these particular regions.

2.c Nutrient supply of the soils

The soils in the Eurasian steppe used for crop farming were hardly fertilized anymore after the fall of the Soviet system. Fertilizer was too expensive and often there was no technology available to apply mineral fertilizer. Therefore, fertilization was forgone in most cases. The nutrient supply happened through the mineralization of the soil humus forced by intensive tillage, particularly black fallow periods. After this practice was pursued for many years, the soil is no longer able to deliver the smallest amounts of humus. The result is an absolute undersupply of the soils with nutrients.

A completely different approach has since been developed in the North American prairies as well as in Europe. Only the amount of nutrients which is extracted from the soil by the currently cultivated culture is applied in the form of artificial or farm manure. To design this process as effectively as possible and at the same time avoiding oversupply, it is necessary analyze soil samples. This is not required every year. The content of nutrients (with the exception of sulfur and nitrogen) does not change suddenly. An initial examination analyzing all macro- and micronutrients is required to determine the current status. The spatial resolution does not have to be fine. Over the course of the **KULUNDA** project, it was often sufficient to examine one field with higher and one with lower yields in depth to obtain an overview of the conditions.

It is not possible to infer the proportion of existing and/or required nutrients per hectare (kg/ha) directly from the measured content (generally in mg/100 g or mg/kg) due to the specific nature of the soil (particularly the buffer effect in nutrient supply). Methodically, the rather difficult task is to solve the nutrients from the soil while replicating the actual absorption processes of the crops. Various solution processes are used for the different element groups, which, from experience, best reflect the natural conditions. The actual analysis of the nutrients is conducted in the gathered soil solution.

In Germany, all elements are classified into supply stages (content classes) according to their content. Sulfur and nitrogen represent exceptions as their content varies greatly depending on temperature, tillage level, moisture conditions and crop stage. Specific tables exist for each element. The basic principle, however, is always as described below:

A/. very low, strong deficiency	Urgent need for fertilizing
B/. low, deficiency	Increased need for fertilizing
C/. desirable	No need to fertilize to improve soil
D/. high	No need to fertilize
E/. very high	No need to fertilize

Supply stages *(Source: Association of German Agricultural Analytic and Research Institutes, https://www.vdlufa.de).*

After assessing the supply stages of the individual elements, the nutrient extraction of the planned crop is included in the calculations. In the case of deficiencies, more fertilizer than required to compensate for the expected extraction is applied to improve the proportion of the respective element in the soil. For medium supplies (**C**, desirable), the amount that the planned crop will extract is applied in fertilization. The values are in mg or kg per 100 kg for the individual crops. The amount of the individual nutrient elements which need to be applied can be determined using this method.

If no fertilizer is used, the reason for the various supply stages of the elements lies within the chemical composition of the soil-forming substrate. The latter is constantly blended with the topsoil through tillage and bioturbation (mainly vertical movement of the soil biota). The soil-forming substrate continues to be transported to the top and resolved into its chemical components. Depending on the chemical composition of the substrate, the individual elements are contained in the soil to such an extent that fertilization is not necessary (natural supply stage **E**). These elements then do not have to be included in the fertilization.

Field 409		BioChemAgrar		
No.	**Parameter**	**Unit**	**Result (ø 0-30 cm)**	**Content class**
1	pH value (CaCl2)	---	7.5	
2	Phosphor, total	mg/100 g DM	2.2	A
3	Magnesium	mg/100 g DM	27.6	E
4	Potassium	mg/100 g DM	29	E
5	Copper	mg/kg DM	0.9	A
6	Zinc	mg/kg DM	0.81	A
7	Manganese	mg/kg DM	16.4	A
8	Molybdenum	MO plate number*	8.5	E
9	Boron	mg/kg DM	1.2	E
10	Sodium	mg/kg DM	49.8	C
11	Sulfur soluble (Smin)	kg/ha	13.8	
12	Humus content		4.3	
	Legend:			
	Fertilization strongly recommended			(orange)
	Fertilization not required			(green)

Table 2: Example of a soil analysis from the Kazakh dry steppe (Esil District) with content classification. *(Source: Own data)*.

The table shows that the soil-forming substrate supplies sufficient amounts of magnesium and potassium so that fertilization with these elements is not required. When calculating the required fertilizer application, the extraction of the respective crop has to be considered. Moreover, the status of the microelements must be monitored. However, it is sufficient to conduct an examination every 3 to 4 years and then take the appropriate measures.

Element	Required kg per 100 kg yield
N	1.8
P	0.8
K	0.5
Mg	0.4
S	0.2

Table 3: Plant extraction per 100 kg/ha, summer wheat with crop residues remaining in the field. *(Source: LMS AGRARBERATUNG 2007, table 104).*

When examining the macronutrients in this context, the following recommendation is based on the status (A-E) and then uses additional amounts.

The table below shows the extraction of the relevant nutrients for wheat. It must be emphasized that this only refers to nutrient extraction for those crops to be harvested.

The following fertilization recommendation was derived from these values for the location in Kazakhstan (with a target yield of two tons of summer wheat):

Element	Extraction fertilization kg/ha	Recommended amount of fertilizer kg/ha
N	36	40
P	16	25
K	10	0
Mg	8	0
S	4	7

Table 4: Example of fertilization recommendation. *(Source: Own data).*

Nitrogen as the central plant nutrient unfortunately cannot be assessed using a single soil analysis. The content of bioavailable N (nitric nitrogen) changes dynamically depending on the temperature and soil moisture. Moreover, the content changes after the sample was taken unless a certain temperature regime is observed. Therefore, the samples must be analyzed shortly after they were taken to assess the nitrogen status.

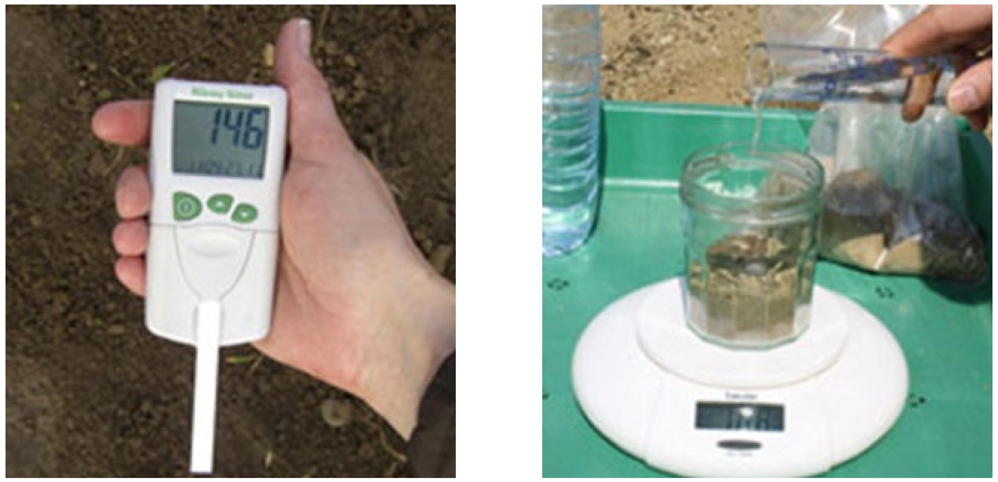


Figure 16: Analysis of the nitrate content in the soil solution. *(Source: Own photos).*

A very good method which is also feasible for the farmers was successfully applied during the **KULUNDA** project and introduced at the farms in the steppe of southern Siberia. It uses test strips which react to the nitric nitrogen content in the soil solution. The color intensity is recorded using a spectrometer and determined in mg/l. This data can subsequently be converted into mg/kg of soil, and further in kg/ha, to assess the reserves in the soil. Specific fertilizing recommendations can then be formulated using the method described above. The analysis of the nitrate content should be conducted before seeding in spring.

Spectrometers for nitrogen analyses are offered by specialist traders and cost less than EUR 1,000. One manufacturer is the company Merck KGaA, 64271 Darmstadt, Germany (RQflex® 20 Reflectoquant®): *http://www.merckmillipore.com/DE/de/product/Reflectometer,MDA_CHEM-117246*

The pH value must be considered as well when recommending fertilizing regimes as it influences the bioavailability of the nutrients in various ways (see **Figure 17**).

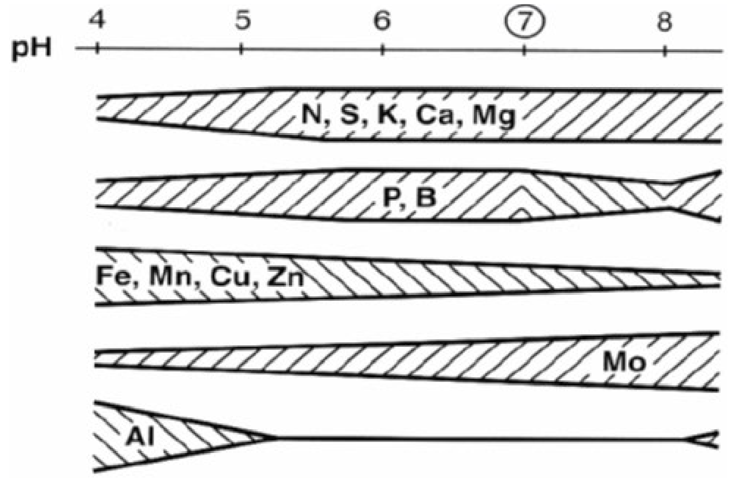


Figure 17: Changes in the content of bioavailable nutrients depending on the pH value. *(Fink, 1968).*

pH values of 7 and higher are typical for dry steppe soils. If the values are too high, however, they limit the bioavailability of some elements *(Mn, Cu, Zn, P, B, according to Fink, 1969)*:

1. Values below 5.5 limit the absorption of nitrogen, phosphate, sulfur and potash.
2. Values above 7 limit the absorption of micronutrients (boron, manganese, copper, zinc) and phosphor.

As the expected yield in Mongolia is relatively low due to low precipitation and low accumulated temperatures, the amount of fertilizer to be applied is also relatively low but absolutely necessary. The trials in the Kulunda steppe showed that an increase of the average yield can only be achieved by applying sufficient amounts of fertilizer. As per the law of the minimum by Justus von Liebig (1840), it is always the scarcest resource which limits crop yield. This can be one insufficiently available microelement. In the sometimes subjective observation of the farmers, water availability and temperature are the deciding factors. However, our growing trials showed that the minimum factor in many cases was not precipitation but the nutrient supply of the soils.

Unfortunately, there is the additional effect that the application of mineral fertilizer (particularly phosphor) not immediately increases the yield in the first few years of transition to soil-conserving methods with reduced tillage all the way to direct seeding. The nutrients are initially retained in the soil and/or straw before becoming bioavailable again after a certain time. Therefore, patience is an absolute necessity when transitioning to reduced tillage methods and introducing mineral fertilizer.

3. PROSPECTIVE FARMING STRATEGIES

3.a Suitable crops

Due to low precipitation and accumulated temperatures in Mongolia, only very few crops can be considered.

Transpiration coefficient* (l H2O/kg DM)	Crop
200 - 300	Millet/sorghum
300 - 400	Maize
400 - 500	Barley, rye, durum wheat
500 - 600	Potato, sunflower, common wheat
600 - 700	Rapeseed, pea, broad bean, oat
> 700	Alfalfa, soy, flax

Table 5: Transpiration coefficient of selected crops. *(Source: BOKU Wien, 2015)*.

In addition to water, the thermal needs of the crops play an important role. This means that cultures such as soy and sorghum cannot be farmed in Mongolia. Of course, the practical experience in cold dry areas and the specific target regions must be considered as well in addition to the theoretical deliberations. Baast & Bartseren (2019), for instance report successful rapeseed cultivation in the central region of Mongolia. This shows that various alternative crops could be cultivated:

1. Linseed

While linseed (oilseed, flax) uses water in a relatively ineffective way according to table 5, our long-term trials in Kazakhstan and the Kulunda Steppe have produced very good results. Flax is a rather frugal culture regarding crop protection. A single herbicide treatment often suffices. Flax does not require high temperatures and is drought-tolerant. The prices are relatively high at around EUR 300/t in Central Asia. With careful cultivation and reasonably beneficial weather conditions, yields of 1.0 to 1.5 t can be expected in Mongolia as well.

The only problem is how to handle the flax straw. Due to its high fiber content, the straw decomposes quite badly and disturbs subsequent measures on the fields such as tillage or seeding. In practice (Kazakhstan, Russia, Canada), the straw is often burned directly on the field. There are some excellent alternatives to this practice, however, which could be interesting for Mongolian agriculture as well. Firstly, modern and effective ovens have been developed which burn flax straw and are used to heat stables or residential buildings. Secondly, flax straw can be turned into fabric. A very interesting project, **LINOKAS**, related to this use is currently running in Kazakhstan *(https://www.bmbf-client.de/projekte/linokas)*. As a conclusion, it is completely advisable to conduct trials for flax farming in Mongolia.

2. Pea

Our trials in the dry steppe also produced very good results for pea cultivation. Pea has a relative short vegetation period and is known to improve soil quality (especially through nitrogen fixation by rhizobia). This crop could also contribute to the feed supply

Figure 18: Flax cultivation in southern Siberia in 2017. *(Source: Own photo)*.

Figure 19: Pea cultivation in the Kazakh dry steppe in 2018. *(Source: Own photo)*.

in Mongolia as it is high in protein. However, one peculiarity must be considered with regard to pea harvesting: The plants, and therefore the pods, are relatively flat which may require the acquisition of special cutting units.

3. Maize

Maize is one of the most effective crops regarding water use. Extensive trials for grain maize cultivation were conducted in the Siberian dry steppe as a part of the **KULUNDA** project. The starting point was the requirement to produce plenty of crop residue to supply organic material to the soil (soil improvement) and to cover the soil (erosion protection and evaporation reduction). These goals were met, and an average grain yield of 5 t was generated in the last seven years. Sales prices are similar to those for wheat, making grain maize a highly profitable crop which also contributes to soil improvement. Being a classic feed crop, maize should be in demand in Mongolia as well. The opinion prevalent in Central Asia, and certainly Mongolia as well, that it is too cold and dry for grain maize must be mentioned in this context. This may have been the case in the past when appropriate hybrids, herbicides and fertilizing strategies and seeding technology (precision seeding) did not yet exist. All of these inputs are now available, making it necessary to reassess the cultivation of maize, particularly grain maize. Extensive maize trials are currently being conducted in Kazakhstan as part of the **REKKS** project. The aspects which need to be considered in this context will be highlighted in chapters 3 and 4. Another substantial benefit of cultivating maize is that the decision whether the crop is grown into grain maize or harvested as silage maize can be made in the late summer according the level of development.

Figure 20: Grain maize harvest in Kazakhstan in 2018. *(Source: Own photo).*

4. Sunflower

The cultivation of sunflower is widespread in southern Siberia and Kazakhstan. While this crop has a relatively long vegetation period, harvesting it in freezing temperatures in November does not represent a problem. The sunflower blooms in early August and the grain filling happens in August/September. Consequently, the comparatively high rainfalls in July and August can be used by the plants (similar to grain maize). As with maize, individual placement of the kernels is mandatory during seeding.

5. Buckwheat

Buckwheat also represents a good alternative in the project area. Due to its relatively short vegetation period, this culture can be integrated into an alternative crop rotation very well.

3.b Crop rotation

Trials running for a minimum of three years must be conducted to recommend suitable crop rotations for the individual agricultural regions of Mongolia. The potential crops must be cultivated under optimum conditions (seeding technology, time of seeding, crop protection, fertilization, harvesting technique), possibly repeatedly. This requires high efforts regarding the organization, consultation and knowledge which can only be implemented as part of a separate project.
When selecting crop rotations, the fundamental principle of monocotyledonous and dicotyledonous plants has to be applied as it causes several positive effects:

- Weeds of the other crop class can be controlled in an easy and relatively inexpensive way using herbicides in the standing crop which leads to clean fields over the years.
- Plant diseases and fungal infestation are typical for mono- and dicotyledonous crops respectively. By changing between the two, the transmission to the following crop is interrupted.
- Various types of straw lead to faster mineralization.

Without the aforementioned analysis to determine the crop rotation, the following combinations would probably be successful in many regions of Mongolia when transitioning to direct seeding and/or minimum tillage (without black fallow periods):

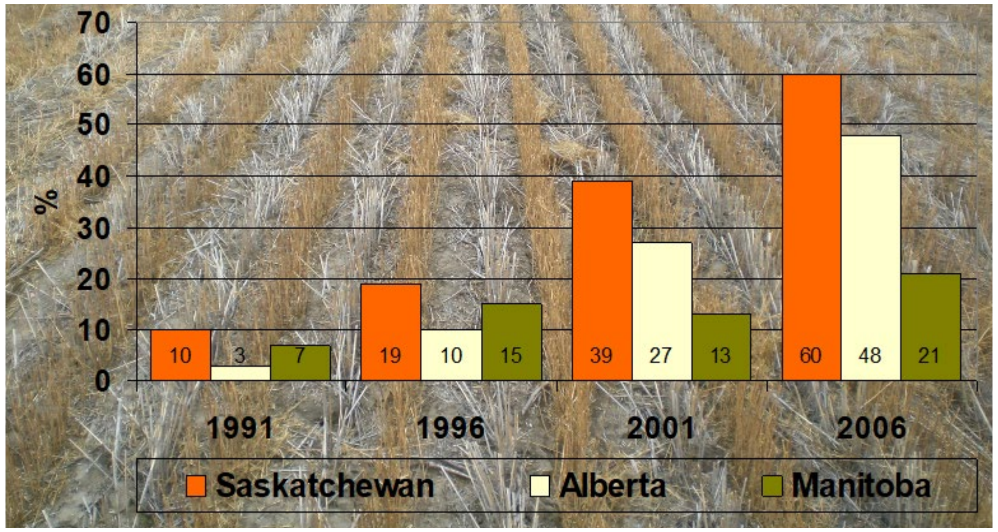
1. Cash crop cultivation:
Summer wheat - flax - summer wheat (summer barley) - pea

2. Feed-oriented crop rotation:
Maize - summer wheat - pea

Introducing alternative cultures and new crop rotations as well as minimizing tillage intensity requires new agricultural engineering, specifically seeding technology. This will be discussed more in-depth in the following chapters.

3.c Direct seeding, strip-tilling

The direct seeding method for temperate grasslands was mainly developed on Canada's prairies. Particularly, the Canadian provinces of Alberta, Saskatchewan and Manitoba faced the challenge of producing sustainable farming concepts while maintaining or increasing yield over the last 50 years. Various scientific examinations documented that the solutions would mainly be found in the minimization of the tillage intensity and an extension of the crop rotations *(Lafond et al., 2006; Campbell et al., 2002)*. Starting in the 1990s, the methods of weed control, seeding, fertilizing and crop rotation were developed based on scientific research. The no-till strategy for the northern Great Plains introduced at the turn of the millennium provided a conclusive farming concept which ensured soil protection while allowing the farmers to operate in an economically viable manner. This knowledge was made accessible to the farmers through brochures and websites with the help of the government *(Pami & SSCA, 1998)*. It must be emphasized, however, that each farmer had to adapt the system to the conditions of natural landscape and his specific crop rotation.



Figue 21: Development of no-till areas in the prairie regions of Canada. *(Source: Own illustration after STATISTICS CANADA, 2009)*.

Figure 21 shows the rapid development of no-till around the turn of the millennium and the diversification of the cultures. The relatively late transition to the no-till method can be explained by the late availability of the required herbicides and delayed introduction of high-quality seeding technology.

Figure 22 clearly illustrates the tendencies for conservative tillage in the Canadian prairies. The reduction of the cultivation area for grain (mainly summer wheat) leads to an increase of that for oilseed leguminous plants required for a sustainable crop rotation. The traditional use of black fallow periods, which promote erosion, decreases.
The extremely successful, sustainable and practically tested farming concept of no-till in the Canadian prairies seems very promising for the regions of Eurasia which have similar agro-geographical characteristics. However, several factors obstruct the introduction of these methods in the project area without a differentiated assessment. Firstly, there are technical and agronomic reasons:

- Chemical crop protection plays a central role in the no-till system. However, for historical reasons the practice has not caught up with the state of the art regarding the methodology and required quantities in Eurasia.
- A wide crop rotation is essential for a functioning no-till system. To this day, the market is still strongly geared towards the grain-focussed crop rotations of the region. The market opens itself for other crops only very slowly.
- The farms rarely have the technology that would allow for a reduction of the tillage

intensity (field sprayers and seed drills suitable for direct seeding).
- The farm structure is different from that in Canada. While the farms in Canada are often family businesses operating about 3000 ha in the prairies, the farms in southern Siberia are often significantly larger. This makes a transition of the production system more difficult and expensive.

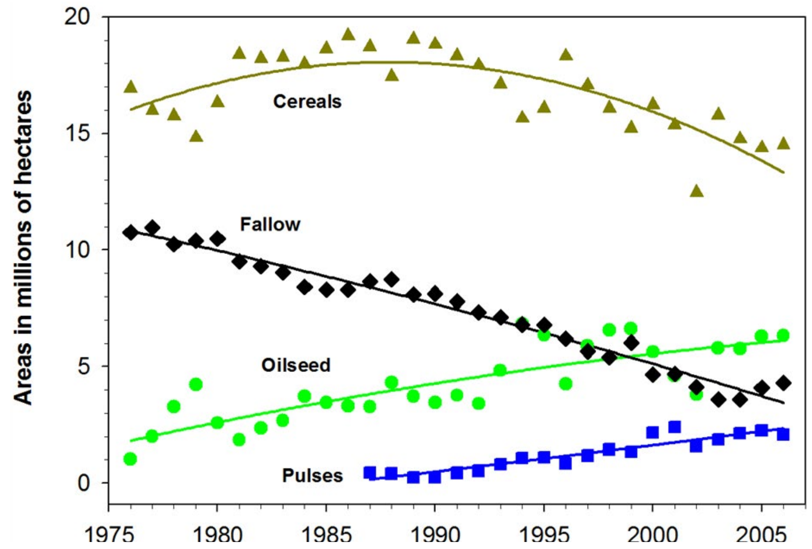


Figure 22: Development of diversification of crop rotations and stepping towards conservational cropping in Canada. *(Source: Own illustration after STATISTICS CANADA, 2009)*.

In addition to the agronomic reasons, there are agro-geographical reasons which require a review of the Canadian no-till method in Eurasia.

- While Canada uses rain-fed agriculture up to an annual precipitation of approximately 300 mm, plant cultivation takes place in the steppe of southern Siberia with precipitation up to 230 mm. With an evapotranspiration at least as high and a similarly high probability of droughts, Mongolia exhibits significantly drier conditions.
- Moreover, the precipitation distribution in the Canadian prairies is suited much better for the cultivation of summer crops than that in the Kulunda steppe. **Figure 23** clearly shows on average lower precipitation in Siberia in May and June. However, particularly the water in early summer is extremely important for the crop yield. The high rainfall in July is often not as relevant as the lack of water during the frequent drought periods in June already damages the crop too much.
- The Canadian no-till system usually includes seeding at the earliest possible stage after the snow has melted. This generally does not cause any problems as the crop can develop well until the rather humid June. This generates the best growth when using optimum crop protection. In Siberia, usually weeds have not developed much by late May, making chemical crop protection in spring less effective compared to Canada. Later seeding could offer better pre-emergence control

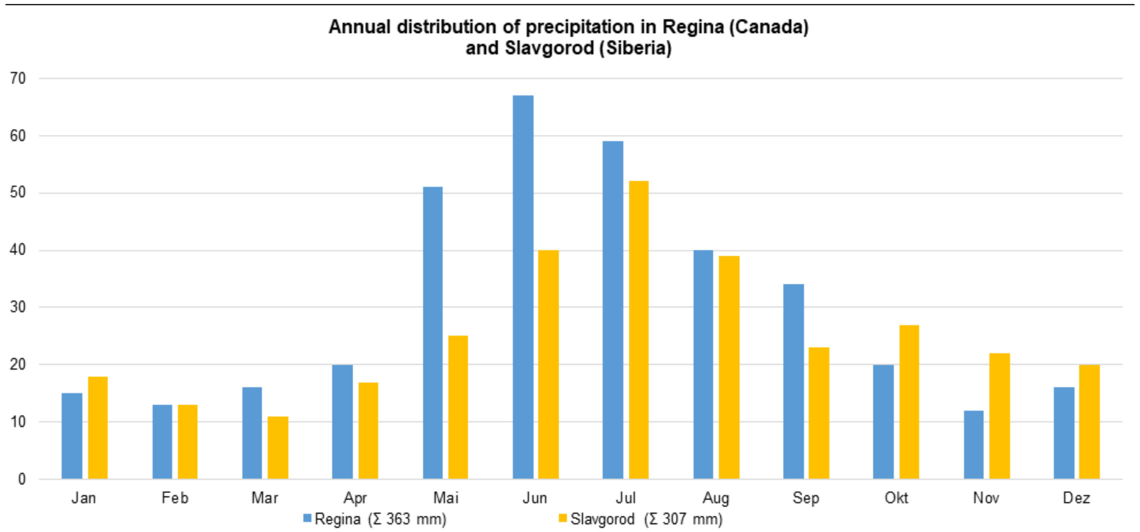


Figure 23: Annual precipitation in the steppe of Siberia and prairie of Saskatchewan. *(Source: Own compilation, data from www.klimadiagramme.de).*

In addition to agronomic and agro-geographical factors, tradition and farming stereotypes decelerate the transition to no-till methods. From an international point of view, that is not something peculiar to the region. Problems occur everywhere in agriculture when transition from traditional to more modern methods takes place.

The positive effects of the no-till method on the soil and yield stability will only become visible a few years after the rigorous transition *(Lafond et al., 2006)*. The conversion of the production process requires great effort; a complete re-orientation mainly related to renouncing of traditional crop farming methods. The acquisition of appropriate technology, the investment in new substances and the internal restructuring of the organization represent hurdles which make it difficult for farmers to take this step. Great inhibitions are fostered by the danger of a moral or financial setback caused by possible mistakes when applying the method or unforeseeable weather and market antics, particularly shortly after transition.

The method should be tested in limited areas to check on the theoretical assumptions regarding the positive potential of a rigorous conversion of the farming system.
It is possible to use shallow tillage initially (max. 8 cm deep using wing shares or compact disc harrows). Obviously, black fallow must not to be used.

Direct seeding does not only mean forgoing tillage and seeding directly into the stubble. In order to be successful, it must be understood as a whole system.

The direct seeding system consists of four elements which all must be applied for this farming method:

1. Suitable crop rotation (see chapter 3.b)
2. Precise seeding directly beneath the straw (see chapter 4.a)
3. Sufficient fertilization of the soil, as close to the plant as possible (see chapter 4.a/b)
4. Perfect crop protection ("clean fields", see chapter 4.c)
5. Straw management (see chapter 4.d)

3.d Minimal tillage/strip-till

To this day, tillage is one of the most important foundations of crop farming. Depending on the region, method and crop, the farming regime is more intensive or extensive. Intensive tillage is problematic in exposed regions where a significant part of the soil moisture is lost by opening the ground and damaging or even destroying the soil as the nutrition base of the crop by erosive wind and/or water forces.

The classical tillage methods are intensively used in the farming region of southwestern Siberia. Measures of mechanical weeding without breaking up the soil entirely were developed as early as in the 1970s. The so-called MALZEV method offers cutting the roots completely, therefore effectively controlling weeds. The soil is not broken up with the exception of a small strip along which the coulter arm runs in the ground. This prevents capping, erosion and retains soil moisture. Disadvantageously, the required wing share cultivator must be guided at a depth of 20 cm. The working width is rather limited due to the deep tillage, with machines mostly designed for a working width of 3 m. These aspects makes the MALZEV method time- and resource-consuming.

Figure 24: Flat-cutting wing blade cultivators do not break up the soil and cut the roots of the weeds and self-sown crops in Aleysky District, Altai Krai. *(Source: Own photos)*.

A well-coordinated crop rotation with sound chemical crop protection can minimize or eliminate tillage, thereby saving time, fuel and soil (moisture). It is recommended to work the field diagonally to the swath after the harvest by using a straw harrow. This helps to better distribute the straw and to initiate germination of self-sown crops and seeding of the weeds.

Using a straw harrow does not count as tillage in the narrow sense. It is applied intensively in the Canadian direct seeding system. Only the upper 2-3 cm of the soil are moved. The broader and often core purpose of this soil working is to better distribute the straw in preparation for seeding.

Mechanical seed drills with disc coulters are mainly used in the more humid forest steppe regions. While these allow for more precise seed placement, a prepared seedbed to ensure a steady ride in the ground is essential. Therefore, the soil is worked again directly before seeding to create a particularly fine texture. This procedure is especially problematic in the dry spring weeks and in the case of the southwestern dry winds, as great amounts of arable soil drift away and valuable soil moisture is lost.

If the seeding technology requires preparation of the seedbed, it is a must to work in a very flat manner to in order to minimize the impact on the soil structure. Shortly after the transition to the new method, an increase in wild plants and self-sown crops is to be expected. The application of pre-emergence herbicides is mandatory at this stage to avoid immediately placing the young plants in competition with others.

Seeding itself may be regarded as tillage as the soil is opened up to place the seed. Depending on the sowing depth, driving speed and the type of share, more or less soil is moved. In addition to mechanical drills with double disc coulters, shares for mechanical drilling similar to wing share cultivators were developed for extremely dry regions

Consequently, this machine can place the seed directly into the unworked soil. The precision may not be very high, but the method saves one work step. The performance of this seed drill overall is very close to that of a cultivator. The risk of soil desiccation and drifting caused by wind is significantly higher after tillage/seeding

Figure 25: Heavy harrow for modern straw management. *(Source: Own photos).*

Strip-till

Over the last few years, the spatial proportion of sunflower cultivation has increased significantly in the farmlands of western Siberia and northern Kazakhstan. It has become the most profitable crop for many farms as it generates good sales prices. Moreover, sunflower is much more capable of withstanding the regularly occurring droughts than other crops. This is mainly due to the relatively early seeding time in early to mid-May and its deep-reaching main roots which allow to draw water from the lower soil levels. Thanks to the highly profitable yield from the cultivation and sales of sunflower, great efforts are made regarding preparation of the seedbed, nutrient management and crop protection.

In this context, tillage is rather intensive even in the driest regions. Sunflowers are usually cultivated after black fallow periods. The seedbed is prepared in combination with a herbicide which is worked into the soil. Weeds are controlled by hoeing between the rows of the standing crop and fertilization takes place during the seeding process. However, the usual and known problems of wind and water erosion, compacting and the subsequent abnormal formation of roots as well as nutrient loss from high mineralization rates can be expected as a result of the high tillage intensity in sunflower cultivation.

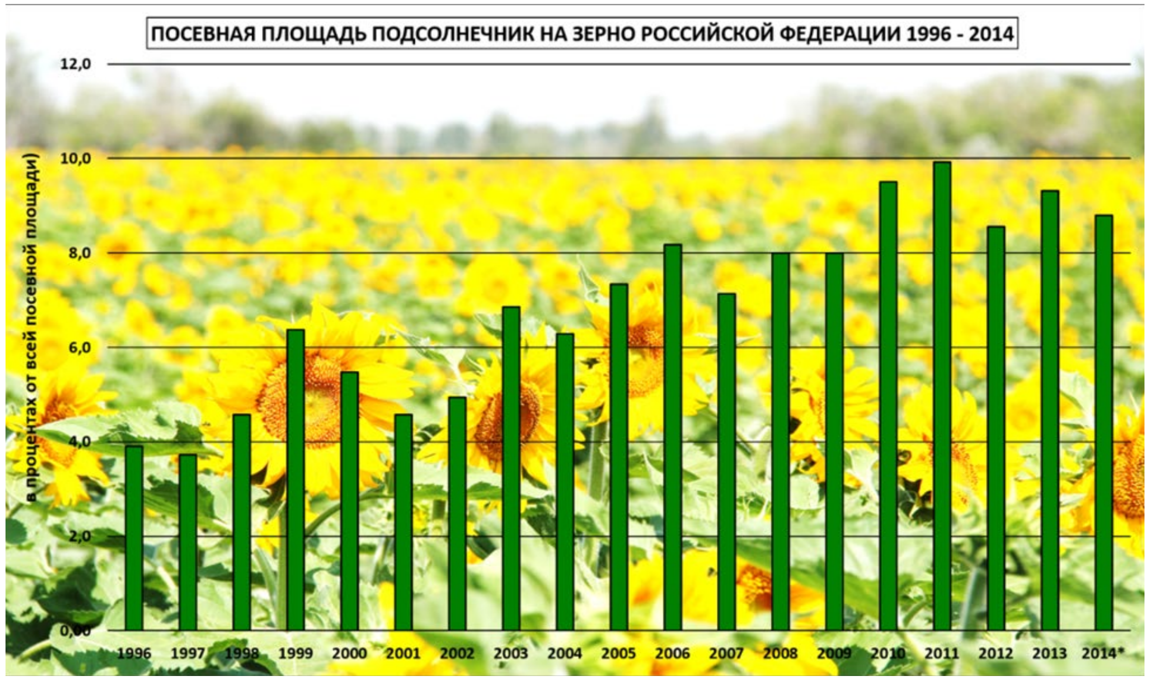


Figure 26: Percentage share of sunflower in the total cropland in the Russian Federation, 1996-2014. *(Source: Rosstat, 2015)*.

Crop rotations with a high proportion of maize have been used in the Northern American farming regions, particularly in the U.S., for several years. Favorable effects are generated by the application of total herbicides specially developed for genetically modified organisms, making the seeding of maize onto maize possible. This aspect, however, shall not be included in the present considerations.

Another important method which can be applied to the western Siberian, northern Kazakh and certainly the Mongolian farming regions is the so-called trip tillage or strip-till.

The soil is deeply loosened in strips and the seedbed is prepared for the crop on these strips. This step can be combined with the placement of a fertilizer band as a deep depot. The distance between the rows equals the distance of the seeding rows of the crops. In Siberia and Kazakhstan, it usually constitutes 70 cm for maize and sunflower.

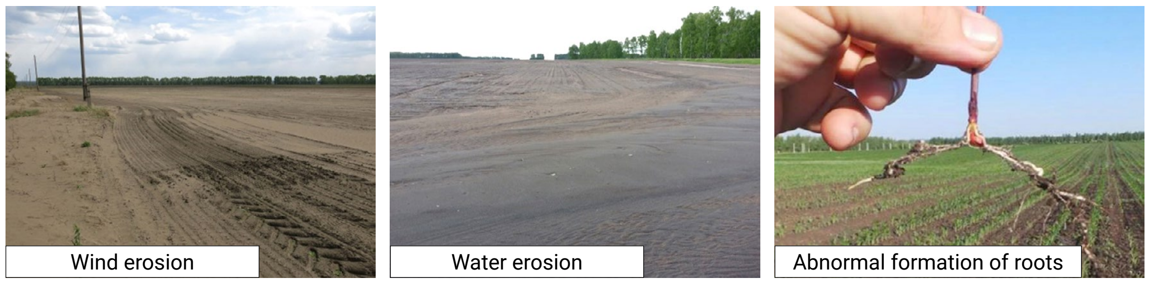


Figure 27: Typical problems of intensive tillage in sunflower cultivation. (Source: Own photos).

The deep loosening of the soil allows the row crops fast development of roots which grow into the deeper soil layers in a targeted manner. As a result, dry stress is avoided and water reserves located deeper in the soil can be reached. The placement of a deep fertilizer band also promotes the fast downward root growth as the fertilizer band attracts the plant roots. Moreover, this method also balances out nutrient deficits which arise from the immobility of certain elements. Phosphor must be named in this context. If fertilizer is not placed into deeper layers but applied to the surface, the highly immobile phosphate accumulates in the upper centimeters of the soil.

Figure 28: Principle of operation and performance of the strip-till machine used in the **KULUNDA** project. *(Source: Amazonen -Werke, 2019)*.

Furthermore, precipitation and meltwater will seep directly into the tilled strips. Consequently, the water quickly runs off the soil surface where it would not be available to the crops due to the high evaporation potential.

Ideally, the soil is worked after the harvest in the fall. The strips are further lifted by frost, therefore improving their soil structure. The upper soil layer settles during the snowmelt which increases navigability, seeding precision and the soil contact of the seed. The threat of the nutrients being washed out is minimal due to low precipitation and low temperatures in winter.

The navigability of the soil improves overall as large proportions are not tilled at all. The space between the rows is covered by organic matter from the last harvest which helps to limit evaporation and the pressure from weeds. Chemical crop protection can be significantly improved by applying a soil herbicide with a depot effect. As a result, subsequent costs which would be incurred from hoeing between the rows of the standing crop are contained. Water erosion can be reduced by the space between the rows being covered. Particularly in the first few weeks after seeding, the crop stands are not closed yet and large amounts of precipitation water directly hit the soil surface. Water erosion and capping problems may occur over the course of the vegetation period.

The traction power requirements must be significantly reduced and, in return, the working speed must be increased by using the strip-till method. In doing so, real costs can be saved in preparing the soil for row crops.

4. AGRONOMICAL AND ENGINEERING-RELATED PRECONDITIONS AND SOLUTIONS

4.a Seeding

A rather central part of the work, particularly for farming methods with reduced tillage and/or direct seeding, is high-quality seeding. Quality parameters include the longitudinal and lateral distribution, good contact between the seed and moist soil as well as uniform coverage of the seed with soil. Reduced tillage often leaves a substantial amount of crop residue on the topsoil, makingit difficult to create a clean furrow for seed placement. The following three share types are frequently used to achieve it:

1. Figure 29: Sweep type opener: Share installed on the frame cuts completely at a depth of approximately 8 cm when seeding *(e.g., Airseeder, SZS 2.1)*.

2. Figure 30: Disc opener: Rotating disc guided at depth which cuts open the soil (and the crop residue). Various tools are used leading or trailing for depth guidance and pressing of the seed.

3. Figure 31: Hoe opener: Often a single share guided at depth which does not work the full soil surface but clears the seeding furrow of crop residue.

(Source: Own photos)

When selecting a seed drill for direct seeding from these three possible basic share types, the following should be considered:

- Possibility to place various types of seed in the range of 2-350 kg/ha in a high-quality manner (cf. requirement to extend crop rotation).
- Sufficient amounts of crop residue should remain on the soil surface after seeding; standing stubble if possible.
- The seed drill should have low traction power requirements and be combinable with existing tractors.
- The seed drill should be able to apply fertilizer during the seeding process.

Figure 32: Condor 12001 seed drill for direct seeding by Amazonen-Werke with Russian tractor K700A. *(Source: Amazonen -Werke, 2012)*.

Even before the launch of the **KULUNDA** project, the company Amazonen-Werke started to develop a machine tailored to these demands. It was then advanced and further adapted to the characteristics required by the partners as part of the project. The result is the Condor large-scale seed drill for direct seeding and/or seeding after minimal tillage.

Single chisel shares guided at depth were chosen as seeding aggregates. They cause significantly less soil movement than for instance wing shares. This prevents the upper soil horizon from drying out and leaves crop residue on the soil. The narrow chisel share (in contrast to disc harrows) clears the seeding furrow into which the seed is placed. The trailing roller keeps the chisel at the defined depth even in the event of high share pressure and presses the seed into the moist soil. **Figure 32** illustrates that this share technology can as well generate excellent field emergence in cases of large amounts of straw.

Figure 33: Precise field emergence with large amounts of straw after using the chisel opener of the Condor 15001 seed drill. *(Source: Own photo).*

A new, significantly improved setting of the coverage height, which allows for much faster adjustment and therefore optimum adaptability to the crops and conditions, was achieved within the framework of the **KULUNDA** project (see **Figure 32**).

Spring steel was chosen as the material for the coulter arm, allowing for a slight horizontal movement in the event of obstacles and/or diversion to either side to softer conditions. Two row distances at 25 cm and 30 cm can be selected. By European standards, these distances are rather wide, however, this is an important feature for good straw interspersion and responds to the low traction power requirements in the project area. The traction power required by the Condor seed drill is relatively low at 18 hp/m of working width. This is extremely important when using the machine on the large surface areas of the project region to keep the cost per hectare low. Only 3-4 liters diesel are required per hectare for seeding. In comparison, seeding with conventional technology uses a minimum of 7-8 l/ha diesel. The low drag resistance of the machine is mainly based on three components:

- An extremely narrow opener.
- Part of the machine weight is transferred to the rear axle of the tractor (lower link suspension). As a result, slipping is noticeably reduced.
- Using spring steel in the coulter arm allows for the share point to evade horizontally so that the coulter always runs at the lowest possible resistance.

To minimize the initial investment costs when introducing direct seeding in the project area, it is vitally important to be able to combine the new seed drills with the tractors available at the farms (mostly K700, K701, K744). Previousley, modern large-surface seed drills used to require the purchase of a high-performance tractor. The investment for the purchase of a tractor-seed drill combination which can seed about 3,000 ha per season totaled about USD 400,000-500,000. As a result of a specially developed hydraulic unit in combination with the drag resistance of the Condor seed drill, farmers can continue to use the Kirovets (see **Figure 32**), thereby significantly reducing the initial investment. The tractors are available at most farms and the price for a Condor constitutes USD 150,000-200,000 which means costs are halved.

The tank of this seed drill with a total capacity of 8,000 l is separated at a 3:1 ratio into one section for seed and one for mineral fertilizer. The application volumes for seed and fertilizer can be set separately. The system is very simple and robust and can dose even minimal amounts precisely. Seed and fertilizer are placed into the furrow together. This practice, however, is only possible to an application of about 30 kg of pure nitrogen as otherwise the seedlings might be damaged. Currently, higher quantities of nitrogen are hardly ever applied during seeding.

When cultivating row crops such as sunflower and maize, the grains must be placed into the soil individually at set distances (precision seeding technology). This technology as well requires the soil to be moved or tilled as little as possible. The seed should be placed directly under a moisture-retaining layer of crop residue in spring. This, however, represent a technological challenge. Within the **REKKS** project, specifically designed row cleaners were adapted for this purpose. They clean a strip of approximately 15 cm in width before the actual sowing coulter and generate fine earth. The opener for fertilizer application is integrated into the row cleaner (see Fig.).

Figure 34: Row cleaner with integrated fertilizing coulters. *(Source: Martin Till, 2019) https://store.martintill.com/content/ 2019%20Catalog%20V%20020719% 20Small%20File%20size.pdf)).*

This composition allows for the direct seeding of maize, for instance. The 2018 and 2019 trials in northern Kazakhstan produced very good results in seeding, crop development and harvest.

Figure 35: Direct maize seeding into the rapeseed stubble. *(Source: Own photo)*.

Figure 36: Very good crop development with direct maize seeding after summer wheat. *(Source: Own photo)*.

4.b Fertilization

Systems for reduced tillage and dry conditions cannot use application methods like a fertilizer spreader, as nutrients would become bioavailable much too late and in insufficient amounts. Due to the poor percolation, some sparingly soluble and/or hardly shiftable nutrients would accumulate on the soil surface. Consequently, the fertilizer must be introduced into the soil. With direct seeding, the only option is to apply the fertilizer simultaneously while seeding. To be able to apply sufficient amounts of fertilizer, it must be separated from the seed starting at 30 kg pure nitrogen. Generally, a depth of 3 cm is sufficient. For this purpose, some manufacturers of seed drills, e.g., SeedHawk, have developed coulters with openers (see **Figure 37**).

Figure 37: Coulter system with two openers. *(Source: Väderstadt, 2019, https://www.vaderstad.com/en/drilling/seed-hawk-air-seeders/seed-hawk-opener/)*.

As the share points for the fertilizer should run a little deeper than the sowing opener, this share creates significantly higher soil movement which leads to greater shifting and increased performance requirements, resulting in higher fuel consumption. The company Amazone decided for a different path using one coulter with one share point. Although only one initial dosage can be applied to the rows, soil movement is reduced significantly.

Figure 38: Cart for liquid fertilizer between tractor and seed drill. *(Source: Own photo)*.

The solution is to apply liquid fertilizer. It is often less expensive than granulated fertilizer and much faster becomes bioavailable in dry soils like in Mongolia as the granulate does not have to dissolve first. Moreover, micronutrients can be added to liquid fertilizer in case the soil analysis shows a need. To apply the liquid fertilizer, a cart is placed between the tractor and seed drill and the seed drill is equipped with a distributor and pipes. Fig. 38 depicts how the liquid fertilizer drips onto the shoulder of the seeding furrow next to the actual opener so it does not get into contact with the seed. Still, the fertilizer is applied close to the crop.

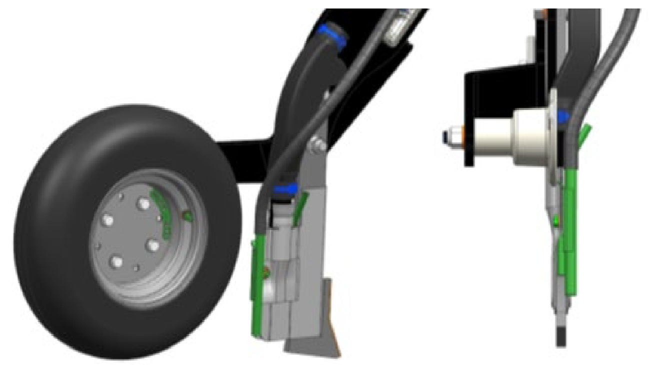


Figure 39: Liquid fertilizer equipment (green) at the coulter of the Condor seed drill. *(Source: Own illustration)*.

Liquid fertilizer can also be applied using a crop protection sprayer. The following method could be an option for the extremely dry conditions in Mongolia:

1. Application of approximately 25 kg of pure nitrogen into the row while seeding.
2. Application of liquid fertilizer (UAN) to the standing crop until the tillering phase as needed (if soil moisture is sufficient and the crop develops well).

Tests on the effectiveness of fertilization in northern Kazakhstan during the 2018 season produced very good results. Three options were tested, all applying a standard amount of nitrogen (in the form of UAN) of 54 kg.

No.	Option	Rapeseed yield (t/ha)
1	Spraying before seeding	1.7
2	Application into the furrow during seeding	2.5
3	Application to the crop	1.4

Table 6: Example of UAN effectiveness for rapeseed (150 l → 54 kg pure nitrogen). (*Source: Own data*).

The additional yield of approximately one ton justifies the increased effort of applying fertilizer using the seed drill in any case.

Phosphor in particular is hardly mobile in the soil. It binds firmly to humus particles and clay minerals. Therefore, it hardly settles into deeper layers. Even when applied into the seeding furrow, it does not reach a sufficient depth. As described above, strip-till is one solution in this context. Prior to seeding a row crop (sunflower, maize) in spring, a sufficient amount of phosphor is applied in fall by using a strip-till unit. It allows for an application of enough phosphor for a 2-3 year period. This equals the sowing of a row crop every 3-4 years, which is realistic.

Figure 40: Maize after strip-till in the Siberian dry steppe, 2019. *(Source: Own photo).*

4.c Plant protection

As previously mentioned in chapter 3.c, weed control plays a central role in methods with reduced tillage. If the weed competition is not eliminated, the crop does not have an opportunity to develop. Weeds are always better adjusted to the local conditions than the cultivated crop. As a result, weeds overgrow the crop unless they are controlled. The following images clearly illustrate this effect.

Figure 41: Left: maize with herbicide treatment, right: without treatment. *(Source: Own photo, 2019).*

Figure 42: Left: sunflower with herbicide treatment, right: without treatment. *(Source: Own photo, 2016).*

The experience from Kazakhstan and the Siberian dry steppe shows that it is extremely important to apply herbicides at the right stage. However, due to weather conditions (rain, wind), this can be problematic. If herbicides cannot be sprayed due to the weather, weeds continue to grow and might become too large to be treated effectively. Therefore, high performance of the crop protection sprayers must be ensured. As a rule, farmers should be able to treat their entire land once within five days. For instance, a farm with 5,000 ha land would require one self-propelled sprayer with a 36 m boom (performance approx. 60 ha/h) or two to three trailed sprayers (24 m boom) with a daily performance of about 400-500 ha.

Without the appropriate plant protection equipment, it is not possible to introduce new crops or methods. In that case, it would be more reasonable to pursue the old system of black fallow even if the soil continues to be irreversibly damaged.
In the dry farming regions of the steppe beyond the Ural, it is advisable to maintain the input in the farming system as low as possible due to the low yield expectations caused by the prevailing climatic conditions. An extensification of tillage must inevitably be accompanied by alternative crop protection strategies which often provoke investments in expensive technology and herbicides. The application of these must be as effective as possible to keep the costs low and avoid excessive strain on the agricultural ecosystem.

Chemical crop protection in minimum-tillage and no-till systems fundamentally consists of three phases: pre-emergence application - crop treatment - post-harvest application. The chemical pre-emergence and post-harvest treatments replace the tillage used in conventional systems to control weeds, which is effective but often causes erosion problems and water shortages. However, the pre-emergence and post-harvest treatments using total herbicides, particularly glyphosate, are increasingly controversial and rather expensive. **Figure 43** shows a typical situation of weed coverage prior to summer crop seeding.

Figure 43: Moderate weed coverage prior to summer crop seeding in highly continental regions. The use of total herbicides over the complete area would have a negative financial result. *(Source: Own photo).*

The coverage of wild plants in spring, prior to seeding, and in late summer, after harvest, is usually moderate to low. On the one hand, the overall vegetation in spring at the time of summer crop seeding, is generally not widely developed. On the other hand, weed pressure in fall is moderate as the standing crop effectively suppresses the weeds until the harvest. If there is a lack of soil moisture, precipitation or accumulated temperature in early fall, weed coverage until the following spring barely changes.

Therefore, the full-area application of glyphosate only has a moderate economic efficiency and introduces large amounts of herbicides into the system, being unnecessary due to the limited weed infestation at the time of application. However, if no herbicides are sprayed and chisel shares or disc harrows are used for seeding the weeds grow faster than the crop.

A promising option is the application of modern but conventional full-area crop protection sprayers with optical systems to detect weeds in the pre-emergence and post-harvest treatment.

Amazonen-Werke has collaborated with the Dutch company ***Rometron*** for several years. The latter has been working in municipal technology on the combination of detecting and chemically controlling weeds on public sidewalks and tested the method of crop protection in large-area systems on glider systems in Australia.

Within the framework of the **KULUNDA** project, the combination of a modern but conventional field sprayer with the spot spraying system ***(AmaSpot)*** has been tested under production conditions on a **KULUNDA** partner farm in Western Siberia since 2013 and the technical solution is being developed further. Moreover, farm management evaluates the economic and agronomic effects of the system under practical conditions.

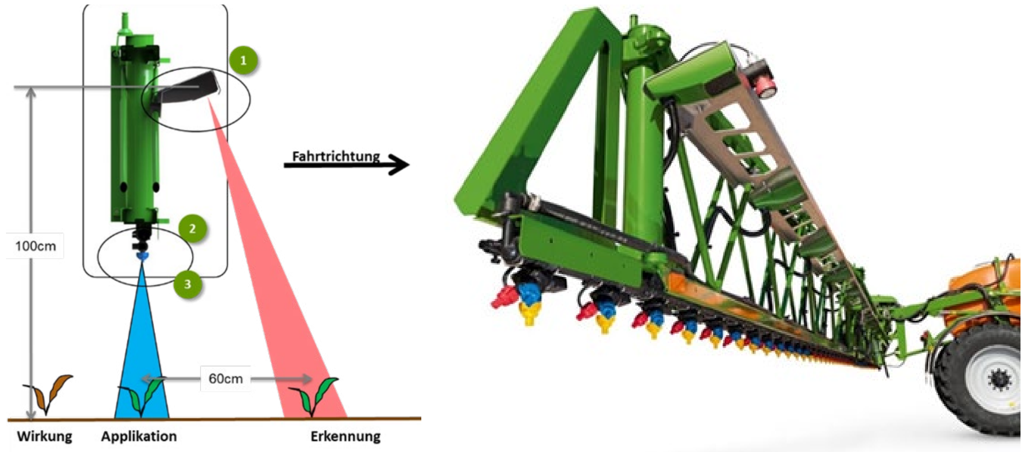


Figure 44: Mode of operation of the spot spraying system. *(Source: Amazonen-Werke, 2019).*

The weed is detected by sensors installed on the sprayer boom. The sensors emit visible red light and in the infrared domain to detect chlorophyll. The reflection is processed by sensors which work by day and night. The night hours, which are beneficial for crop protection as air humidity is high, thus allowing for better wetting of the plants, can be used. This is of particular significance when using contact herbicides such as glyphosate. Moreover, wind speed is lower at night, thus drifting is reduced while efficiency is maintained.

Each sensor monitors four sprayers of the spot spraying system. The detection is reliable starting with a plant size of just under 2 cm in diameter so that even the smallest weeds can be eliminated effectively. The sprayers open and close by activation of electromagnetic vents. Extremely short reaction times can be achieved, therefore a high system reliability can be maintained at driving speeds beyond 20 km/h. To achieve an even more effective control of the smallest weed, a constant proportion of the usual application rate can be administered using pulse width modulation (PWM). Then a full dosage is only applied if an actual weed is detected.

The trial farm usually applies 2 l of glyphosate per 100 l/ha of whole broth pre-emergence. This value represents the amount to be applied for full-area treatment. As the spot spraying system does not work with variable pressure but in a time-controlled manner following the frequency of the weed, the amount to be applied directly depends on the latter.

However, this system caused problems in the pre-seeding treatment. The sensors do not recognize small, germinating weeds. Subsequently, these grow faster than the crops. To control small plants, equally small amounts are necessary. Therefore, another feature was added to the AmaSpot system. It is now possible to spray 20 % of the regular amount all over the surface and to treat the detected larger weeds completely through the spot feature. In the trial phase, the integrated flow meters measured between 30 and 40 l/ha. This means that more than 50 % of the regular amount were saved. In individual cases, application was reduced by more than 80 %. This generates high financial savings potential. On the one hand, large amounts of herbicides can be saved. On the other hand, refills have to be made far less frequently which reduces downtime and labor costs significantly. Moreover, the great saving potential justifies the increase of the herbicide

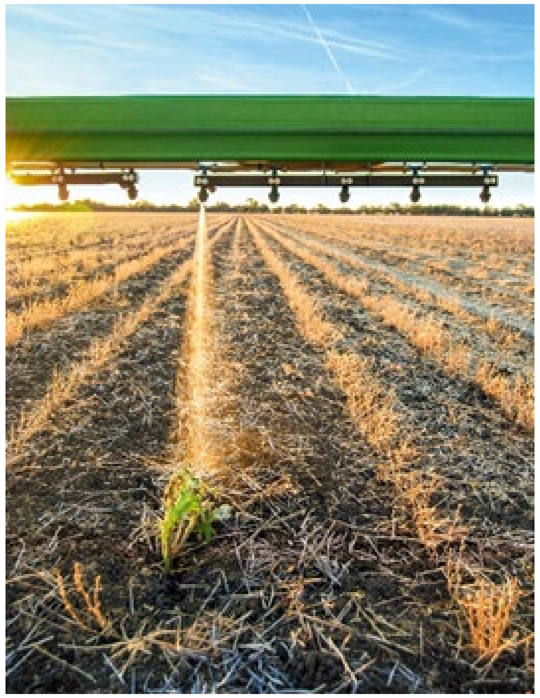


Figure 45: On-point weed treatment using the AmaSpot system. *(Source: Own photo).*

concentration in the compound from an economic perspective. From an agronomic point of view, this measure can help to prevent resistances. These occur when plants survive the herbicide application several times in a row and eventually mutate as a result of the effects of the herbicide.

In the conventional farming systems of the dry steppe the proportion of black fallow periods in crop rotation is relatively high. To this day, the soil is kept clear of any coverage for an entire vegetation period every six years on average. This measure represents the most significant factor contributing to erosion damage and loss of soil fertility. Many reasons are listed in favor of black fallow periods. The improvement of soil moisture and nutrient content are generally named first. The truly most effective factor, however, is mechanical weed control. The effect of chemical summer fallow was examined by agronomists within the framework of several long-term trials in the farming regions of northern Kazakhstan.

During the tests, the arable land is treated with herbicides at intervals to kill wild plants. As a result, dehydration is significantly reduced by the almost complete elimination of transpiration

Evaporation decreases due to the surface being well shaded by plant residue. Therefore, the organic matter remains within the system which promotes humus formation and soil

Figure 46: Selective treatment using AmaSpot on a chemical fallow area. *(Source: Own photo).*

structuring. Water loss is reduced and weed pressure minimized. The aforementioned aspects apply in this scenario as well: The full-area application of glyphosate is inefficient due to the low coverage of living wild plants. The use of the spot spraying system in the chemical summer fallow period was tested with great success in the **KULUNDA** project.

It achieves direct erosion protection. Diesel consumption decreased as the traction power requirement of the sprayer, in relation to the working width, is significantly lower than that of the tillage machines. The application of chemical herbicides becomes much more efficient leading to major economic and agronomic benefits. The **KULUNDA** trial farm management estimates the total saving potential of the system to exceed 80 % of the previous costs.

The system has been launched on the market. In the future, it can contribute significantly to making chemical crop protection more efficient from an economic as well as an agronomic and ecological perspective. The recommendation to support the system is mainly addressed to political decision-makers. It should be integrated into an agricultural subsidy program supporting the farms in purchasing it. Transitioning to this system and extensifying tillage could happen much faster and much more consistently due to the lower costs for herbicides. The yield can be maintained at a reasonable level, even during the transition period. The application of herbicides to the soil-plant system can be reduced significantly.

4.d Harvest

The main task during harvest is to extract the produce quickly with as little loss as possible. If alternative cultures, such as pea or lentil, are introduced, the harvesting process must be very shallow to reach the deep-seated grains. In Siberia, Kazakhstan and certainly Mongolia as well, usually simple cutter bars which do not or insufficiently adjust to the soil are used. Therefore, flexible and universal cutter bars (grain, rapeseed, flat crops) should be purchased when investing in new harvest technology. The manufacturers MacDon, HoneyBee and Geringhoff offer suitable cutter bars.

Figure 47: Fully flexible cutter bar with perfect adjustment to the soil. *(Source: https://www.geringhoff.com/en_US/Products/Draper-Heads/TruFlex-TruFlex-Razor/p/gp_TruFlex).*

Row crops such as sunflower and grain maize require special cutter bars to avoid losses.

A second, also very important aspect of the harvest in a farming system with reduced tillage is to distribute the straw on the field as evenly as possible. The old combine harvesters are often not equipped with the appropriate choppers so that the straw is basically placed in the swath. Distributing it later, using straw harrows, for instance, can prove to be rather difficult. As the accumulated straw hinders the seed (clogging the seed drill), straw is often burned on the field, which is catastrophic regarding the humus content of the soil and the CO_2 balance.

Figure 48: Perfect straw distribution over the entire working width. *(Source: Own photo).*

Another aspect to be considered for harvesting in very dry and cold climates is snow retention the following winter. Naturally, high stubble retains the drifting snow best. To achieve a maximum stubble length, "cutter" bars were developed which strip the crop going up the stem, so they no longer cut. A manufacturer that has perfected this technique is Shelbourne (see Figure 49).

Figure 49: Left: harvest using a stripper; right: harvested field with very high stubble for snow retention. *(Source: https://cpb-ap-se2.wpmucdn.com/farmnet.com.au/dist/c/8/files/2016/12/DSC_0893a-12kgkl1.jpg).*

5. RECOMMENDATIONS FOR THE INTRODUCTION OF ALTERNATIVE FARMING STRATEGIES

The experiences from Canada and the target areas of the **KULUNDA** and **REKKS** projects show that the introduction of modern farming concepts represents a great challenge. Whereas in North America the transition often took place with a generational change in the large family farms over a relatively short period of time, the reform on the territory of the CIS is a much slower process. Often, only individual elements of the system are

tested,frequently leading to setbacks and the goals being abandoned. One reason is that the direct seeding and/or minimal tillage systems only work under application of all of the elements (see chapter 3.b).

For instance, farmers often try to use their existing seeding technology to sow directly into the stubble and forgo black fallow periods. Naturally, without appropriate plant protection, sufficient fertilization and suitable crop rotation, more diseases and weeds occur, leading to decreasing yields. The understandable reaction is to fall back on conventional methods and resume black fallow.

To achieve a successful conversion to sustainable farming methods, certain requirements need to be met which also means investing in agricultural engineering and resources. The following will present different approaches which can support a successful conversion on the farms.

5.a Required steps to be taken by the farms

A conversion which takes place too fast and is all-encompassing bears certain risks. At first, decision-makers need to obtain the appropriate knowledge and familiarize themselves with the new technology. It is strongly advisable to remove farmland from the usual production and apply the new methods over a period of at least five years. As described above, the positive effects of crop rotations and minimal tillage only occur over time. Moreover, mistakes can be expected when applying new methods (as well as crops or herbicides) which must not interfere with the overall operations.

The requirements a farm needs to meet for converting to sustainable farming include technological and skills-related aspects.

Technological requirements:

- Seeding technology: As described above, a crop rotation is part of sustainable farming. Consequently, the farms need a seeder which can precisely dose various seeds (fine seeds such as rapeseed, linseed, grasses as well as cultures such as peas with seeding rates of 200 kg/ha). The seeder must perfectly comply with the placement depth under various conditions (different types of stubble, with and without tillage) and be able to apply at least granulated fertilizer with the seed (see 4.a/b).
- Plant protection: The availability of a crop protection sprayer is essential. Initially, basic technology may be used if the unit is used and maintained appropriately. Obviously, a sprayer with booms that can be guided very low above the ground and a precise and uniform dosage are recommended. Only then the desired effect from the often rather expensive agents is guaranteed.

The transition can be launched with these two machines. The new machines can certainly be used in a conventional system as well, thereby contributing to a better quality of the work steps.

Agronomic knowledge:

Unfortunately, it is not possible to compile a catalogue of practical measures such as specific seeding rates, seeding times or herbicides. The conditions on the individual farms are too variable. Every farmer and decision-maker must obtain the required knowledge from various sources. The following three methods are suitable for this purpose:

- Fundamental information on farming alternative cultures and applying herbicides can be found in specialist literature. However, our experiences in Russia and Kazakhstan have shown that many publications are only available in English which means the knowledge contained therein is hardly accessible to the farmers in Eurasia. Therefore, all project reports and expert opinions were translated into the language of the respective country.
- Participating in workshops, field days and visits to other farms working in a similar sphere can be helpful in expanding agronomic knowledge. It prevents the same mistakes being made multiple times on different farms. It can be assumed that all mistakes during the conversion to direct seeding have been made before and that solutions were also found, irrespective of the country or region.
- Another significant source of knowledge is learning by doing. As described above, processes such as seeding new cultures using new machines must be tested several times under the respective conditions by the farmers themselves. The agronomic timing of the individual process steps can only be derived from the farmers' own experiences.

5.b Political requirements, potential funding

Generally speaking, the intensity of land use desired by politics and the orientation towards alternative crops can be achieved by appropriate subsidies. These could be granted for suitable agricultural equipment (see chapter 4), resources or in relation to the arable land. Subsidies for diesel are often granted in CIS countries to this day which naturally contradicts the idea of soil protection by forgoing black fallow periods, among other things.

Mineral fertilizers and herbicides should be subsidized instead. Converting to sustainable farming systems requires higher investments per hectare of cultivated crop. The farms do not have the financial liquidity at their disposal to meet this increased demand for investment. With regard to agricultural equipment, the purchase of suitable universal seeders and field sprayers should be subsidized instead of the purchase of tillage machines.

Another precondition which can and must be controlled by politics is the marketing of alternative crops. If land users do not have a possibility to sell the new crops, they will only grow traditional grains. Mongolia, for instance, would have a huge neighboring market for oilseeds and grain maize in China.

Moreover, politics should organize and foster knowledge transfer regarding the new methods. The following measures would be beneficial and imaginable in the case of Mongolia:

- Provision of relevant journals, books and consulting materials in the national language;
- Creation of a website for the dissemination of knowledge and the exchange of information among farmers;
- Mutual visits between farmers from similar agro-geographical regions, including international exchange (e.g. Kazakhstan, Canada);
- Training state-licensed consultants to advise the farmers;
- Establishment of laboratories which assess the soil quality according to international standards and develop appropriate fertilization recommendations;

- Establishment of research facilities in the relevant regions to evaluate and present the new methods;
- Organization of workshops covering topics such as plant protection and fertilization strategies on a regular basis;
- Training staff on modern agricultural equipment.

Particularly the international exchange between farmers often leads to extremely positive effects. The trips of Russian farmers to Germany and Canada organized as a part of the KULUNDA project as well as the visits of innovative German farmers to the project region produced new perspectives and approaches for all sides on how to improve land use in the respective regions both economically and ecologically.

Another idea would be CO_2-trading at national level in the future. Energy-intensive industries with high CO_2 emissions could acquire certificates from the farmers who actively sequester carbon in the soils through sustainable land use. Systems like these have already been introduced in Canada, for instance https://thecarbonfarmer.ca.

REFERENCES

AMAZONEN-WERKE (2019): https://info.amazone.de/DisplayInfo.aspx?id=45910

Erdenebolor B. & Nyamgerel B. (2019): Der mongolische Ackerbausektor im Überblick –natürliche, agrar politische und institutionelle Rahmenbedingungen. Ulaanbaatar: Deutsch–Mongolisches Kooperationsprojekt Nachhaltige Landwirtschaft.

Balesdent J. et al. (1988): Soil organic matter turnover in a long-term field experiment as a revealed by carbo-13 natrual abundance. Soil Sci. 52, 118-124.

Belyaew V.I., Frühauf M. & Meinel T. (2014): Vergleichende Untersuchungen zum Bodenerosionspotential und der Ertragsbildung bei konventioneller und konservierender Grundbodenbearbeitung und verschiedenen Brachevarianten in der Steppenzone der Altairegion. (russ.). Journal der Staatlichen Agraruniversität Barnaul, №1 (21), S. 11-17.

BOKU Wien (2015): https://www.wifo.ac.at/jart/prj3/wifo/resources/person_dokument/person_dokument.jart?publikationsid=58147&mime_type=application/pdf

Burke I. C. et al. (1989): Texture, Climate and Cultivation Effects on Soil Organic Matter Content in US Grassland Soils. In: Soil Sci. Soc. Am. J., Vol. 53, S. 800-805.

Campbell C. A., R. P., Zentner S. Gameda, B.; Blomert, D.; D. Wall (2002): Production of annual crops on the Canadian prairies: Trends during 1976–1998. Canadian Journal of Soil Science, 2002, 82(1): 45-57, 10.4141/S01-046.

Eule W. (1962): Das Problem der Neulandgewinnung in der Sowjetunion. Diss. Universität Bonn.

Fink A. (1969): Pflanzenernährung in Stichworten. Hirt, Kiel 1969.

Frank C. (2005): Wirksamkeit von dünnen Windschutzstreifen auf Sockelwällen in luv- und leeseitiger Anordnung, Dissertationsreihe am Institut für Hydromechanik der Universität Karlsruhe (TH)

Frühauf M. & Meinel T. (2003): Die geoökologischen Folgen der sowjetischen „Neulandaktion“ in Südsibirien. Geoöko. Bd. 24, S. 203-228.

Георгиев А.В. (1955): Год работы по освоению целины и залежных земель в Алтайском крае, Сельхозгис, Москва.

ГУГС (1977): Главное Управление Гидрометеорологической службы, (Хрсг, 1977): Справочник по климату Bd. 20, Новосибирск.

Grunwald Lars-Christian (2010): Geoökologische und agronomische Effekte der Schwarzbrache in Steppenregionen Russlands. Diplomarbeit zur Erlangung des akademischen Grades Diplom-Geograph (Dipl.Geogr.) Mathematisch - Naturwissenschaftlich - Technischen Fakultät, der Martin - Luther - Universität Halle/Wittenberg, unpublished.

Hassenpflug W. (1998): Bodenerosion durch Wind. In: Richter, G [Hrsg.]: Bodenerosion. Wissenschaftliche Buchgesellschaft, Darmstadt.

Houghton R. A. (1995): Changes in the storage of terrestrial carbon since 1850. In: Lal, R., Kimble, J., Levine E., Stewart B.A. (Hrsg.): Soils and Global Change. Boca Raton: CRC Press, 45-65.

Investigation of the National Land Survey Office of the Altai Krai (1951) unpublished.

Investigation of the GIPROSEM Institute/Barnaul (1969,1979): unpublished.

Klimadiagramme (2019): http://www.klimadiagramme.de
Костровский S. (1959): Пыльные бури в Алтайских степях, Сельское хозяйство Сибири, Омск Nr. 2S. 35ff.
Lafond G.P., May W.E., Stevenson F.C., Derksen D.A. (2006): Effects of tillage systems and rotations on crop production for a thin Black Chernozem in the Canadian Prairies. Soil & Tillage Research 89 (2006) 232–245.
Lal R., Kimble J., Llevine E.U., Stewart B.A. [HRSG.] (1995): Soil Management and Greenhouse Effect. Boca Raton, S. 25-40.
LMS Agrarberatung (2007): https://www.lms-beratung.de/de/
Mann L.K. (1986): Changes in Soil Carbon Storage after Cultivation. In: Soil Science, Vol. 142, Nr. 5, S. 279-288.
Martin Till (2019): https://store.martintill.com/content/2019%20Catalog%20V%20020719% 20Small%20 File%20size.pdf)
Morgan R. (1986): Soil Erosion and Conservation. Longman, London.
PAMI & SSCA [publ.] (1998): Direct Seeding Manual, A farming system for the new millennium. Prairie Agricultural Machinery Institute (Canada), Saskatchewan Soil Conservation Association, Saskatchewan. Saskatchewan Agriculture and Food, Humboldt, Sask.
Rostankowski P. (1979): Agrarraum und Getreideanbau in der Sowjetunion 1948-1985. Duncker & Humblot, Berlin.
Росстат (2015): https://www.gks.ru/storage/mediabank/selhoz15.pdf
Scheffer P., Blume H.P., Brümmer G. et al (1992): Lehrbuch der Bodenkunde. Ferdinand Enke, Stuttgart.
Sources of Kolkhoz Grishkovka (2000): unpublished
Späth H.J. (1980): Die agro-ökologische Trockengrenze in den zentralen Great Plains von Nord-Amerika. Steiner, Stuttgart.
Statistics Canada (2009): http://www5.statcan.gc.ca
Väderstadt 2019: https://www.vaderstad.com/en/drilling/seed-hawk-air-seeders/seed-hawk-opener/
VDLUFA (2019): https://www.vdlufa.de
Wein N. (1983): Die sowjetische Landwirtschaft seit 1950. Blutenberg-Verlag, München.
Wein N. (1980): Fünfundzwanzig Jahre Neuland. In: Geogr. Rundschau 32 H. 1.

ASSESSMENT OF CLIMATE CHANGE IMPACTS ON THE ARABLE FARMING SECTOR OF MONGOLIA

MODELLING OF EXPECTED YIELD DEVELOPMENTS IN SPRING WHEAT AND POTATO PRODUCTION

Authored by:

***Dr.* Noleppa S.**
***Dr.* Hackenberg I.**
Federal Republic of Germany, HFFA Research GmbH
Email address: office@hffa-research.com

CONTENT

ACKNOWLEDGEMENT

This report has been prepared as a contribution to the German-Mongolian Cooperation Project on Sustainable Agriculture (DMKNL). The DMKNL is led by IAK Agrar Consulting GmbH and funded by the German Federal Ministry of Food and Agriculture within its Bilateral Cooperation Programme.

The authors particularly wish to thank Dr. Alfred Kather and Dr. Erdenebolor Baast for their valuable inputs and comments during the preparation of this report. The results of this study, however, are the sole responsibility of the authors.

1. INTRODUCTION

Climate change has become one if not "the" dominating socio-economic and environmental challenge of the 21st century for every country at the global scale. This particularly applies to the Asian country of Mongolia, where the impacts of a rapidly warming climate have become alarmingly manifest in recent years. Mongolian air temperatures have risen at a rate three times faster than the global average in the past seven decades *(WPR, 2019; Tuul, 2012)*. This, in turn, poses huge challenges for the Mongolian agricultural sector as both, animal husbandry and arable farming, are very dependent on any changes occurring in the weather patterns and the related climatic conditions.

Taking the above argumentation as a point of departure, it is the overall objective of this paper to assess the current and future climate change impacts on the arable farming sector of Mongolia. The cases of spring wheat and potato production will therefore be used, and more particularly, the expected yield developments in these two arable crops will be assessed and modelled considering the potential impacts of future climate change.

In order to achieve this rather ambitious objective, a gradual analytical approach combining standard methodologies of agricultural economics and climate impact research is needed. The procedure applied is mirrored by the structure of this report as follows:

- The subsequent **chapter 2** will briefly discuss the arable farming sector in Mongolia, with an emphasis on spring wheat and potato production.
- **Chapter 3** will then concentrate on the major challenges the arable farming sector in Mongolia is currently facing. The importance of climate change issues will particularly be highlighted.
- Following up next, **chapter 4** will discuss the most recent and likely future developments of available yield and climate indicators at the regional, i.e. Aimag (or provincial), scale.
- Based on that, **chapter 5** will provide concrete scenario-based yield projections, focussing on trends as well as annual variations.
- Finally, **chapter 6** will derive several important conclusions.

2. ARABLE FARMING IN MONGOLIA: THE CASE OF SPRING WHEAT AND POTATO

In a historic context, arable farming can still be considered a rather young discipline in terms of economic activities in Mongolia. On a significant scale, arable farming mainly developed in the 1960s, when the sector was newly established as part of a large-scale government-led cultivation campaign. Accordingly, long-term experience and knowledge on cultivating arable crops are still scarce, production practices are often not well adapted to local conditions, and - compared to other countries - many industries related to the sector are still in their infancy.

In fact, Mongolian agriculture is still dominated by livestock farming and only 0.50 percent of all agricultural land (respectively 0.37 percent of Mongolia's total land area) *(FAO, 2019)* is currently used for crop cultivation. According to data provided by NSOM (2019), sown areas accounted for 524,300 hectares in 2017, and 507,900 hectares in 2018. Spring wheat (342,400 hectares), oilseed rape (OSR) (61,400 hectares), other cereals (24,400 hectares), and potato (12,900 hectares) were the major arable crops sown in the country in 2018 *(NSOM, 2019)*[1] . Fallow is practiced to a large extend on the remaining arable land.

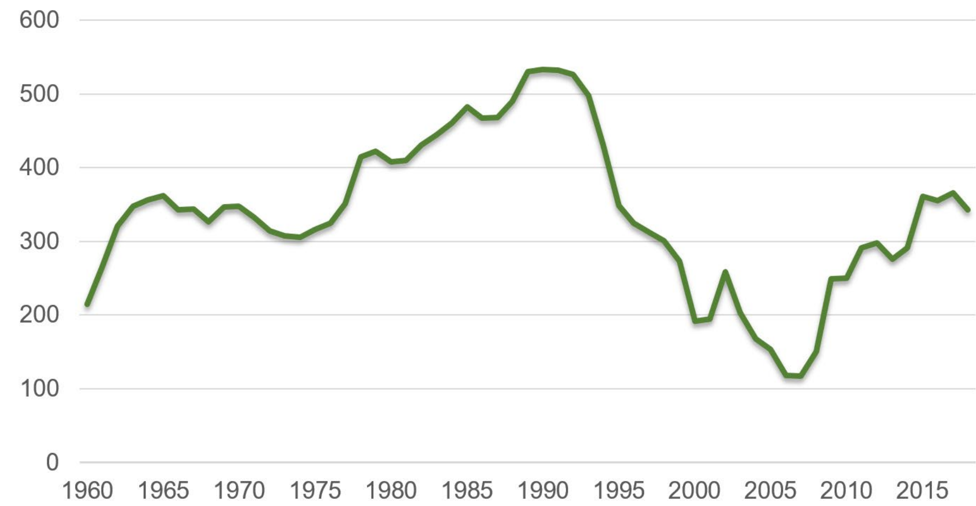


Figure 1. Development of spring wheat cultivated area in Mongolia from 1980 to 2018 (in 1,000 hectares). *(Source: Own figure based on NSOM (2019)).*

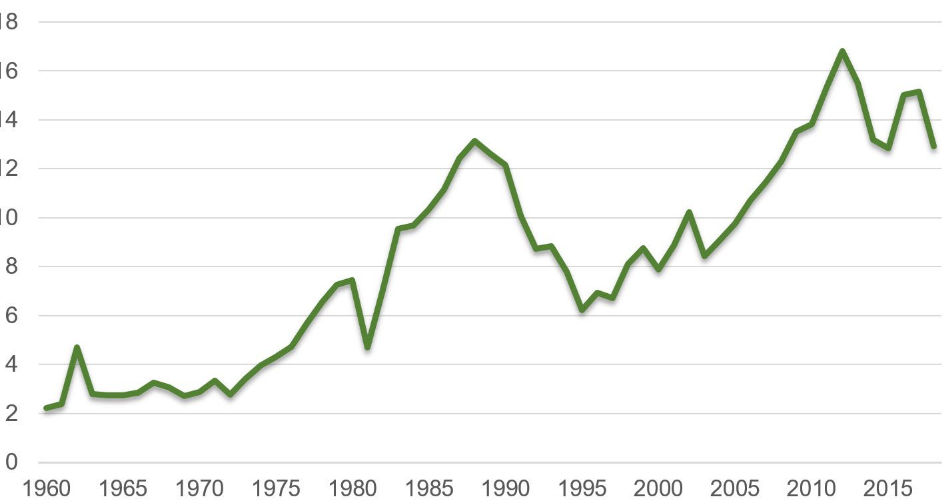


Figure 2. Development of potato cultivated area in Mongolia from 1980 to 2018 (in 1,000 hectares). *(Source: Own figure based on NSOM (2019)).*

[1] *Data on arable land use in Mongolia differs slightly depending on the consulted source. According to FAO (2019) data, arable land use in Mongolia accounted for 567,000 hectares in 2016/17, with spring wheat (366,000 hectares), OSR (38,000 hectares), other cereals (25,000 hectares), and potato (15,000 hectares) as the major arable crops sown in the country.*
[2] *From here on, this study will focus on the production of spring wheat and potato in Mongolia from 1980 onwards.*

Additionally, it can be stated that after a considerable expansion of the agricultural area and an increase in yields observed until around the early 1990s, the sector's production dropped drastically following the collapse of the former socialist system. During the subsequent economic crises hitting the country in the first years of transition in the 1990s, the cultivated area was considerably reduced. In this respect, the following two figures show the development of spring wheat **(Figure 1)** and potato **(Figure 2)** cultivated area from 1960 to 2018².

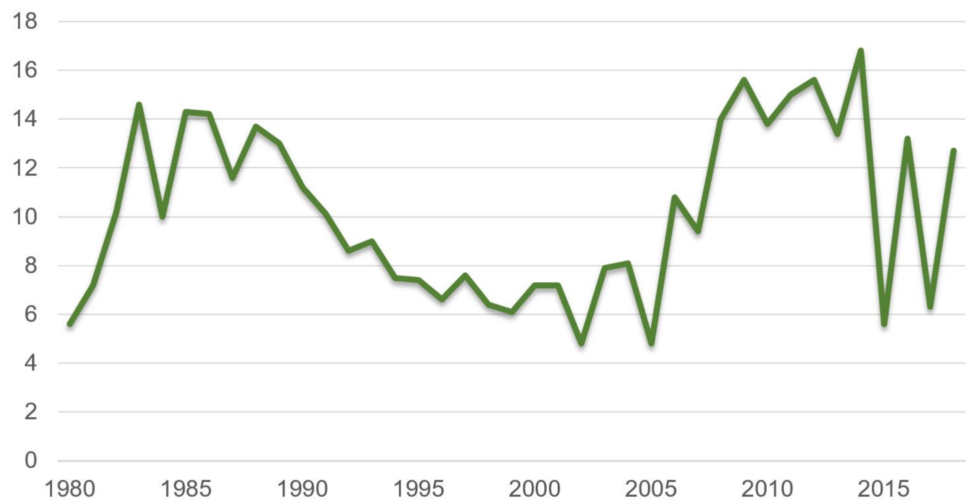


Figure 3. Development of the average yield for spring wheat in Mongolia from 1980 to 2018 (in 100 kilograms per hectare). *(Source: Own figure based on NSOM (2019)).*

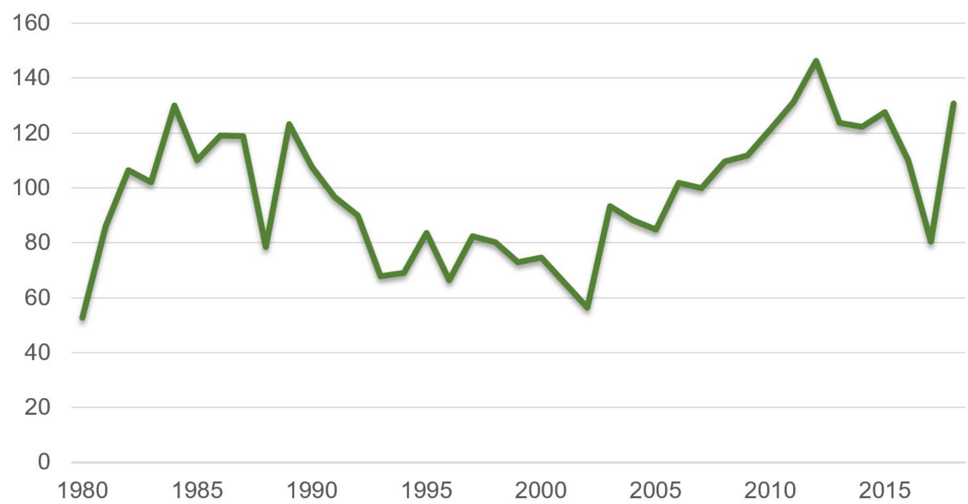


Figure 4. Development of the average yield for potato in Mongolia from 1980 to 2018 (in 100 kilograms per hectare). *(Source: Own figure based on NSOM (2019)).*

The decline in cultivated area from 1990 onwards is clearly visible, but also the recent increase during the past decade, i.e. between 2000 and 2010. In fact, the "Third Campaign for Reclamation", which was launched by the Mongolian government in 2008 in an effort to achieve improved food self-sufficiency (see, e.g., Priess et al., 2011), led to a recovery of the arable farming sector in the succeeding years *(MET, 2018)* reflected in a

renewed increase in cultivated area and also in an improvement in hectare yields.

In this respect, **Figure 3** (spring wheat, on this page) and **Figure 4** (potato, see next page) show the yield developments for Mongolian spring wheat and potato between 1980 and 2018 at the national level. The marked loss in land productivity following the end of the socialist period in the 1990s becomes evident in both crops as does the recovery of yields starting around the mid-2000s.

The two figures 3 and 4 also show that yields can vary strongly from year to year, especially in spring wheat, where extreme fluctuations have been observed, for instance, most recently between 2014 and 2018:

- In 2014, the average spring wheat yield in Mongolia was 1.68 tonnes per hectare; one year later, only an average of 0.56 tonnes per hectare were harvested.
- After recovering in 2016, yields fell again in 2017 to only 0.63 tonnes per hectare, whereas last year yields rose again to 1.27 tonnes per hectare.

Despite the ups and downs over time and most recent variability, yields have generally followed a positive trend since 1980 and particularly from 2000 onwards. This becomes apparent when looking at **Figure 5**, showing the linear and exponential trends for spring wheat and potato yield development during different periods be-tween 1980 and 2018.

Trend	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear	+4.3	-22.6	+33.4	+62.2	-142.0	+304.5
Exponential	+0.3	-2.3	+3.3	+0.6	-1.4	+3.2

Figure 5. Trends in yield development for spring wheat and potatoes in Mongolia from 1980 to 2018 (linear trend in kilogram per hectare and year; exponential trend in percent per year) *(Source: Own calculations and figure based on NSOM (2019)).*

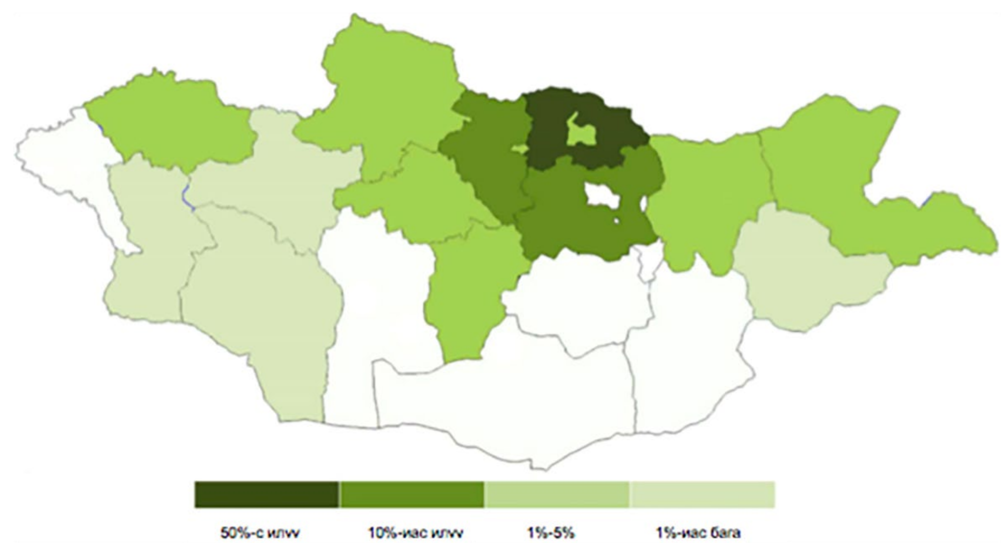


Figure 6. Share of each Aimag in total spring wheat production in Mongolia from 2013 to 2017. *(Source: Baast and Nyamgerel (2018)).*

Having experienced such massive changes in recent decades, it can be stated that currently spring wheat is by far the most important crop in arable farming of Mongolia with a total cultivated area of 342,366 hectares and a total production volume of 436,114 tonnes in 2018 *(NSOM, 2019)*. Production is thereby strongly concentrated in the Selenge Aimag (surrounding the Darkhan-Uul Aimag) in the central-northern part of the country, where 41 percent of spring wheat cultivated area is located, and 42 percent of the total production was harvested in 2018 *(NSOM, 2019)*. Other important production regions are the Tuv Aimag and the Bulgan Aimag, as visualized in **Figure 6**.

Similarly, **Figure 7** displays where potato is mainly cultivated in Mongolia. It turns out that potato was grown on an area of 12,924 hectares in 2018 with a total production volume of 168,882 tonnes *(NSOM, 2019)*. In this respect, it is furthermore worth to note that:

- while only around 2.5 percent of cultivated area in the country is used for potato production,
- the crop is one of the major staple foods of Mongolian population and therefore seen as very important to ensure food stability and security of the Asian country.

As such, potato is produced in all Aimags. However, production is again highly concentrated in the Tuv Aimag and Selenge Aimag in the central-northern part and major agricultural region of Mongolia.

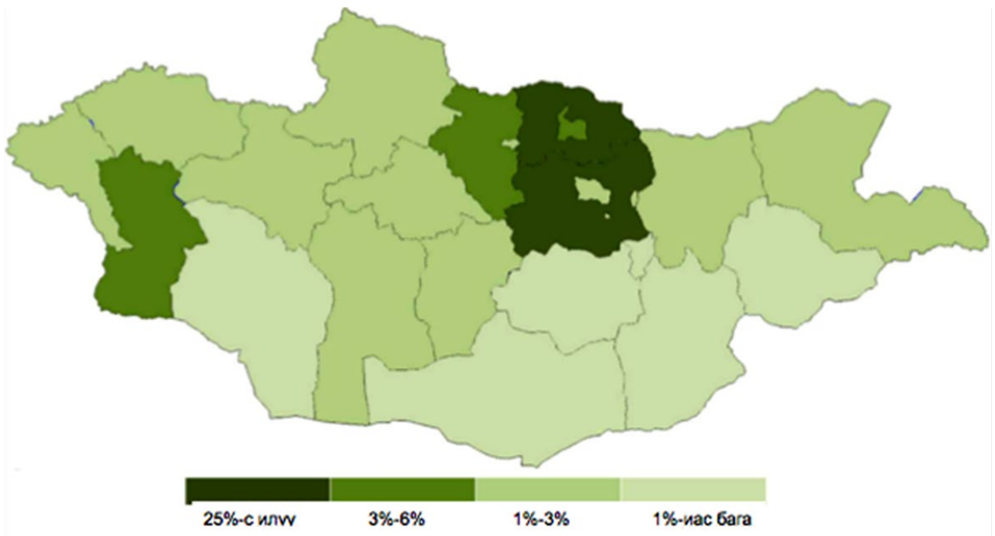


Figure 7. Share of each Aimag in total potato production in Mongolia from 2013 to 2017. *(Source: Baast and Nyamgerel (2018)).*

3. CHALLENGES FOR ARABLE FARMING IN MONGOLIA WITH SPECIAL EMPHASIS ON CLIMATE CHANGE

Although the agricultural sector has somewhat recovered from the downturn experienced in the 1990s and 2000s, today's arable crop production in Mongolia still faces considerable problems. The sector has long been constrained by the lack of financial resources. As a result, enough inputs to ensure a modern and sustainable agricultural production - including fertilizers, plant protection products, modern machinery, high-quality seeds, etc. - are lacking in the country or can currently not be provided in an adequate

quality. Furthermore, as the sector is rather young many related value chain segments such as the plant breeding sector are still under development, often lack the necessary financial resources and need a considerable knowledge transfer to grow.

Adding to these socio-economic constrains, Mongolia's environmental conditions can make crop production extremely difficult. Mongolian soils have a relatively low humus content, and studies have consequently revealed the general soil fertility to be low *(see, e.g., Baast and Nyamgerel, 2019)*. Accordingly, nearly 60 percent of agricultural soils have low nitrogen contents, 55 percent have low potassium contents and around 35 percent of agricultural soils have low levels of phosphorus. To make things worse, Baast and Nyamgerel (2019) also report that around 96 percent of agricultural soils in Mongolia are affected by strong to moderate erosion, and the share of strongly eroded agricultural soils in Mongolia has been rapidly rising in past 20 years.

These conditions already represent many challenges for Mongolian agriculture. However, one of the biggest challenges for Mongolian arable farming - if not the most important one - is posed by the country's harsh and strongly continental climatic conditions and changes thereof. A usually rather short vegetation period normally lasting from May to September, low and erratic rainfall of 200 to 300 mm on average and extremely low winter temperatures (which can regularly reach -30 °C in the coldest month of January) only allow the cultivation of early maturing spring crops such as spring wheat, potato and certain fodder crops. Due to the extremely hot temperatures reached in the summer season *(Batima et al., 2005)* paired with a limited water availability in many parts of the country, even the cultivation of this small spectrum of arable crops can routinely become a risky business.

Where irrigation cannot be provided, arable farming is therefore extremely dependent and influenced by each year's (often highly variable) weather conditions, and es-pecially by often occurring droughts. Indeed, with annual precipitation ranging from 110 to 140 mm in the south and western regions, from 200 to 230 mm in the eastern regions, and from 220 to 350 mm in the northern and central regions of the country, Mongolia is a rather vulnerable country in terms of overall climatic conditions. In fact, although most rainfall is registered during summer and autumn and winters can be extremely dry *(Batima et al., 2005)*, precipitation patterns are very variable from year to year, and annual rainfall patterns can also differ strongly from region to region. Consequently, it is this regional and temporal variability of precipitation patterns that poses a huge challenge to agricultural crop production in the country, with the regular occurrence of droughts considered as one of the main factors responsible for causing the huge production losses experienced by farmers in recent years *(MET, 2018)*.

Mongolia's extreme climatic conditions might now be even further exacerbated by the effects of surging global climate change. In its Third National Communication under the United Nations Framework Convention on Climate Change (UNFCCC), two unfavourable climate-related developments have been reported for Mongolia *(MET, 2018)*:

- an increase in annual mean near-surface temperatures of 2.24 °C between 1940 and 2015 and
- a small decrease of seven percent in annual precipitation during the same time horizon.

If related to the vegetation period (i.e. crop growing period), both developments, increasing temperatures and slightly lower rainfall, act to increase the risk of drought and, hence, of unfavourable conditions for agricultural production. In fact, researchers have warned that the rising temperatures and uncertainties in rainfall associated with global warming in Mongolia are likely to increase the (a) frequency and (b) magnitude of climate variability and extremes, increasing the risk of negative im-pacts on agriculture and other economic activities in the country *(Batima et al., 2005)*. Therefore, it is not surprising at all that periods of drought have already been reported to increase since 1940, especially droughts occurring in consecutive years *(MET, 2018)*.

Yet again, research has shown that annual drought events are seldom related between different sites, often showing no correlation regarding when and where precipitation deficits occur *(Sternberg, 2018)*. Certainly, one of the specific traits of precipitation distribution in Mongolia is that the changes in annual precipitation have a very localized character, decreasing at one site and increasing at another (often even located nearby). Moreover, in the face of the multitude of different factors affecting the Mongolian productivity of the agricultural sector, isolating the influence of climatic conditions and climate change on crop yields proves to be a challenging endeavour. Because of this, some researchers find little value in focusing on countrywide averages of climate change indicators at the local level *(Batima et al., 2005)*.

In the face of these most likely locally diverging conditions and climatic developments, the remainder of this study will focus on assessing the expected impacts of climate change on the Mongolian arable farming sector at the scale of individual Aimags - and specifically on the spring wheat and potato yields per Aimag - by 2050[3]. Data of altogether eight Aimags (and weather stations located in these Aimags) is used:

- Uvs (Baruunturuun),
- Dornod (Khalkhgol),
- Xo'vsgol (Tarialan),
- Khentii (Undurkhaan),
- Darkhan-Uul (Darkhan),
- Tuv (Ugtaal),
- Selenge (Tsagaannuur), and
- Arkhangai (Tuvshruulekh).

The following discussion, however, concentrates on two of the major agricultural production regions, i.e. the Selenge Aimag with respect to spring wheat and the Tuv Aimag as regards potato. Respective information for the two crops in all Aimags can be obtained from the supplemental material.

4. YIELD DEVELOPMENT AND CLIMATE CHANGE IN MONGOLIA AT THE AIMAG LEVEL

It has been briefly highlighted above that many factors have influenced the development and performance of Mongolian arable farming over the last 30 years and that climatic conditions are a strong determinant for overall agricultural and especially land

[3] As Mongolian agriculture is mostly based on animal production - 30 percent of the population are currently dependent on livestock farming *(Sternberg, 2018)* - there is ample literature covering the (past and potential future) impacts of recurring droughts and more particularly dzud conditions on animals and herders *(see e.g. Middleton et al., 2015; Miao et al., 2016; Nandintsetseg et al., 2018)*. However, to our best knowledge, research assessing the potential impacts of climate change on the arable farming sector of Mongolia is still lacking. The following should there-fore be considered a first attempt towards filling this still existing knowledge gap.

productivity. Therefore, it makes sense to start the impact analysis by looking at regional yield developments in recent years. In this context, Figure 8 displays the annual variations of spring wheat yield in the Selenge Aimag vs. its trend since the turn of the millennium[4]. The greener (redder) the cells in the last column are, the higher the positive (negative) variation of observed yield data from the regional trend (which accounts for an annual yield increase of 4.8 percent, and is therefore well above the national average of a 3.3 percent yield increase since 2000 (see **Figure 5**)).

It turns out that individual years show a remarkable topping up vs. the regional yield trend. In the years 2008 and 2009, for instance, 50 percent more spring wheat could be harvested per hectare than the yield trend would have suggested. However, there are also a couple of years - altogether six since the turn of the millennium - which show a (partly) considerable yield underperformance. In the years 2002, 2005 and 2015, for instance, approximately half of the expectable yield could only be harvested.

Year	Observed yield (in 100 kilograms)	Trend yield (in 100 kilograms)	Observed vs. trend (in percent)
2000	8.3	6.6	25.7
2001	6.1	6.9	– 11.9
2002	3.6	7.3	– 50.4
2003	8.2	7.6	7.9
2004	8.9	8.0	11.7
2005	3.8	8.3	– 54.5
2006	11.0	8.7	25.7
2007	10.0	9.2	9.1
2008	14.8	9.6	54.0
2009	15.5	10.1	53.9
2010	13.8	10.6	30.8
2011	14.5	11.1	31.1
2012	17.1	11.6	47.5
2013	13.5	12.1	11.1
2014	17.8	12.7	39.8
2015	5.8	13.3	– 56.5
2016	16.8	14.0	20.2
2017	9.8	14.7	– 33.1
2018	13.1	15.4	– 14.7

Figure 8. Variations of observed yield vs. trend yield data for spring wheat in the Selenge Aimag from 2000 to 2018. *(Source: Own figure based on own calculations based on NSOM (2019)).*

[4] The analysis starts with the year 2000 in order to remove the bias related to the economic crisis in first years of transition (see **Figure 3**). It uses the exponential trend, i.e. the determination of an annual percentage change, to better fit the yield forecast model used below. This model basically works with log-linear (yield) production functions and therefore needs pivotal shift factors explaining climate impacts on yield in terms of percent.

An almost similar picture can be drawn for potato production in the Tuv Aimag as visualized by **Figure 9**. Again, six years after the turn of the millennium show a (partly) considerable underperformance, but huge positive variations are also observable, for instance in the year 2012 (2003), when much more potato could be harvested than expected in accordance to the regional trend, which is based on a 4.5 percent yield increase per annum (compared to a national trend of 3.2 percent (see **Figure 5**)).

Year	Observed yield (in 100 kilograms)	Trend yield (in 100 kilograms)	Observed vs. trend (in percent)
2000	67.8	64.6	5.0
2001	51.2	67.5	– 24.1
2002	33.1	70.5	– 53.1
2003	105.2	73.7	42.8
2004	83.6	77.0	8.6
2005	80.3	80.5	– 0.2
2006	95.6	84.1	13.7
2007	86.2	87.9	– 1.9
2008	95.2	91.8	3.7
2009	112.7	95.9	17.5
2010	127.5	100.3	27.2
2011	136.6	104.8	30.4
2012	199.6	109.5	82.3
2013	132.8	114.4	16.1
2014	121.8	119.6	1.9
2015	153.5	125.0	22.8
2016	105.6	130.6	– 19.1
2017	60.5	136.4	– 55.7
2018	142.6	142.6	0.0

Figure 9. Variations of observed yield vs. trend yield data for potato in the Tuv Aimag from 2000 to 2018. *(Source: Own figure based on own calculations NSOM (2019)).*

The two regions also show remarkable annual changes in some important climate indicators, as visualized by **Figure 10**. This figure displays the variations of the "accumulated growing period degree days" (i.e. the sum of daily mean temperatures)[5] and the precipitation volume from May until August (representing the months that should be considered most crucial for biomass accumulation in arable crops like spring wheat and potato) from 2000 to 2018 in the two Aimags of Selenge and Tuv.

[5] The usefulness of the "accumulated growing period degree days" concept in cli-mate change analysis has been proven, for instance, by Sommer et al. (2013).

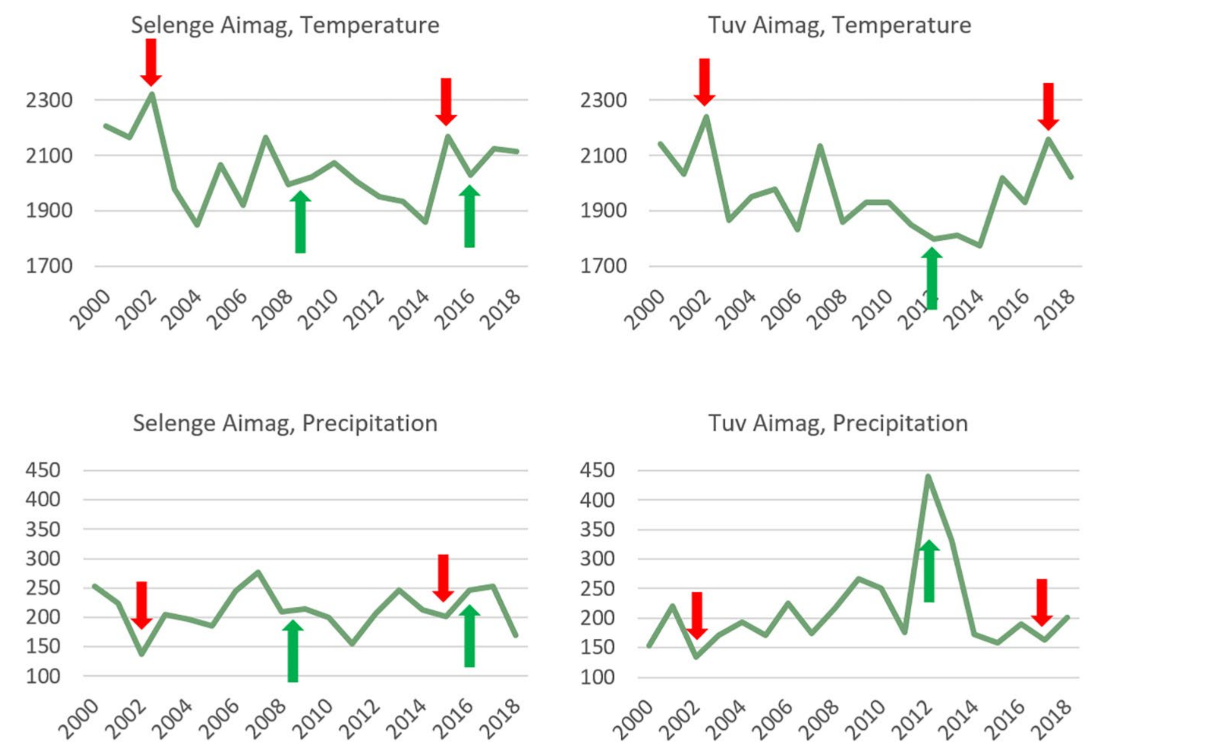


Figure 10. Development of the accumulated growing period degree days (in °C-days) and precipitation volume (in mm) between May to August in the Selenge Aimag and Tuv Aimag from 2000 to 2018 *(Source: Own calculations and figure.)*

It has been stated previously that longer dry periods, i.e. periods with comparably higher temperatures and/or less precipitation, are to be considered major climatic events in Mongolia, having strongly negative effects on the country's crop yields. This is partly mirrored by **Figure 10** (see the red arrows):

- The low spring wheat yields in the Selenge Aimag in 2002 or 2015, for instance, may be related to the rather high accumulated daily temperatures observed during these growing periods, accompanied by relatively low levels of precipitation.
- Also, and to take another example, the rather low potato yields in the Tuv Aimag in 2002 or 2017 may be related to the high temperatures and lower than average precipitation levels observed during those seasons.

In opposite to that, it can also be observed that in years with rather good yields, such as 2008/09 and 2016 in the case of spring wheat and 2012 in the case of potato, high yields tend to coincide with rather high (if not extraordinarily high) precipitation levels and modest temperatures during the respective vegetative periods (see the green arrows in **Figure 10**). In addition, it needs to be taken into account that the short-term distribution of precipitation is particularly important, as water availability is essential during specific growth stages of the crop. In the case of wheat, this normally applies to the weeks between early June and the beginning of July (until the start of the reproductive stage).

Not only therefore, drawing conclusions from the above observations is not that simple, and these data are far from allowing one-to-one yield predictions based on temperature or precipitation levels as additional influencing factors will certainly need to be considered.

Indeed, the visualisation in **Figure 10** is only based on monthly data from two selected weather stations (one per Aimag). Two aspects are worth mentioning in this respect:

- It has been found that, too often, certain weather events can occur that are very local and short-term, such as late frosts, storms, etc. that may have a huge local impact on harvests and, thus, lower a region's average yields. Monthly data tend to blur extreme events like these. This context, in combination with the fact that "climate" studies focussing on Mongolia are still comparably rare, makes forecasting the countries yield developments a challenging task.
- The challenge becomes even greater when considering that there is only a lim-ited number of weather stations permanently operating in the country[6], while on the other hand certain events are too local to be measured by weather stations that - on average - are located 200 to 300 km away from each other *(MET, 2018)*. In Mongolia there currently is only one weather station per 11,800 square kilometres *(MET, 2018)* (compared to other countries with a rather low population density such as nearby Kazakhstan with one station for every 8,200 square kilometres or Iceland with one per 1,470 square kilometres). This means, in turn, that much detail is lost due to issues of scale, and that results may differ once measurements become available on a more detailed level *(Sternberg, 2018)*. In addition, the automated weather stations network of Mongolia has been reported to consist of different types of stations installed by different companies from different countries, creating an additional challenge for the comparability and usability of the data *(MET, 2018)*.

5. YIELD PROJECTIONS FOR SPRING WHEAT AND POTATO IN MONGOLIA: AN APPLICATION OF SCENARIO ANALYSIS

It is condensed scientific wisdom that sound scenario analysis should be applied whenever the information basis and data background are still rather weak - as it is the case in the Mongolian context. Therefore, the following yield projection approach is not only based on the particularities already discussed above but also on additional academic findings gathered via a substantial meta-analysis. As data availability for Mongolia is generally limited, scientific arguments concerning the greater Mongolian Plateau *(see, e.g., Miao et al., 2016)* are additionally included into this analysis in order to build the (scenario) forecasting of yields for spring wheat and potato in the country upon the soundest knowledge base possible.

It has been stressed above that Mongolian yields as regards spring wheat and potato have on average (considerably) increased since the turn of the millennium onwards, and that many factors may have contributed to this increase. But to what degree, if any, have these yield developments been influenced by climate change? To answer this question, a distinction needs to be made between the obvious, i.e. observable, yield developments affected by ongoing climate change and (potential) yield development without climate change.

Economists prefer to use the total factor productivity (TFP) growth rate approach to assess an unbiased (in this context also: not influenced by climate change) productivi-ty increase over time and relate this to annual yield improvements, i.e. gains in land productivity *(see, e.g., Lotze-Campen et al., 2015)*. Unfortunately, the TFP data background

[6] More precisely: 135 meteorological stations were reported to be operating in ac-cordance with the standard programme of the World Meteorological Organization (WMO) in 2018 *(MET, 2018)*.

as regards Mongolia can be described as rather weak and highly uncertain. Most recently, annualised TFP growth rates (which somehow can be related to Mongolian crop production) bridge an interval raging from -2.2 percent (IFPRI, 2018) to 3.1 percent *(Fuglie, 2015)* percent - also including 0.6 percent *(Fuglie, 2012)*.

One might argue now that the likely yield increase without climate change is somewhere within this interval and consequently assume various growth rate levels. And indeed, this may act to accentuate the following analysis which in opposite will solely focus on a very specific growth rate value. In fact, we will make use of already existing yield forecast values for Mongolia. According to FAO (2018a)[7], the following yield increases - already including a climate change impact - can be expected:

- 1.15 percent per annum in the case of spring wheat and
- 1.10 percent per annum in the case of potato.

Using such as level can be considered appropriate as IFPRI (2018) most recently has also calculated with a general land productivity (yield) increase in Mongolia of slightly above 1.1 percent per year.

The just mentioned yield improvements already incorporate the current climate change impact. The question is: How large is the partial impact of climate change exactly? FAO (2018a) assumes that the region Mongolia belongs to may experience a general yield loss per hectare of eight percent or slightly more than 0.2 percent per year until 2050. Other academic findings support this outcome and provide further evidence that climate change, by means of annual changes in the weather patterns, tends to lower spring wheat and potato yields in Mongolia:

- Chen et al. (2018), for instance, arrive at the conclusion that wheat yields in the Mongolian Plateau region will decrease by 15 to 25 percent within 100 years due to climate change. This corresponds to an average decrease by a rate of 0.15 to 0.25 percent per year.
- According to Zhao et al. (2017), each °C of mean temperature increase registered in the greater continental region that Mongolia belongs to can be related to a decrease in wheat yields of six percent. Since Tuul (2012) as well as WPR (2019) point at a temperature increase of 0.3 °C per decade, an increase in the mean temperature by 1.0 °C would take only 33 years to happen. Consequently, following the argumentation of Zhao et al. (2017), an annual wheat yield decrease of 0.18 percent could be assumed.
- Yield depressions because of climate change in Mongolia are further supported by findings of Tao et al. (2014) and Chavas et al. (2009). The latter authors also see a slightly (almost 20 percent) higher decrease in potato yields than in wheat yield.

Taking these findings as a point of departure for the upcoming scenario/forecasting analysis for spring wheat and potato yields, the following two scenarios are defined:

- In a business as usual (BAU) scenario with climate change - hereafter named "BAU with CC" - spring wheat and potato yields in Mongolia on average are assumed to increase until 2050 by 1.15 percent per year and 1.10 percent per annum respectively

[7] The forecast values are basically the outcome of a process led by FAO that heavily relied on in-house expertise, but also involved partnerships with other interna-tional institutions including the International Fund for Agricultural Development (IFAD), the Organisation for Economic Co-operation and Development (OECD), the International Food Policy Research Institute (IFPRI), the European Union (EU), and the Intergovernmental Panel on Climate Change (IPCC).

(i.e. in accordance to the growth rates published by FAO (2018a)). Regional differences between the various Aimags are thereby taken into consideration by gradually adapting currently observable yield trends to-wards the defined percentage values over time (until 2050).

- This "BAU with CC" scenario will then be contrasted by a BAU scenario without considering the effects of climate change - hereafter called "BAU w/o CC". In the case of spring wheat (potato), the now excluded climate change will lead to a counteracting yield increase of 0.2 (0.25) percent per annum between 2020 and 2050. The difference in yield growth between the two scenarios is the trend-related climate change effect over time.

Apart from assessing the overall yield trends in relation to climate change, it might be equally if not more important to assess the frequency and intensity of their annual variations. This is evidenced by the fact that most of the observed shocks hitting spring wheat and potato production in Mongolia in individual years between 1980 and 2012 are considered to be the result of adverse weather/climate conditions *(World Bank, 2015)*. Again, scientists arrive at a straightforward argument:

- Hessl et al. (2018), for instance, state that as temperatures continue to warm, the role of moisture delivery to Inner Asia in general, and particularly into Mongolian territory, becomes increasingly critical. As Mongolia is already strongly affected by droughts, the fact that precipitation levels are expected to stay rather constant will again increase the risk for additional droughts to occur. Therefore, Hessl et al. (2018) conclude that a drying trend can be expected in the region at least until the mid of the 21st century. This may be related both to the frequency as well as to the severity of droughts during upcoming years and decades.
- Sukh (2012) also states that the likelihood for hot temperatures, and especially for temperature extremes, is increasing. This is furthermore supported by Schubert et al. (2014), who - after undertaking a comprehensive literature analysis - arrive at the conclusion that the likelihood of heatwaves is increas-ing in a Eurasian context.
- Similarly, Chen et al. (2018) show that the probability of yield decreases associ-ated to droughts will rise with increasing temperatures in the region.
- Analyses conducted by Liu et al (2019) also support the assumption of a slight increase in the frequency of weather extremes with relevance to the growing period of arable crops.
- Finally, findings by Park and Min (2016) shall be highlighted here. The authors argue that both, the frequency as well as the intensity of warmer periods will increase in Mongolia.

In qualitative terms, the expected climate change impacts on yields in the country seem obvious. Both, the frequency as well as the intensity of weather extremes with the potential to have negative impacts on arable crop yields in Mongolia are expected to increase.

But what about the quantitative dimension? When attempting to answer this question, academic wisdom is less profound; but based on MET (2018) it can be assumed hereafter that both - the frequency of droughts as well as their relative intensity - are expected to increase by 15 percent until 2050. This will additionally be embedded into the "BAU with CC" scenario. Observed frequency and intensity of droughts in the past will be gradually

increased until 2050 to fit this assumption.

In order to now forecast the potential yield developments for spring wheat and potato in Mongolia until 2050 we will make use of a sophisticated modelling approach. Best would be to use one of the available crop growth simulation models adaptable to climate change issues such as DSSAT *(see, e.g., Eitzinger et al., 2017)*. However, these models need a lot of data - often daily figures on future temperatures, precipitation, solar radiation, etc. - in order not to be based only on assumptions.

It has been stated above that the corresponding data background in the context of this project is limited. Therefore, we do not apply such a more sophisticated but data consuming crop-climate model. Instead, we use a standard model of agricultural economics that (a) has been proven to be powerful for future-oriented simulations and (b) is capable of internalising and operationalising climate change by proper so-called shift factors. Basically, our model is a combination of:

- a system of log-linear (Cobb-Douglas), pivotal moving crop-region-specific production (or yield) functions and
- a stochastic climate generator using randomized extrapolated trends, frequencies and intensities of historically available monthly temperature and precipitation data. More simplified, the underlying algebra of the applied forecasting/projection model can be summarized as stated with the following equation (E.1):

$$q_{l,g}(p_{m,l,g}) = b_{l,g} \cdot (\prod_{m=1}^{w} (p_{m,l,g})^{\varepsilon_{m,l,g}}) \cdot c_{l,g} \qquad \text{(E.1)}$$

where:

$q_{l,g}$ = quantity harvested (yield) of commodity l in region g,
$b_{l,g}$ = constant parameter (calibration factor) for that yield,
$p_{m,l,g}$ = production (input) factors m for commodity l in region g,
$\varepsilon_{m,l,g}$ = elasticity of production (input) factor m for commodity l in region g,
m = 1, …, w = set of production factors,
$c_{l,g}$ = climate related pivotal shift factor for commodity l in region g.

Results of simulated calculations

Applying the model described above to the scenarios defined above leads to the following outcome. First, the situation for spring wheat in the Selenge Aimag is presented in **Figure 11**. It displays four graphs. In the upper left box, the "BAU with CC" scenario is contrasted with the "BAU w/o CC". In a world of non-changing climate, Mongolia - specifically the Selenge Aimag - will experience considerable spring wheat yield growth within the next 30 years. Yields may increase by more than 40 percent if adaptation of technological progress continues (see the "BAU w/o CC" trend line). Climate change as forecasted by FAO (2018a), however, will act to decrease the growth in spring wheat yield (see the "BAU with CC" trend line): In 2050, the yield decline may accumulate to approximately 150 kilograms per hectare. Average yields with climate change would therefore be six percent lower than without climate change.

This trend already marks a considerable negative climate change impact. However,

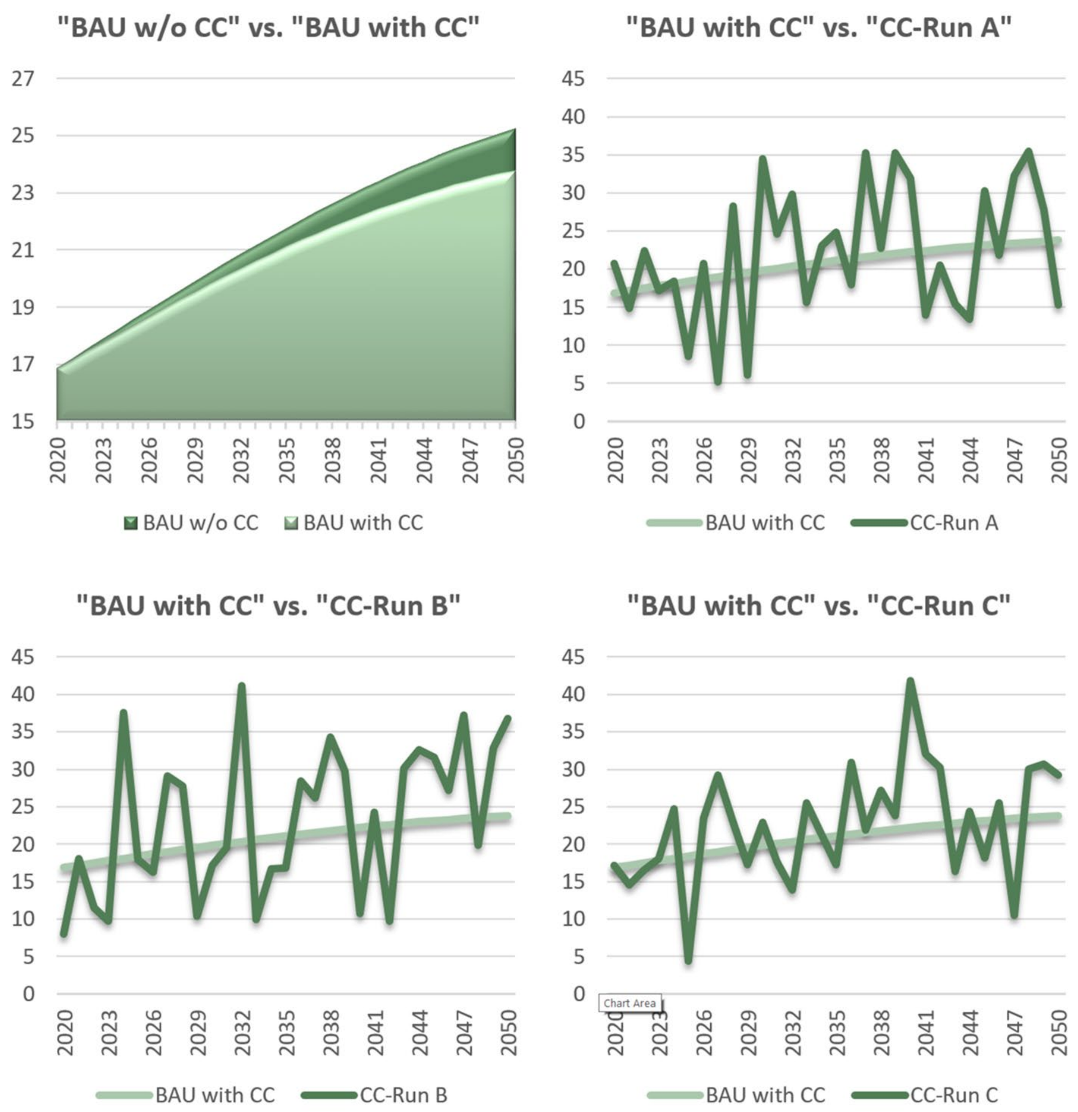


Figure 11. Expected spring wheat yield developments in the Selenge Aimag from 2020 to 2050. (its trend (upper left box) and three runs of randomized annual variations (other three boxes)) (in 100 kg per hectare) *(Source: Own calculations and figure).*

this trend impact should not be overemphasised. In fact, it is much more important to look at the annual variations of this trend, which are exemplary depicted in the three other boxes of **Figure 11**. In fact, these boxes make it evident that huge yield fluctuations will continue to occur in the future, with the potential to lead to (at least in part) devastating situations. The following two examples may serve to better explain what the expected outcomes could mean in practice, given the defined scenarios:

- In the randomized climate change run A ("CC-Run A"), a rather low spring wheat yield of approximately 0.6 tons per hectare in 2029 would be contrasted by a com-parably high yield of more than 3.4 tons per hectare in 2029. The lat-ter being 70 percent higher than the expected trend value.
- The randomized climate change run C ("CC-Run C") also marks potentially low

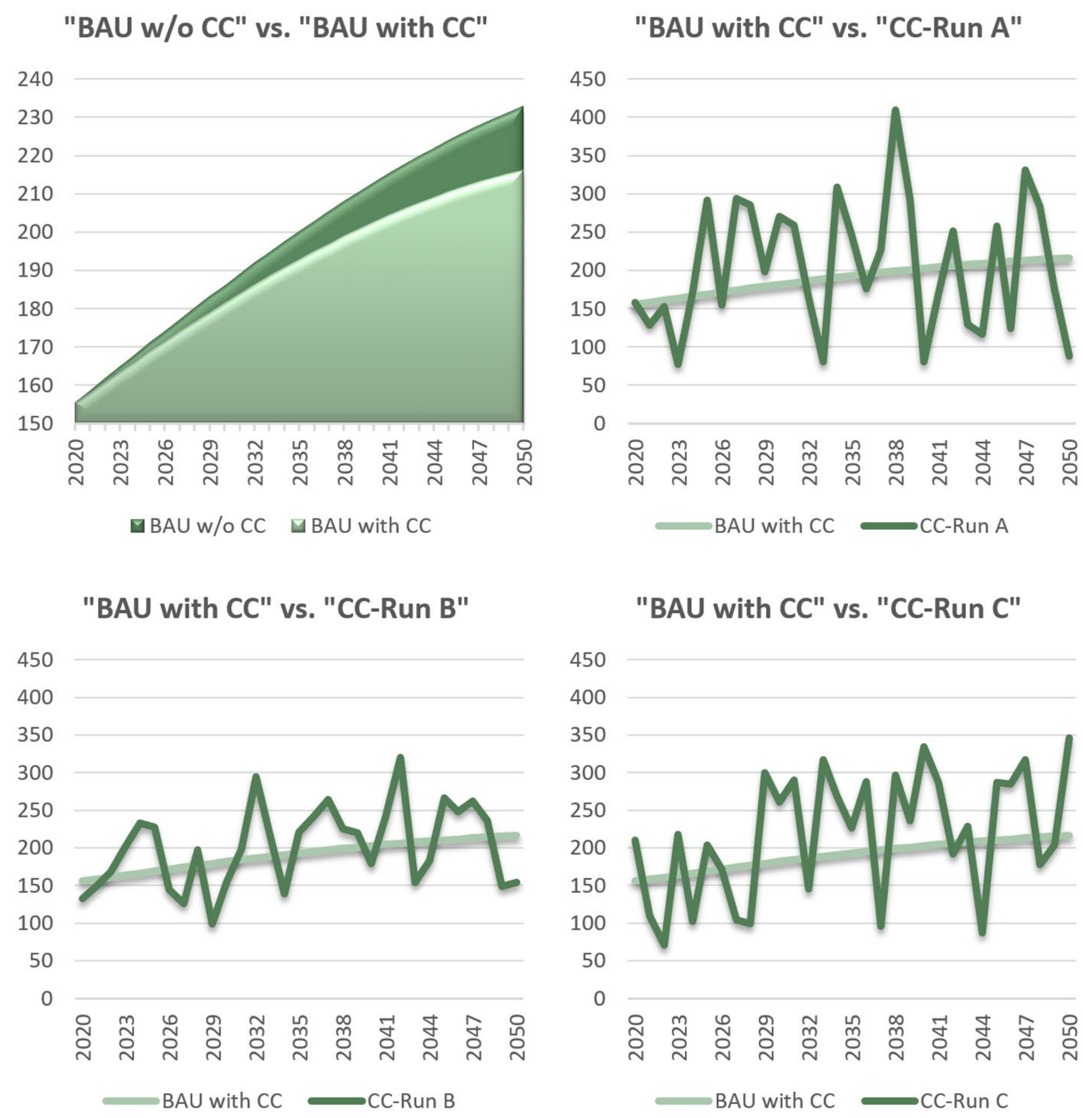


Figure 12. Expected potato yield developments in the Tuv Aimag for 2020 to 2050. (its trend (upper left box) and three runs of ran-domized annual variations (other three boxes)) (in 100 kg per hectare) *(Source: Own calculations and figure).*

yields, for instance in the year 2025 with just 0.4 tons per hectare (which is less than a third of the expected trend-driven spring wheat yield in that year) and in the year 2047 with 1.1 tons per hectare.

Therefore, it becomes apparent that instead of highlighting the trend component, it is much more important to emphasize on the annual anomalies of the climate change induced spring wheat developments.

This is also mirrored when looking at potato yield developments in the Tuv Aimag. Similar to **Figure 11**, **Figure 12** shows the expected developments for potato in the Tuv Aimag.

The developments displayed in the four graphs of **Figure 12** can be interpreted as follows:

- In a future without climate change, Mongolian potato yields - in this case exemplified for the Tuv Aimag - will considerably increase. Within the next 30 years, yields may increase by approximately 8.0 tons (see the "BAU w/o CC" trend line). However, climate change, again, will reduce this growth (see the "BAU with CC" trend line): In 2050, the yield decline in potatoes may accumu-late to approximately 1.7 tons per hectare, an amount seven percent lower than without climate change.
- Annual variations will again be strong. There might be very good years with extra-ordinary high yields, as in the case of the year 2038 in "CC-Run A" when the randomized yield will be twice as high as the expected yield in accordance to the trend. However, "bad" years with yields considerably underperforming if measured against the trend will also occur quite often. A good illustrative example is the year 2044 in "CC-Run C" where the randomized potato yield would only be around 40 percent of the expected trend-based yield.

Consequently, it can be stated that climate change will have two effects on arable crop yields in Mongolia. Ceteris paribus, it will act to slightly decrease yields. Moreover, it will contribute to considerable annual yield variations more frequently and intensely than in the past leading to negative outcomes. A question arises: What to do in order to cope with climate change?

6. RECOMMENDATIONS: CLIMATE CHANGE AND FOOD SECURITY

Climate change, on an annual basis, may heavily affect food security in Mongolia. This can be considered a straightforward conclusion when looking at the potential annual yield variations for spring wheat and potatoes displayed in **Figure 11** and **Figure 12**, as well as in the supplementary material provided with this study. In this respect, food secu-rity issues for Mongolia in the face of a changing climate and op-tions to combat poten-tial negative consequences shall briefly be discussed hereafter.

Basically, food security is a multidimensional concept encompassing availability, ac-cessibility, utilization, and stability of food (supply) in order to be present *(FAO, 1996; Pinstrup-Andersen, 2009; Saint Ville et al., 2019)*. More precisely, food security in accordance to FAO (1996) is defined as:

- the availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports,
- accessibility by individuals to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet,
- utilization of food through adequate diet, clean water, sanitation, and health care to reach a state of nutritional well-being where all physiological needs are met, and
- stability, because to be food secure, a population, household or individual must always have access to adequate food.

Taking this as a point of departure, it must be argued that food security and climate change have multiple interrelated risks and uncertainties for societies and socio-eco-logical systems. The different aspects of climate change could have a range of effects on all four dimensions of food security, especially in countries already suffering from high levels of hunger and also in countries and communities that are vulnerable to the effects of extreme weather and climate shocks *(Wheeler and von Braun, 2013)*. The stability of the whole food system may be at risk under climate change because of short-term variability in supply. However, the potential impact is less clear at re-gional scales. Therefore, it is also important to note that potential climate change impacts on local agriculture are only one aspect of ensuring food security.

Using this perspective, ensuring a productive and climate-resilient local food production can be a very important part of the food security equation. However, other risks posed by climate change on food security, such as price increases due to yield shortages etc. can also have a huge impact. This way, climate change can be an important determinant for future price trends and is also likely to increase food market volatili-ty. At the same time, food security (especially of the poor) is strongly affected by sta-ple food prices *(Wheeler and von Braun, 2013)*.

But how does all this relate to Mongolia? According to the Global Hunger Index 2018, Mongolia has been characterized as a country with a moderate level of hunger, and the country's score has been continuously improving for the last two decades, although the rate of improvements has slowed down in recent years *(von Grebmer et al., 2018)*. In addition, Mongolia is listed as one of the "high commodity-dependent" countries in the newest report on the state of food security and nutrition in the world *(see FAO et al., 2019)*. In fact, food imports made up for a share of ten percent of Mongolia's total merchandise imports *(UNCTAD, 2019)* and Mongolian self-sufficiency rates for potato and wheat were approximately around 98 percent and 81 percent, respectively *(FAO, 2019; UN, 2019)* on average over the last five years.

Wheat (flour), and also potatoes, can both be considered important staple foods in Mongolia - in fact, wheat and wheat flour have even been explicitly labelled as strategic foods in Mongolia's Food Law. Therefore, the observed partial lack of domestic production of these important foodstuffs makes the country more vulnerable in the case of climate related (and other) production shocks. Wheat alone, for instance, covers almost 50 percent of the daily food requirement of the urban population and over 70 percent of the daily food requirement of the rural population in the country *(Hoffmann et al., 2016)*. Ultimately, an important and critical factor determining whether the direct and indirect impacts of climate change will affect the food security of the Mongolian population is the ability of individuals and households to cope with negative yield shocks as, for instance, those that have been depicted for various years in **Figure 11**.

Accordingly, it is very important not only to be aware of the risks - here especially of the risks of severe weather events in the context of climate change - but also to find solutions in order to better manage these risks. Therefore, it will be very important to enable farmers and the agricultural sector to meaningfully adapt to climate change, i.e. to better cope with the decreasing growth trends and the increased uncertainty of weather conditions such as droughts.

The concept of climate-smart agriculture (CSA) - defined as agriculture that sustainably increases productivity and resilience (adaptation), reduces/removes greenhouse gases, and enhances achievement of national food security and development goals *(FAO, 2018b)* - might be key here. CSA options may target, among others, the following challenges present in Mongolia:

- **Sustainable water use and improvement of water use efficiency**

  Water in Mongolia is a highly limited resource. As Mongolia plans to move its agricultural sector toward food self-sufficiency, withdrawals for irrigation will certainly increase from a yet reported irrigation capacity of about 57,000 hectares toward the country's full irrigation potential of about 518,000 hectares *(see FAO, 2019; Pederson et al., 2013)*. Along with that, the competition for water will increase not only within agriculture but also between the different sec-tors of the Mongolian economy. To ensure long-term resource availability with-out negative ecological and economic impacts, appropriate monitoring and governance of water resources are urgently needed *(Priess et al., 2011)*. Otherwise, it is reasonable to expect what model simulations are already suggesting, namely that irrigation supply in some areas of the country and especially in the western breadbasket region may fall short in the future *(Priess et al., 2011)*. Climate change may worsen this situation since the precipitation trend is not positive and 90 percent of all precipitation in the country usually evaporates *(Baast, 2016)*.

- **Improvement of soil fertility through thorough fertilization management**

The identification and implementation of more sustainable land and fertilizer management practices is of high priority in order to achieve higher crop yields in Mongolia. In this respect, Hoffmann et al. (2016) analysed the nutrient depletion resulting from land-use intensification and the expansion of arable land in Mongolia (especially in the Kharaa River basin, where around a fifth of Mongolian wheat production is harvested) and found significant nutrient im-balances between rural and urban areas, with partly considerable deficits for nitrogen and phosphorous on agricultural land. Unfortunately, this trend is continuing, as nutrients lost due to crop harvests are currently neither replaced by natural input sources, nor by the application of chemical fertilizer *(Hoffmann et al., 2016)*. In fact, the use of fertilizer in Mongolia remains extremely low compared to international levels *(FAO, 2019)*.

- **Minimization and stop of soil erosion**

Wind erosion of soils has been predicted to increase in Mongolia, further exacerbating the soil erosion problem that is already pronounced across the region. Some researchers have explicitly pointed at wind erosion for being the most serious outcome of projected climate change in the region *(Angerer et al., 2008)*.

It becomes apparent that arable farming in Mongolia faces manifold challenges, and most of these challenges will not become easier to address in the face of a changing climate. Instead, climate change is expected to make the management of productive agricultural soils even more challenging than it is today. Therefore, the straightforward conclusion can only be to make responsible use of all existing options in order to sustainably push the productivity of the country's agricultural area. The following "no regret" options shall finally be highlighted in this respect:

- **Exploit the potential of plant breeding and modern seed production!**

Capacities to enhance the climate-resilience of the agricultural sector need to be improved locally. Especially, thorough research, knowledge and technologies are needed to breed new crop varieties that are adapted to the challenging local conditions. This might lead to the (re-)discovery of local crop varieties, or to the increased use of foreign genetics that are better adapted to droughts and heat spells than the currently used varieties. Strengthening and technologically im-proving the national production of seeds of adapted crop varieties will also be

necessary.

- **Increasingly install sustainable, i.e. water saving, irrigation technologies!**

Since water is a very scarce resource in Mongolia, any effort needs to be undertaken not to overuse this natural resource (as an overuse would make agriculture even more difficult in the future). High-tech and digital irrigation solutions could help in this regard and should be installed whenever and wherever possible. This is seen as a must since irrigation can particularly mitigate parts of the effect of high temperature extremes in a situation when temperature-related weather extremes show a stronger association with (negative) yield anomalies than precipitation-related factors *(Vogel et al., 2019)* and limited water supply largely affects yields in Mongolia *(Priess et al., 2011)*.

- **Organise substantial knowledge transfer!**

Guidance needs to be provided to farmers in many terms: the selection of suitable seeds and crops, a more divers crop rotation, the overall crop management, an efficient water management, the proper use of irrigation technologies, etc. These are only some of the factors that will be critical for farmers to successfully adapt to changing climatic conditions. Therefore, agricultural extension ser-vices need to be trained and equipped with the necessary knowledge and technology to pass on this knowledge and technologies to farmers. In this respect, one way forward for Mongolia could also be to learn from other countries' experiences about how agriculture in general and arable farming in particular can succeed under semiarid and arid conditions, as well as how best practices can be adapted to the local needs of farmers *(Pederson et al., 2013)*.

- **Collect more and better climate information and forward it to farmers!**

Much of the adaptation of agricultural practices to climate change will be driven by decisions at the farm level *(Wheeler and von Braun, 2013)*. However, these decisions will make it necessary to access information on potential climate developments on a very fine geographic scale, currently not existing in Mongolia. Therefore, enlarging and improving the accessibility to sound weather and climate (change) data is a necessity. In this respect, research has repeatedly highlighted the need for comprehensive monitoring and forecast systems, especially to better predict drought events in the region. Both, short-term and long-term monitoring are needed to improve decision making, reduce risk and devel-op adaptive management strategies. These weather and drought forecasts would assist producers and government in taking precautionary actions to-wards drought and extreme weather events *(Angerer et al., 2008)*. The provision of information to farmers will especially be key for adequately adapting to an increase in rainfall variability. In this regard, early-warning systems to ensure preparedness for extreme events are especially important.

- **Install early warning systems and further develop the meteorological system!**

In recent years, several organizations have worked on the installation of early warning systems in different regions of the country, primarily directed at livestock herders and focussed on predicting dzud *(Suvdantsetseg et al., 2015; Da-vaadorj et al., 2017; Mercy Corps, 2017)*. While some of this information could also be useful to increase the disaster preparedness of arable farmers, the provision of more targeted information will require further development of the meteorological system in the country. In fact, meteorological stations in Mongolia are relatively sparse, have missing and short in lengths values, and rarely have data before the 1950s *(Pedersen et al., 2013)*. With regard to the livestock early warning systems now operating in the country, researchers have also pointed out that the information delivered through these systems often does not reach the final recipients (be it herders or arable farmers) in an easily understandable way *(Suvdantsetseg et al., 2015)*. Therefore, while installing the necessary technical infrastructure and obtaining more suitable data is important; it is at least as important to invest in training and communication efforts targeted at making this information as useful - and therefore also as usable - as possible to the individual farmer.

- **Provide sufficient financing!**

Adequate financial mechanisms that ensure the establishment of the aforementioned measures is needed. This also applies to farmers' access to loans, which can help them to better cope with climate-related shocks, while they can also be a key to ensure a sustainable transformation of the sector towards a higher climate resilience.

Altogether it can be stated that yields in Mongolian arable farming will potentially face some severe impacts caused by climate change in the future. However, the above analysis has also shown that trend-related impacts (which are in the range of below ten percent) are expected to be less severe than impacts related to annual variations which can even reach minus 60 percent and more. As a priority, it will therefore be necessary to implement a wide range of solutions - as long as they are applicable at a large scale - in order to minimize the annually recurring risks associated with an extremely high climate variability. Basically, there are two options for minimizing these risks:

(1) to increase average yields as much as possible and

(2) to decrease annually occurring (negative) yield differences as much as possible.

The following measures are based on Gantulga and Otgonbaatar (2017) and may serve as examples and as a starting point to further discuss the issue post this research:

- Widen the crop rotation and decrease fallow; instead, integrate more crops into the rotation including oilseeds, other grains and feeding crops.
- Use modern, e.g. drought-resistant, crop varieties if available and invest in Mongolian seed breeding.
- Sustainably use already available and new plant protection products to minimise crop losses on field.
- Invest in soil fertility and productivity. Use animal manure, as well as legumes and other fertilizers whenever possible and appropriate.
- Increase the use of low tillage methods to avoid soil erosion and thus additional productivity losses.

Far from being an exhaustive list, the above measures have the potential to boost crop yields in a Mongolian context. However, it is also important to keep in mind that a new systematic policy and management approach is urgently needed in the country in order to cope with the upcoming challenges: Farmers, advisors, policy makers, and

international support and development institutions are asked to closely cooperate herein. If viable solutions to cope with climate change and variability, as well as substantial improvements to Mongolian arable farming are not implemented quickly, there is a high probability that arable farming in Mongolia (and the entire agricultural sector of the country) will be hit hard by climate change due to its currently lacking capacity to adequately cope with the consequences.

REFERENCES

Angerer, J.; Han, G.; Fujisaki, I.; Havstad, K. (2008): Climate change and ecosystems of Asia with emphasis on Inner Mongolia and Mongolia. In: Rangelands (3): 46-51.

Baast, E.; Nyamgerel, B. (2019): Der mongolische Ackerbausektor im Überblick - natürliche, agrarpolitische und institutionelle Rahmenbedingungen. Ulaanbaatar: Deutsch-Mongolisches Kooperationsprojekt Nachhaltige Landwirtschaft.

Baast, E.; Nyamgerel, B. (2018): Value chain analysis of wheat, potato and rapeseed in Mongolia. Ulaanbaatar: Deutsch-Mongolisches Kooperationsprojekt Nachhaltige Landwirtschaft.

Baast, E. (2016): Beschreibung und Bewertung des mongolischen Agrarsektors unter besonderer Berücksichtigung der Schwerpunktthemen des DMKNL. Ulaanbaatar: Deutsch-Mongolisches Kooperationsprojekt Nachhaltige Landwirtschaft.

Batima, P.; Natsagdori, L.; Gombluudev, P.; Erdenetsetseg, B. (2005): Observed Climate Change in Mongolia. AIACC Working Papers.

Chavas, D.R.; Izaurralde, R.C.; Thomso, A.M.; Gao, X. (2009): Long-term climate change impacts on agricultural productivity in Eastern China. In: Agricultural and Forest Metereology (149): 1118-1128.

Chen, Y.; Zhang, Z.; Tao, F. (2018): Impacts of climate change and climate extremes on major crops productivity in China at a global warming of 1.5 and 2.0 °C. In: Earth System Dynamics (9): 543-562.

Davaadorj, A.; Erdenetsetseg, B.; Elbegjargal, N.; Oyunjargal, L (2017): Dzud early warning system over Mongolia. The 5th Session of the EASCOF, Tokyo, 8-10 November 2017.

Eitzinger, A.; Läderach, P.; Rodriguez, B.; Fisher, M.; Beebe, S.; Sonder, K.; Schmidt, A. (2017): Assessing high-impact spots of climate change: spatial yield simulations with Decision Support System for Agrotechnology Transfer (DSSAT) model. In: Mitigation and Adaptation Strategies for Global Change (22): 743-760.

FAO (Food and Agriculture Organization of the United Nations); IFAD (International Fund for Agricultural Development); UNICEF (United Nations International Children's Emergency Fund); WFP (World Food Programme); WHO (World Health Organization) (2019): The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns. Rome, FAO. Licence: CC BY-NC-SA 3.0 IGO.

FAO (Food and Agriculture Organization of the United Nations) (2019): FAOSTAT. In: Internet (http://www.fao.org/faostat/en/#data/RF) [Last access: October 03rd, 2019].

FAO (Food and Agriculture Organization of the United Nations) (2018a): The future of food and agriculture – alternative pathways to 2050. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations) (2018b): The state of agricultural commodity markets 2018: agricultural trade, climate change and food security. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations) (1996): Declaration on world food security. World food summit. Rome: FAO.

Fuglie, K.O. (2015): Accounting for growth in global agriculture. Italian Agricultural & Applied Economics Association Annual Conference, Ancona, June 11-12, 2015.

Fuglie, K.O. (2012): Productivity growth and technology capital in the global agricultural economy. In: Fuglie, K.O; Wang, S.L.; Ball, V.E. (eds.): Productivity growth in agriculture: an international perspective. Wallingford, UK: CABI.

Gantulga, G.; Otgonbaatar, I. (2017): Traditionelle und erweiterte Fruchtfolge in der Druschfruchtproduktion: Vergleichsanalyse. Ulaanbaatar: Deutsch-Mongolisches Kooperationsprojekt Nachhaltige Landwirtschaft.

Hessl, A.E.; Anchukaitis, K.J.; Jelsema, C.; Cook, B.; Vyambasuren, O.; Leland, C.; Nachin, B.; Pederson, N.; Tian, H.; Hayles, L.A. (2018): Past and future drought in Mongolia. In: Science Advances (4): e1701832.

Hoffmann, J.; Tuul, D.; Enkhtuya, B. (2016): Agriculture in Mongolia under pressure of agronomic nutrient imbalances and food security demands: a case study of stakeholder participation for future nutrient and water resource management. In: Borchardt, D.; Bogardi, J.; Ibisch, R. (eds): Integrated water resources man-agement: concept, research and implementation, 471-514.

IFPRI (International Food Policy Research Institute) (2018): Agricultural total factor productivity (TFP), 1991–2014: 2018. Global Food Policy Report. Annex Ta-ble 5. Washington, DC: IFPRI.

Liu. Z.; Yao, Z.; Huang, H.; Batjav, B.; Wang, R. (2019): Evaluation of extreme cold and drought over the Mongolian Plateau. In. Water (11): 74.

Lotze-Campen, H.; von Witzke, H.; Noleppa, S.; Schwarz, G. (2015): Science for food, climate protection and welfare: an economic analysis of plant breeding research in Germany. In: Agricultural Systems (136): 79-84.

Mercy Corps (2017): Mongolia strategic resilience assessment. Final Report, April 2017. Portland, OR: Mercy Corps.

MET (Ministry of Environment and Tourism of Mongolia) (2018): Third National Communication of Mongolia under the United Nations Framework Convention on Climate Change. Ulaanbaatar: MET.

Miao, L.; Fraser, R.; Sun, Z.; Sneath, D.; He, B.; Cui, X. (2016): Climate impact on vegetation and animal husbandry on the Mongolian plateau: a comparative analysis. In: Natural Hazards (2): 727-739.

Middleton, N.; Rueff, H.; Sternberg, T.; Batbuyan, B.; Thomas, D. (2015): Explaining spatial variations in climate hazard impacts in western Mongolia. In: Land-scape Ecology (30): 91-107.

Nandintsetseg, B.; Shinoda, M.; Erdenetsetseg, B. (2018): Contributions of multiple climate hazards and overgrazing to the 2009/2010 winter disaster in Mongolia. In: Natural Hazards (92): 109-126.

NSOM (National Statistics Office of Mongolia) (2019): Mongolian Statistical Information Service. In: Internet (URL: http://www.1212.mn/tables.aspx? TBL_ID =DT_NSO_1002_006V1) [Last access: October 03rd, 2019].

Park, C.; Min, S.K. (2016): Multi-RCM future projections of climate extremes over East Asia. Stockholm: ICRC-CORDEX.

Pederson, N.; Leland, C.; Nachin, B.; Hessl, A.E.; Bell, A.R.; Martin-Benito, D.; Saladyga, T.; Suran, B.; Brown, P.M.; Davi, N.K. (2013): Three centuries of shifting hydroclimatic regimes across the Mongolian Breadbasket. In: Agricultural and Forest Meteorology (178/179): 10-20.

Pinstrup-Andersen, P. (2009): Food Security: definition and measurement. In: Food Security (1): 5-7.

Priess, J.A.; Schweitzer, C.; Wimmer, F.; Batkhishig, O.; Mimler, M. (2011): The consequences of land-use change and water demand in Central Mongolia. In: Land Use Policy (28): 4-10.

Saint Ville, A.; Po, J.Y.; Sen, A. (2019): Food security and the Food Insecurity Experience Scale (FIES): ensuring progress by 2030. In: Food Security (3): 483-491.

Schubert, S.D.; Wang, H.; Koster, R.D.; Suarez, M.J.; Groisman, P.Y. (2014): Northern Eurasian heat waves and droughts. In: Journal of Climate (27): 3169-3207.

Sukh, T. (2012): Local understanding of hydro-climate changes in Mongolia. Fort Collins, CO: Colorado State University.

Suvdantsetseg, B.; Akihiro, O.; Yan, W.; Altanbagana, M. (2015): Early warning system for pastoral herders to reduce disaster risk by using a mobile SMS service. In: Proceedings of the Trans-Disciplinary Research Conference: Building Resilience of Mongolian Rangelands, Ulaanbaatar, June 9-10, 2015.

Sommer, R.; Glazirina, M.; Yuldashev, T.; Otarov, A. Ibraeva, M.; Martynova, L.; Bekenov, M.; Kholov, B.; Inbragimov, N.; Kobilov, R.; Karaev, S.; Sultonov, M.; Khasanova, F.; Esanbekov, M.; Mavlyaniv, D.; Isaev, S.; Abdurahimov, S.; Ikramov, R.; Shezdyukova, L.; de Pauw, E. (2013): Impact of climate change on wheat productivity in Central Asia. In: Agriculture, Ecosystems and Environment (178): 78-99.

Sternberg, T. (2018): Investigating the presumed causal links between drought and dzud in Mongolia. In: Natural Hazards (92): 27–43.

Tao, F.; Zhang, Z.; Xiao, D.; Zhang, S.; Rötter. R.P.; Shi, W.; Liu, Y.; Wang, Y.; Liu, F., Zhang, H. (2014): Responses of wheat growth and yield to climate change in different climate zones of China, 1981-2009. In: Agricultural and Forest Meteorology (189/190): 91–104.

Tuul, D. (2012): Agricultural soil fertility of Mongolia. Darkhan-Uul: PSARI.

UN (United Nations) (2019): UN comtrade database. In Internet: (URL: https://comtrade.un.org/) [Last access: September 14th, 2019]

UNCTAD (United Nations Conference on Trade and Development) (2019): The state of commodity dependence 2019. Geneva: United Nations.

Vogel, E.; Donat, M.G.; Alexander, L.V.; Meinshausen, M.; Ray, D.K.; Karoly, D.; Meinshausen, N.; Frieler, K. (2019): The effects of climate extremes on global agricultural yields. In: Environmental Research Letters (14): 054010.

von Grebmer, K.; Bernstein, J.; Sonntag, A.; Klaus, L.M.; Fahlbusch, J.; Towney, O.; Foley, C.; Gitter, S.; Ekstrom, K.; Fritschel, H. (2018): 2018 Global Hunger In-dex: forced migration and hunger. Bonn and Dublin: Welthungerhilfe and Con-cern Worldwide.

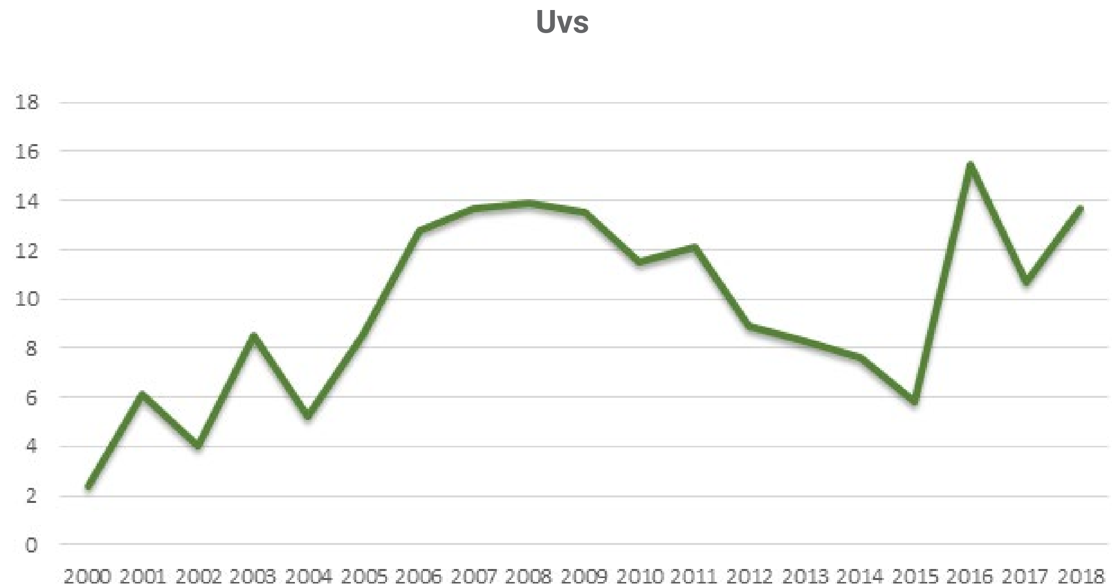
Wheeler, T.; von Braun, J. (2013): Climate change impacts on global food security. In: Science (341): 508-513.

World Bank (2015): Mongolia: agricultural sector risk assessment. Washington, D.C.: World Bank Group.

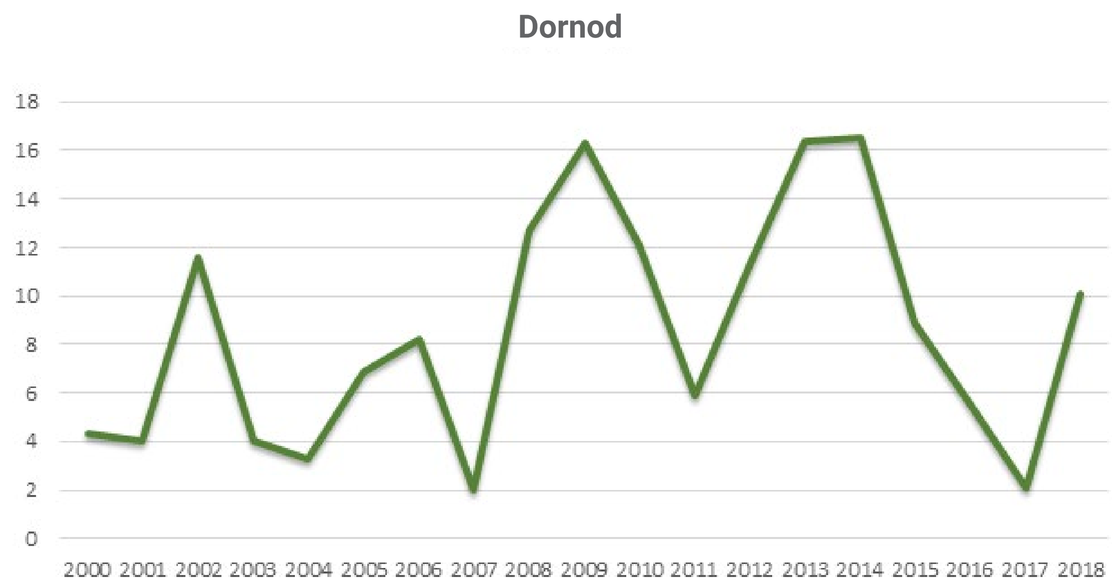
WPR (World Policy Review) (2019): Climate change could threaten Mongolia's ability to feed itself. In: WPR, Wednesday, January 2, 2019.

Zhao, C.; Liu, B.; Piao, S.; Wang, X.; Lobell, D.B.; Huang, Y.; Huang, M.; Yao, Y.; Bas-su, S.; Ciais, P.; Durand, J.L.; Elliott, J.; Ewert, F.; Janssens, I.A.; Li, T.; Lin, E.; Liu, Q.; Martre, P.; Müller, C.; Peng, S.; Peñuelas, J.; Ruane, A.C.; Wallach, D.; Wang, T.; Wu, D.; Liu, Z.; Zhu, Y.; Zhu, Z.; Asseng, S. (2017): Temperature in-crease reduces global yields of major crops in four independent estimates. In: PNAS (35): 9326-9331.

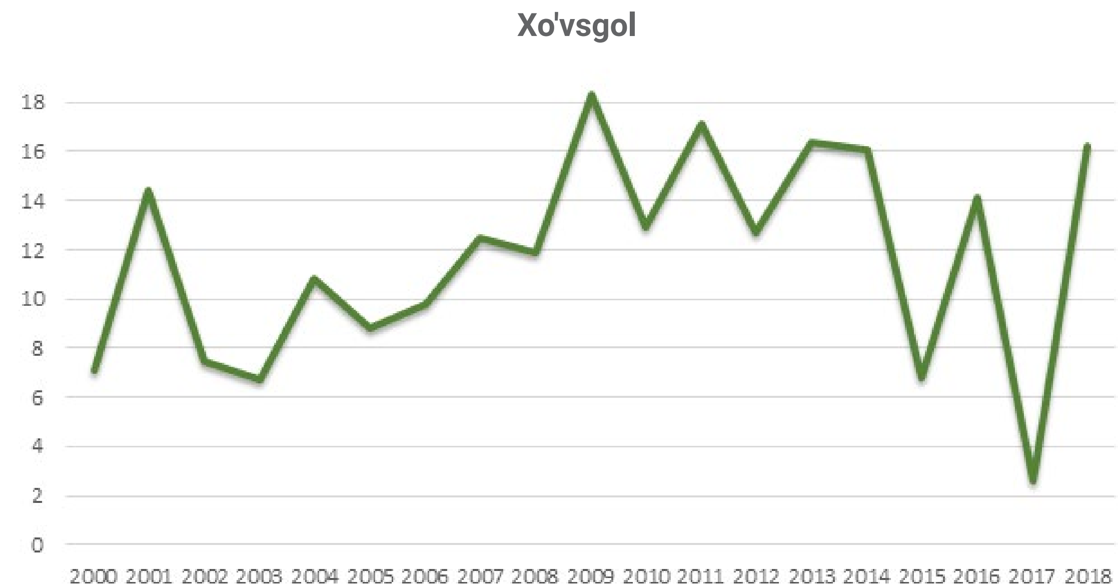
SUPPLEMENTARY MATERIAL



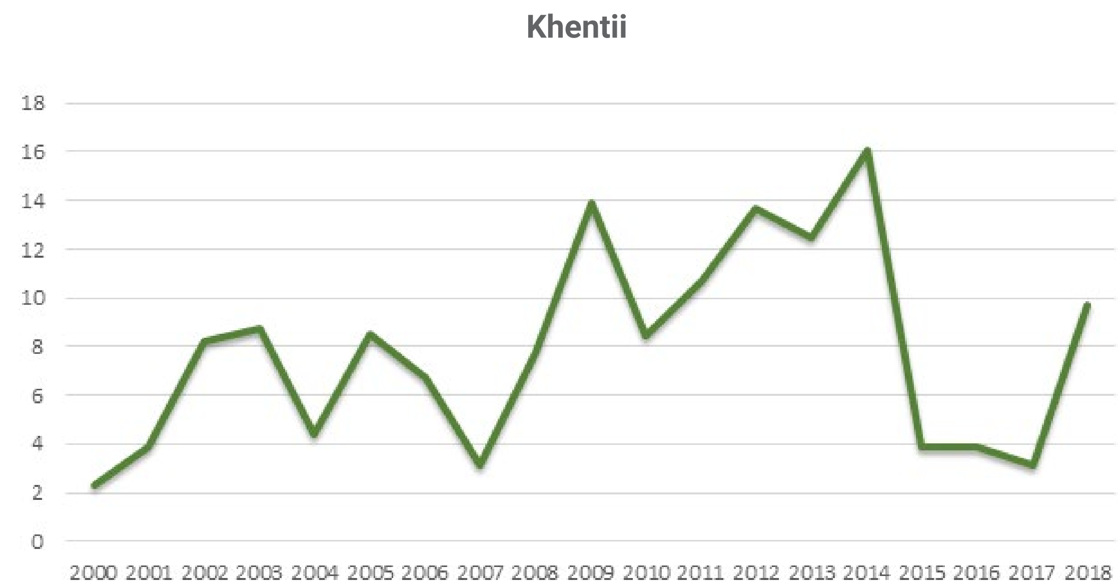
Annex A: Development of average spring wheat yields from 1980 to 2018. (in 100 kilograms per hectare) *Source: Own figure based on NSOM (2019).*



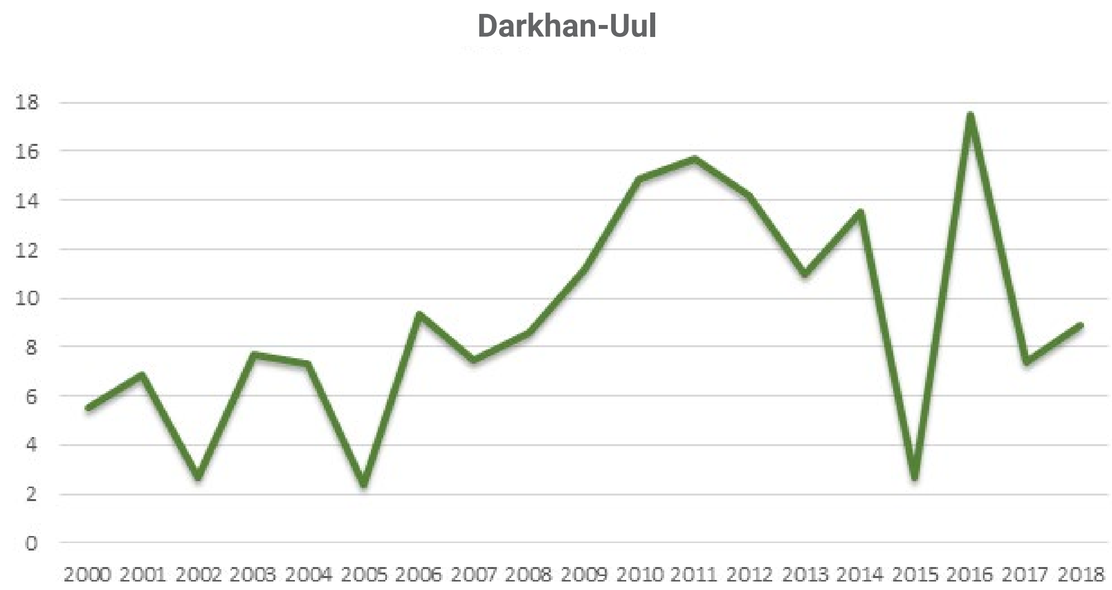
Annex A: Development of average spring wheat yields from 1980 to 2018. (in 100 kilograms per hectare) *Source: Own figure based on NSOM (2019).*



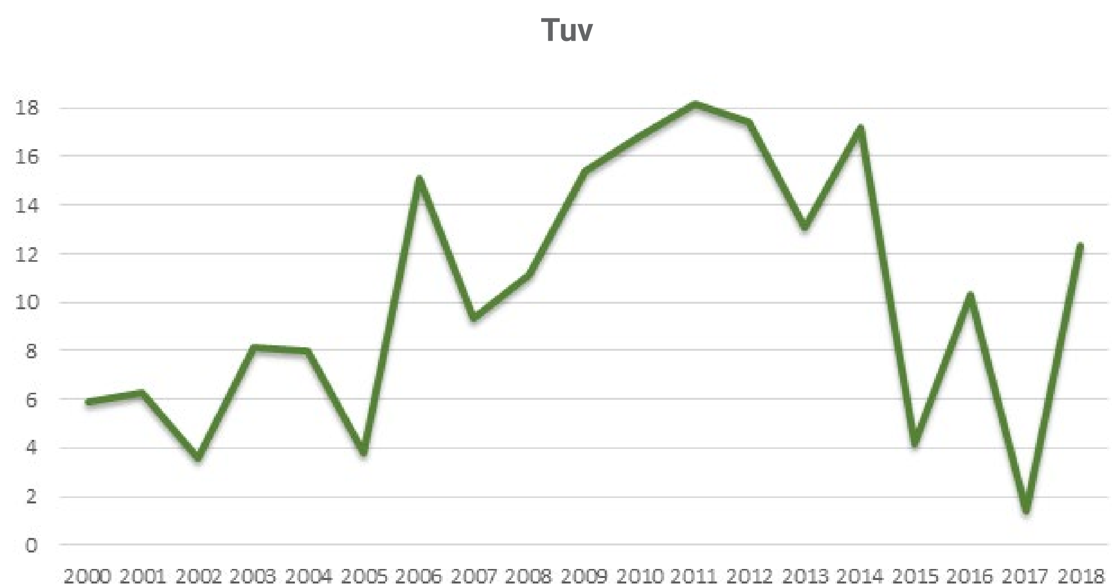
Annex A: Development of average spring wheat yields from 1980 to 2018. (in 100 kilograms per hectare) *Source: Own figure based on NSOM (2019).*



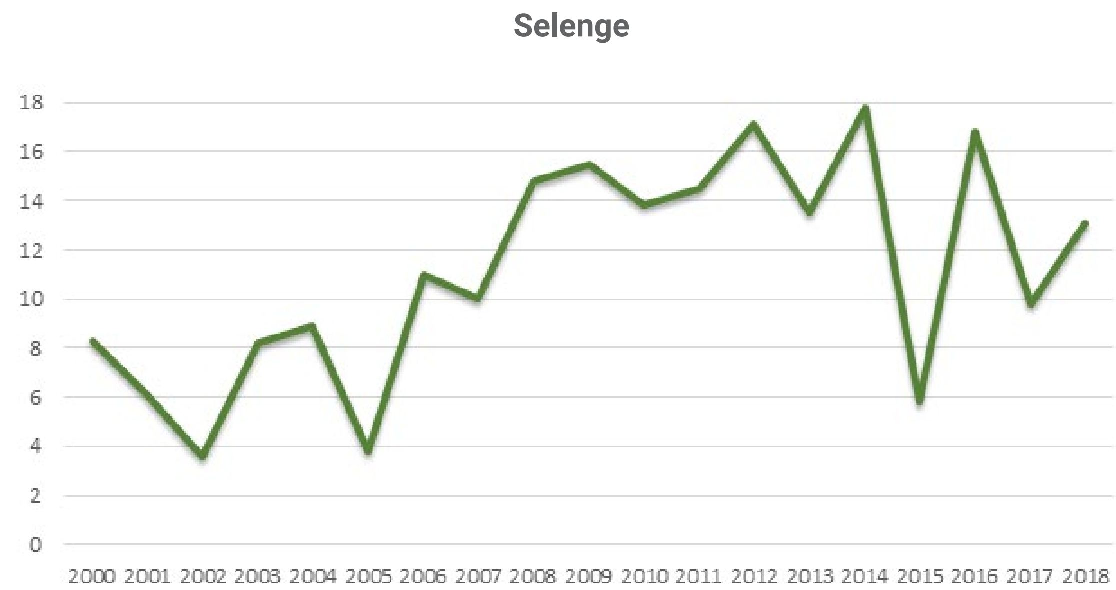
Annex A: Development of average spring wheat yields from 1980 to 2018. (in 100 kilograms per hectare) *Source: Own figure based on NSOM (2019).*



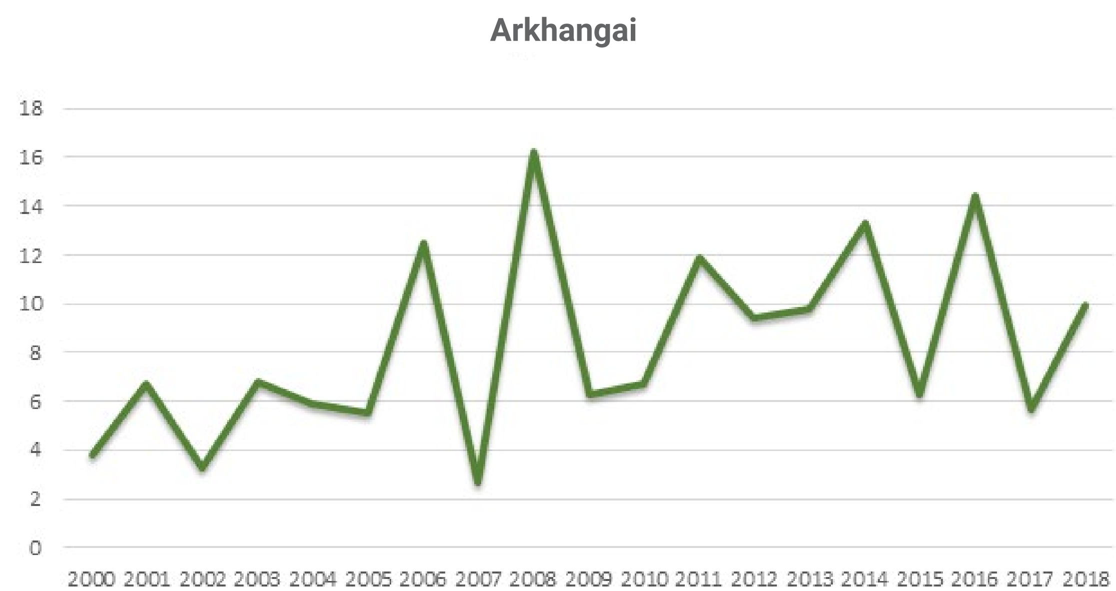
Annex A: Development of average spring wheat yields from 1980 to 2018. (in 100 kilograms per hectare) *Source: Own figure based on NSOM (2019).*



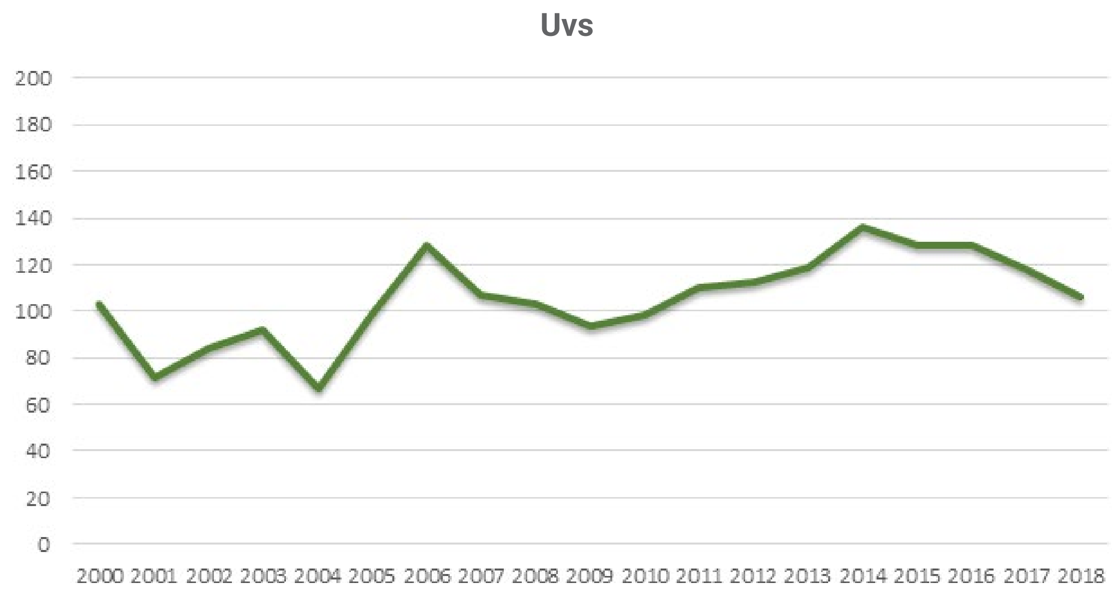
Annex A: Development of average spring wheat yields from 1980 to 2018. (in 100 kilograms per hectare) *Source: Own figure based on NSOM (2019).*



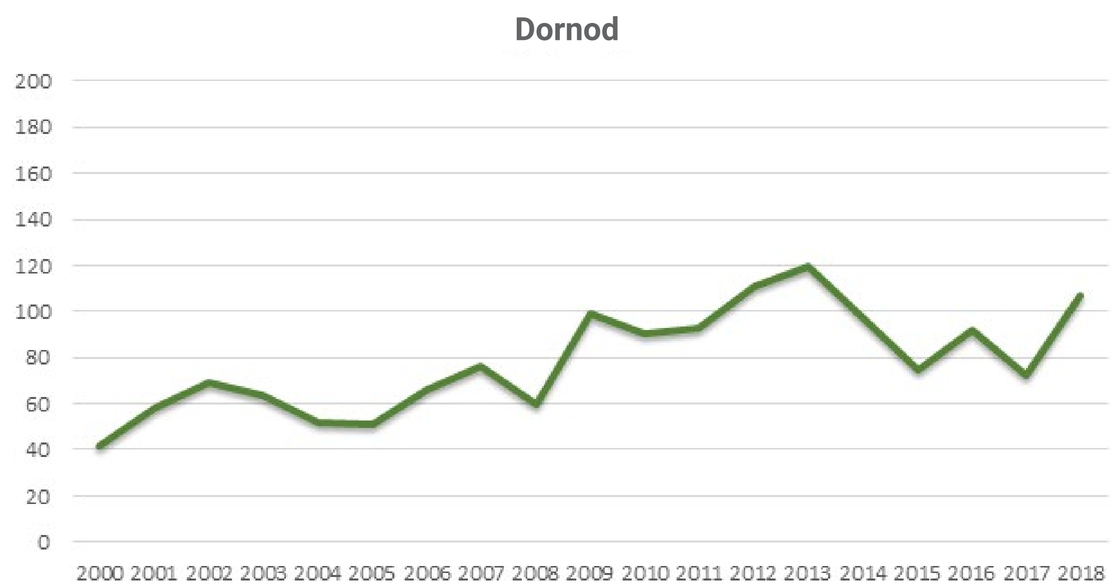
Annex A: Development of average spring wheat yields from 1980 to 2018. (in 100 kilograms per hectare) *Source: Own figure based on NSOM (2019).*



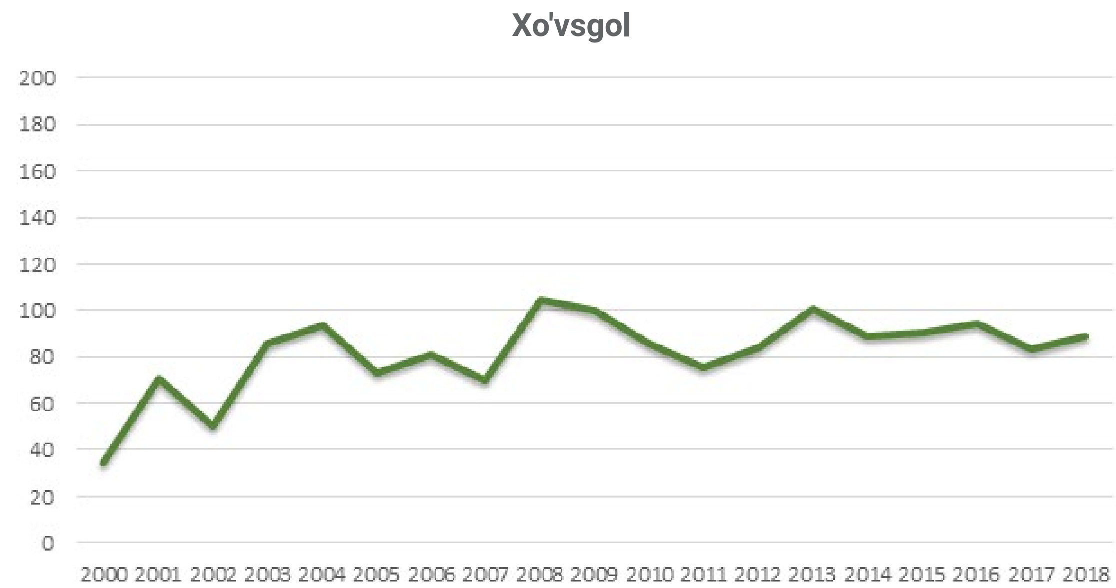
Annex A: Development of average spring wheat yields from 1980 to 2018. (in 100 kilograms per hectare) *Source: Own figure based on NSOM (2019).*



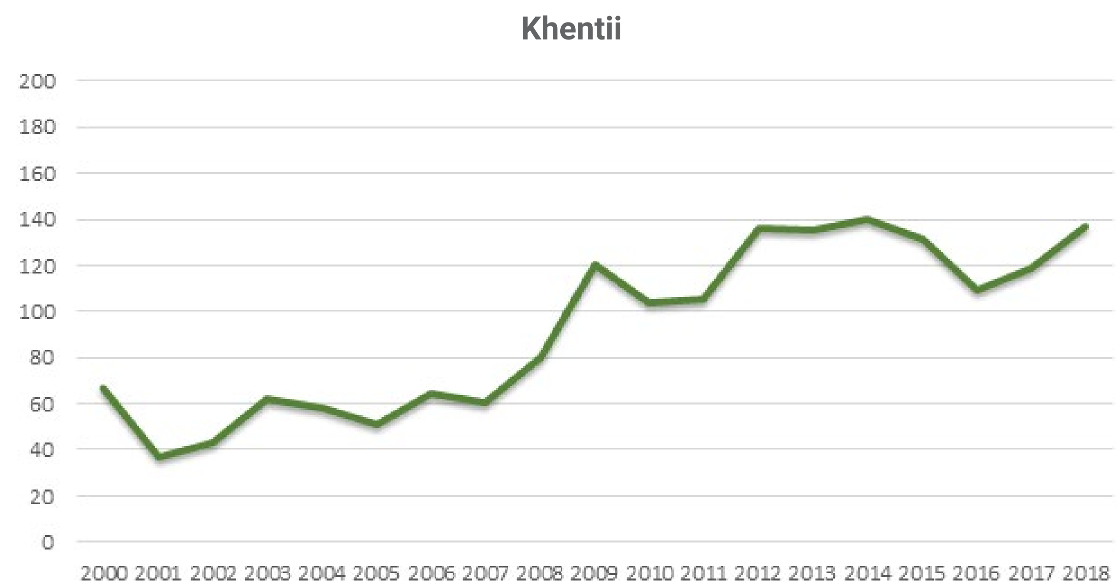
Annex B: Development of average potato yields from 1980 to 2018. (in 100 kilograms per hectare)
Source: Own figure based on NSOM (2019).



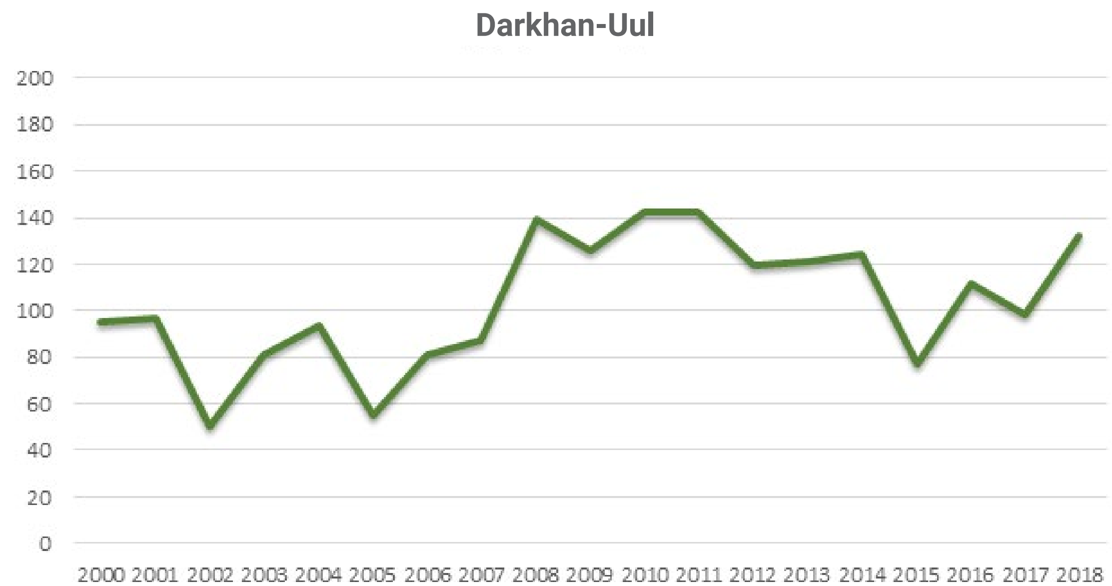
Annex B: Development of average potato yields from 1980 to 2018. (in 100 kilograms per hectare)
Source: Own figure based on NSOM (2019).



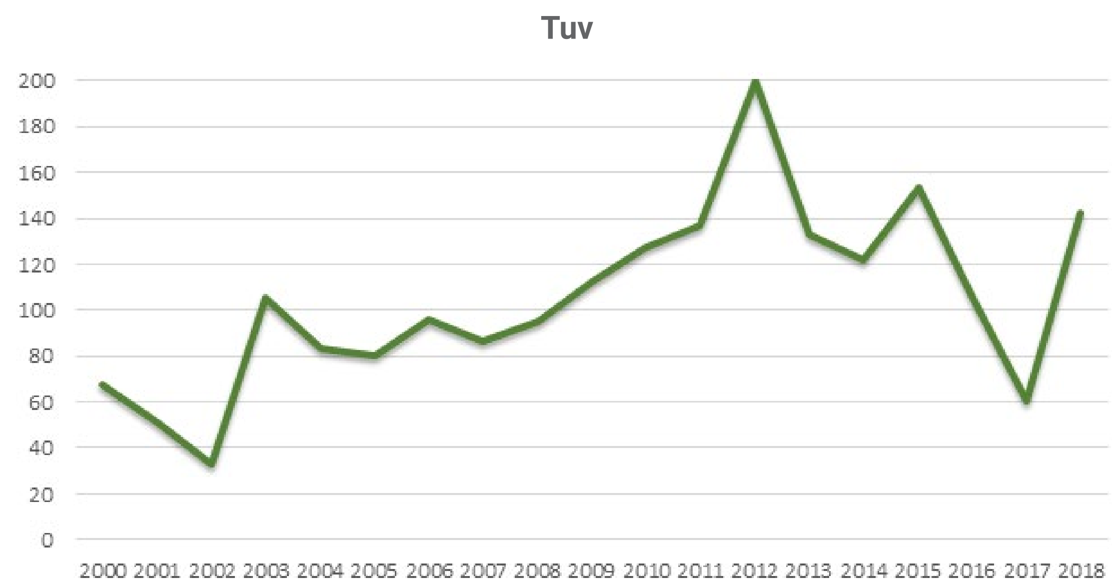
Annex B: Development of average potato yields from 1980 to 2018. (in 100 kilograms per hectare)
Source: Own figure based on NSOM (2019).



Annex B: Development of average potato yields from 1980 to 2018. (in 100 kilograms per hectare)
Source: Own figure based on NSOM (2019).

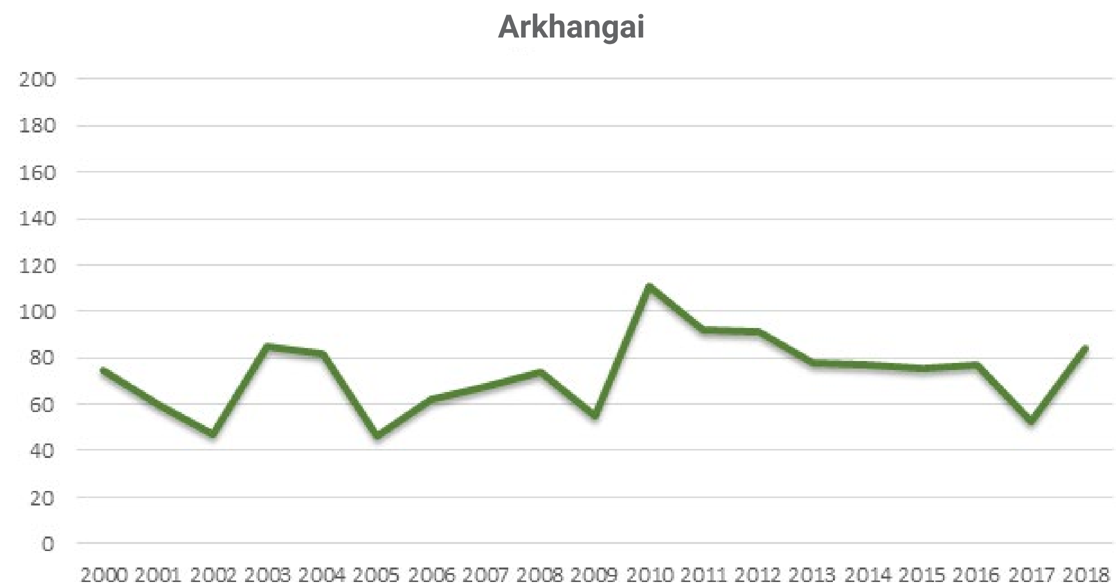


Annex B: Development of average potato yields from 1980 to 2018. (in 100 kilograms per hectare)
Source: Own figure based on NSOM (2019).



Annex B: Development of average potato yields from 1980 to 2018. (in 100 kilograms per hectare)
Source: Own figure based on NSOM (2019).

Annex B: Development of average potato yields from 1980 to 2018. (in 100 kilograms per hectare)
Source: Own figure based on NSOM (2019).



Annex B: Development of average potato yields from 1980 to 2018. (in 100 kilograms per hectare)
Source: Own figure based on NSOM (2019).

Uvs:

Period	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear Trend (kg/ha*a)	7.4	– 37.2	34.4	144.8	30.4	228.1
Exponential Trend (%/a)	1.0	– 6.9	4.8	1.6	0.4	2.3

Dornod:

Period	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear Trend (kg/ha*a)	4.7	– 10.9	25.2	153.4	138.5	282.4
Exponential Trend (%/a)	0.2	– 1.8	2.9	2.5	3.2	3.9

Xo'vsgol:

Period	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear Trend (kg/ha*a)	5.7	– 22.3	19.3	135.3	– 53.3	178.5
Exponential Trend (%/a)	0.4	– 2.0	0.7	2.1	– 1.6	2.8

Khentii:

Period	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear Trend (kg/ha*a)	2.4	– 1.4	19.8	221.5	59.6	568.1
Exponential Trend (%/a)	0.3	0.6	2.4	2.9	1.6	6.8

Darkhan-Uul:

Period	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear Trend (kg/ha*a)	7.4	– 37.2	34.4	144.8	30.4	228.1
Exponential Trend (%/a)	1.0	– 6.9	4.8	1.6	0.4	2.3

Annex C: Trends in yield development for spring wheat and potatoes in eight Mongolian Aimags from 1980 to 2018. *Source: Own calculations and figure based on NSOM (2019).*

Tuv:

Period	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear Trend (kg/ha*a)	0.6	– 32.1	27.3	– 17.4	– 293.3	419.5
Exponential Trend (%/a)	– 0.4	– 3.7	1.6	– 0.1	– 2.5	4.5

Selenge:

Period	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear Trend (kg/ha*a)	5.0	– 18.8	45.7	108.8	– 230	236
Exponential Trend (%/a)	0.4	– 1.4	4.8	1.0	– 2.0	2.1

Arkhangai:

Period	Spring wheat			Potato		
	1980-2018	1980-1999	2000-2018	1980-2018	1980-1999	2000-2018
Linear Trend (kg/ha*a)	– 0.7	– 37.8	30.8	4.5	– 44.5	78.2
Exponential Trend (%/a)	– 0.1	– 6.9	4.3	0.2	– 0.7	1.2

Annex C: Trends in yield development for spring wheat and potatoes in eight Mongolian Aimags from 1980 to 2018. *Source: Own calculations and figure based on NSOM (2019).*

Uvs

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	2.4	5.6	– 57.4
2001	6.1	5.9	3.3
2002	4.0	6.2	– 35.4
2003	8.5	6.5	31.0
2004	5.2	6.8	– 23.5
2005	8.6	7.1	20.7
2006	12.8	7.5	71.4
2007	13.7	7.8	75.0
2008	13.9	8.2	69.5
2009	13.5	8.6	57.0
2010	11.5	9.0	27.7
2011	12.1	9.4	28.2
2012	8.9	9.9	– 10.1
1013	8.3	10.4	– 20.0
2014	7.6	10.9	– 30.1
2015	5.8	11.4	– 49.1
2016	15.5	11.9	29.9
2017	10.7	12.5	– 14.5
2018	13.7	13.1	4.5

Dornod

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	4.3	5.4	– 20.8
2001	4.0	5.6	– 28.4
2002	11.6	5.8	101.7
2003	4.0	5.9	– 32.4
2004	3.3	6.1	– 45.8
2005	6.9	6.3	10.1
2006	8.2	6.4	27.2
2007	2.0	6.6	– 69.9
2008	12.7	6.8	86.0
2009	16.3	7.0	132.0
2010	12.1	7.2	67.4
2011	5.9	7.4	– 20.7
2012	11.2	7.7	46.3
1013	16.4	7.9	108.2
2014	16.5	8.1	103.6
2015	8.9	8.3	6.7
2016	5.5	8.6	– 35.9
2017	2.1	8.8	– 76.2
2018	10.1	9.1	11.1

Annex D: Variations of observed yields vs. yield trends for spring wheat from 2000 to 2018. (*Source: Own figure based on own calculations*).

Xo'vsgol

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	7.1	10.0	– 29.3
2001	14.4	10.1	42.3
2002	7.5	10.2	– 26.4
2003	6.7	10.3	– 34.7
2004	10.8	10.3	4.5
2005	8.8	10.4	– 15.4
2006	9.8	10.5	– 6.5
2007	12.5	10.5	18.5
2008	11.9	10.6	12.0
2009	18.3	10.7	71.1
2010	12.9	10.8	19.7
2011	17.1	10.8	57.6
2012	12.7	10.9	16.3
1013	16.4	11.0	49.1
2014	16.1	11.1	45.3
2015	6.8	11.2	– 39.0
2016	14.1	11.2	25.5
2017	2.6	11.3	– 77.0
2018	16.2	11.4	42.2

Khentii

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	2.3	5.4	– 57.7
2001	3.9	5.6	– 30.0
2002	8.2	5.7	43.7
2003	8.7	5.8	48.9
2004	4.4	6.0	– 26.5
2005	8.5	6.1	38.7
2006	6.7	6.3	6.8
2007	3.1	6.4	– 51.8
2008	7.8	6.6	18.5
2009	13.9	6.7	106.3
2010	8.4	6.9	21.8
2011	10.7	7.1	51.5
2012	13.7	7.2	89.4
1013	12.5	7.4	68.7
2014	16.1	7.6	112.2
2015	3.9	7.8	– 49.8
2016	3.9	8.0	– 51.0
2017	3.1	8.1	– 61.9
2018	9.7	8.3	16.3

Annex D: Variations of observed yields vs. yield trends for spring wheat from 2000 to 2018. (*Source: Own figure based on own calculations*).

Darkhan-Uul

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	5.5	5.5	0.8
2001	6.9	5.7	21.4
2002	2.7	5.9	– 54.4
2003	7.7	6.2	24.8
2004	7.3	6.4	13.5
2005	2.4	6.7	– 64.2
2006	9.3	7.0	33.2
2007	7.5	7.3	3.1
2008	8.6	7.6	13.5
2009	11.2	7.9	41.8
2010	14.9	8.2	81.1
2011	15.7	8.6	83.1
2012	14.2	8.9	58.9
1013	11.0	9.3	18.1
2014	13.5	9.7	39.2
2015	2.7	10.1	– 73.3
2016	17.5	10.5	66.1
2017	7.4	11.0	– 32.6
2018	8.9	11.4	– 22.2

Tuv

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	5.9	7.6	– 21.9
2001	6.3	7.7	– 17.9
2002	3.6	7.8	– 53.8
2003	8.1	7.9	2.3
2004	8.0	8.0	– 0.6
2005	3.8	8.2	– 53.5
2006	15.1	8.3	81.8
2007	9.3	8.4	10.2
2008	11.1	8.6	29.5
2009	15.4	8.7	76.8
2010	16.8	8.9	89.8
2011	18.2	9.0	102.4
2012	17.4	9.1	90.4
1013	13.1	9.3	41.1
2014	17.2	9.4	82.4
2015	4.2	9.6	– 56.2
2016	10.3	9.7	5.8
2017	1.4	9.9	– 85.8
2018	12.3	10.0	22.4

Annex D: Variations of observed yields vs. yield trends for spring wheat from 2000 to 2018. (*Source: Own figure based on own calculations*).

Selenge

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	99.3	106.7	– 6.9
2001	76.8	108.9	– 29.5
2002	85.7	111.2	– 22.9
2003	121.0	113.5	6.6
2004	108.0	115.9	– 6.8
2005	118.9	118.3	0.5
2006	153.7	120.8	27.2
2007	154.4	123.4	25.1
2008	156.6	126.0	24.3
2009	154.2	128.6	19.9
2010	147.3	131.3	12.2
2011	165.8	134.1	23.7
2012	153.2	136.9	11.9
1013	139.4	139.8	– 0.3
2014	154.3	142.7	8.1
2015	131.2	145.7	– 9.9
2016	130.0	148.7	– 12.6
2017	110.4	151.9	– 27.3
2018	141.5	155.1	– 8.7

Arkhangai

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	74.3	64.2	15.7
2001	60.0	65.0	– 7.7
2002	47.2	65.8	– 28.2
2003	85.0	66.6	27.7
2004	81.6	67.4	21.2
2005	46.0	68.2	– 32.5
2006	62.4	69.0	– 9.5
2007	67.4	69.8	– 3.4
2008	73.7	70.6	4.3
2009	54.7	71.5	– 23.5
2010	110.5	72.3	52.7
2011	91.7	73.2	25.2
2012	91.5	74.1	23.5
1013	77.8	75.0	3.8
2014	76.6	75.9	0.9
2015	75.1	76.8	– 2.2
2016	76.8	77.7	– 1.2
2017	52.3	78.6	– 33.5
2018	83.7	79.6	5.2

Annex D: Variations of observed yields vs. yield trends for spring wheat from 2000 to 2018. (*Source: Own figure based on own calculations*).

Uvs

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	103.3	84.4	22.4
2001	71.8	86.4	– 16.9
2002	83.8	88.3	– 5.1
2003	91.8	90.4	1.6
2004	67.0	92.4	– 27.5
2005	99.0	94.6	4.7
2006	127.9	96.7	32.2
2007	107.3	99.0	8.4
2008	103.0	101.2	1.7
2009	93.2	103.6	– 10.0
2010	98.6	106.0	– 6.9
2011	110.1	108.4	1.6
2012	112.3	110.9	1.3
1013	118.6	113.4	4.5
2014	135.9	116.1	17.1
2015	128.5	118.7	8.2
2016	128.4	121.5	5.7
2017	117.7	124.2	– 5.3
2018	105.9	127.1	– 16.7

Dornod

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	41.6	53.2	– 21.8
2001	57.7	55.3	4.3
2002	69.5	57.5	21.0
2003	63.8	59.7	6.9
2004	51.8	62.0	– 16.5
2005	51.0	64.4	– 20.9
2006	66.3	67.0	– 1.0
2007	76.4	69.6	9.8
2008	59.7	72.3	– 17.4
2009	98.7	75.1	31.4
2010	90.1	78.0	15.5
2011	93.0	81.1	14.7
2012	110.7	84.2	31.4
1013	119.7	87.5	36.8
2014	97.1	90.9	6.8
2015	75.0	94.5	– 20.6
2016	91.9	98.2	– 6.4
2017	72.2	102.0	– 29.2
2018	107.0	106.0	1.0

Annex E: Variations of observed yields vs. yield trends for potatoes from 2000 to 2018. *(Source: Own figure based on own calculations).*

Xo'vsgol

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	34.5	62.2	– 44.5
2001	70.5	63.9	10.3
2002	50.2	65.7	– 23.6
2003	85.8	67.5	27.0
2004	93.7	69.4	35.0
2005	73.1	71.4	2.4
2006	81.0	73.4	10.4
2007	70.0	75.4	– 7.2
2008	104.9	77.5	35.3
2009	99.6	79.7	24.9
2010	85.9	81.9	4.8
2011	75.7	84.2	– 10.1
2012	84.3	86.6	– 2.7
1013	100.8	89.0	13.2
2014	89.0	91.5	– 2.7
2015	90.6	94.1	– 3.7
2016	94.2	96.7	– 2.6
2017	83.1	99.4	– 16.4
2018	89.0	102.2	– 12.9

Khentii

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	66.5	46.1	44.1
2001	37.2	49.3	– 24.5
2002	42.8	52.6	– 18.7
2003	62.4	56.2	11.0
2004	58.4	60.0	– 2.7
2005	50.7	64.1	– 20.9
2006	64.3	68.5	– 6.1
2007	60.1	73.1	– 17.8
2008	80.4	78.1	2.9
2009	120.5	83.4	44.4
2010	103.6	89.1	16.3
2011	105.5	95.2	10.9
2012	136.2	101.6	34.0
1013	135.0	108.5	24.4
2014	140.2	115.9	20.9
2015	131.0	123.8	5.8
2016	109.3	132.2	– 17.3
2017	119.0	141.2	– 15.7
2018	136.6	150.8	– 9.4

Annex E: Variations of observed yields vs. yield trends for potatoes from 2000 to 2018. *(Source: Own figure based on own calculations).*

Darkhan-Uul

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	95.2	78.6	21.1
2001	96.3	80.7	19.3
2002	50.3	82.9	– 39.3
2003	80.9	85.2	– 5.0
2004	93.4	87.5	6.8
2005	55.1	89.8	– 38.6
2006	81.3	92.2	– 11.9
2007	87.1	94.7	– 8.1
2008	139.4	97.3	43.3
2009	125.5	99.9	25.6
2010	142.1	102.6	38.5
2011	142.5	105.4	35.2
2012	119.4	108.2	10.3
1013	121.1	111.1	9.0
2014	123.9	114.1	8.5
2015	76.9	117.2	– 34.4
2016	111.8	120.4	– 7.1
2017	98.4	123.6	– 20.4
2018	132.1	127.0	4.0

Tuv

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	67.8	64.6	5.0
2001	51.2	67.5	– 24.1
2002	33.1	70.5	– 53.1
2003	105.2	73.7	42.8
2004	83.6	77.0	8.6
2005	80.3	80.5	– 0.2
2006	95.6	84.1	13.7
2007	86.2	87.9	– 1.9
2008	95.2	91.8	3.7
2009	112.7	95.9	17.5
2010	127.5	100.3	27.2
2011	136.6	104.8	30.4
2012	199.6	109.5	82.3
1013	132.8	114.4	16.1
2014	121.8	119.6	1.9
2015	153.5	125.0	22.8
2016	105.6	130.6	– 19.1
2017	60.5	136.4	– 55.7
2018	142.6	142.6	0.0

Annex E: Variations of observed yields vs. yield trends for potatoes from 2000 to 2018. *(Source: Own figure based on own calculations).*

Selenge

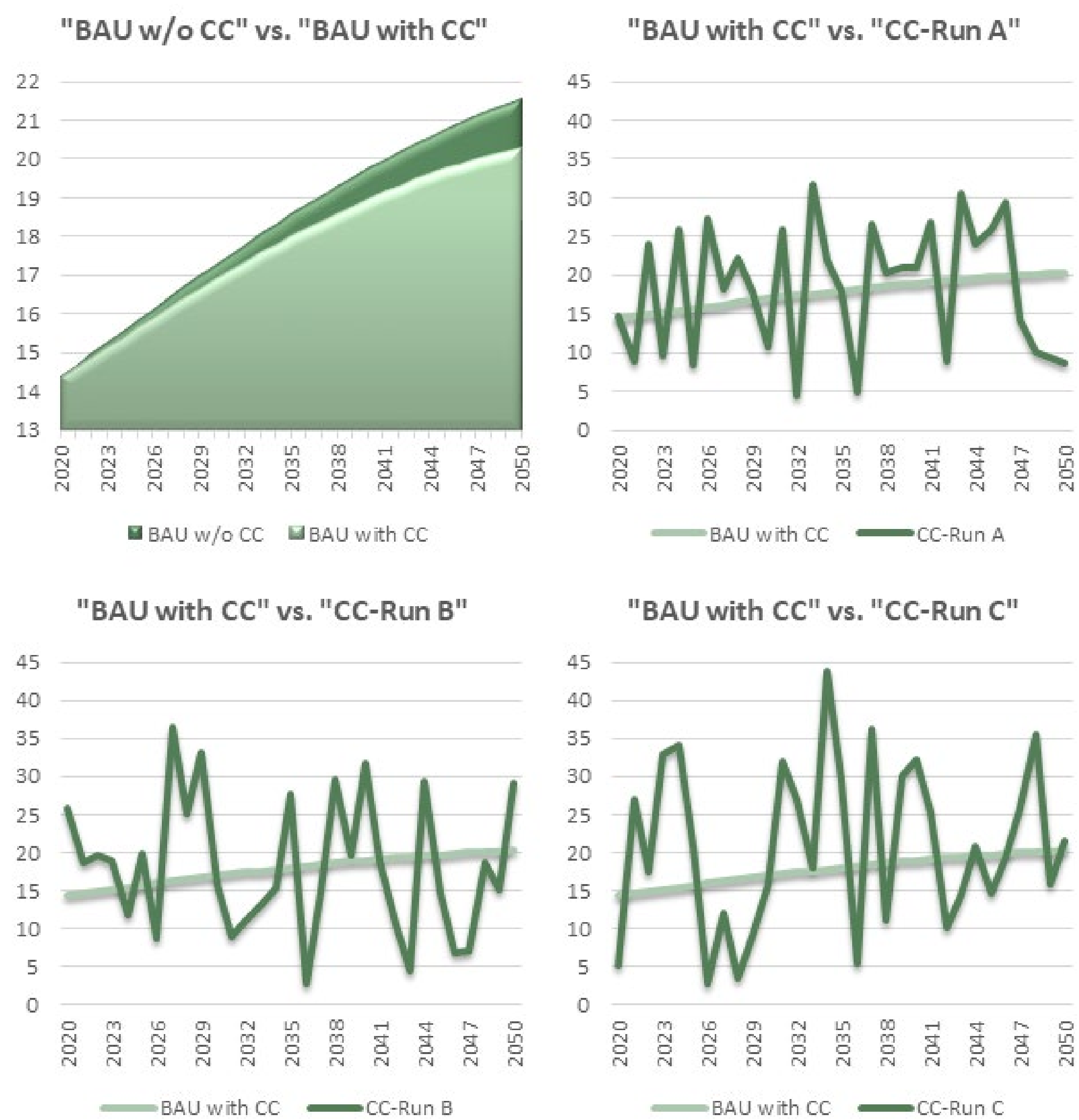
Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	99.3	106.7	– 6.9
2001	76.8	108.9	– 29.5
2002	85.7	111.2	– 22.9
2003	121.0	113.5	6.6
2004	108.0	115.9	– 6.8
2005	118.9	118.3	0.5
2006	153.7	120.8	27.2
2007	154.4	123.4	25.1
2008	156.6	126.0	24.3
2009	154.2	128.6	19.9
2010	147.3	131.3	12.2
2011	165.8	134.1	23.7
2012	153.2	136.9	11.9
1013	139.4	139.8	– 0.3
2014	154.3	142.7	8.1
2015	131.2	145.7	– 9.9
2016	130.0	148.7	– 12.6
2017	110.4	151.9	– 27.3
2018	141.5	155.1	– 8.7

Arkhangai

Year	Observed yield (in 100 kilo-grams)	Trend yield (in 100 kilo-grams)	Ob-served vs. trend (in per-cent)
2000	74.3	64.2	15.7
2001	60.0	65.0	– 7.7
2002	47.2	65.8	– 28.2
2003	85.0	66.6	27.7
2004	81.6	67.4	21.2
2005	46.0	68.2	– 32.5
2006	62.4	69.0	– 9.5
2007	67.4	69.8	– 3.4
2008	73.7	70.6	4.3
2009	54.7	71.5	– 23.5
2010	110.5	72.3	52.7
2011	91.7	73.2	25.2
2012	91.5	74.1	23.5
1013	77.8	75.0	3.8
2014	76.6	75.9	0.9
2015	75.1	76.8	– 2.2
2016	76.8	77.7	– 1.2
2017	52.3	78.6	– 33.5
2018	83.7	79.6	5.2

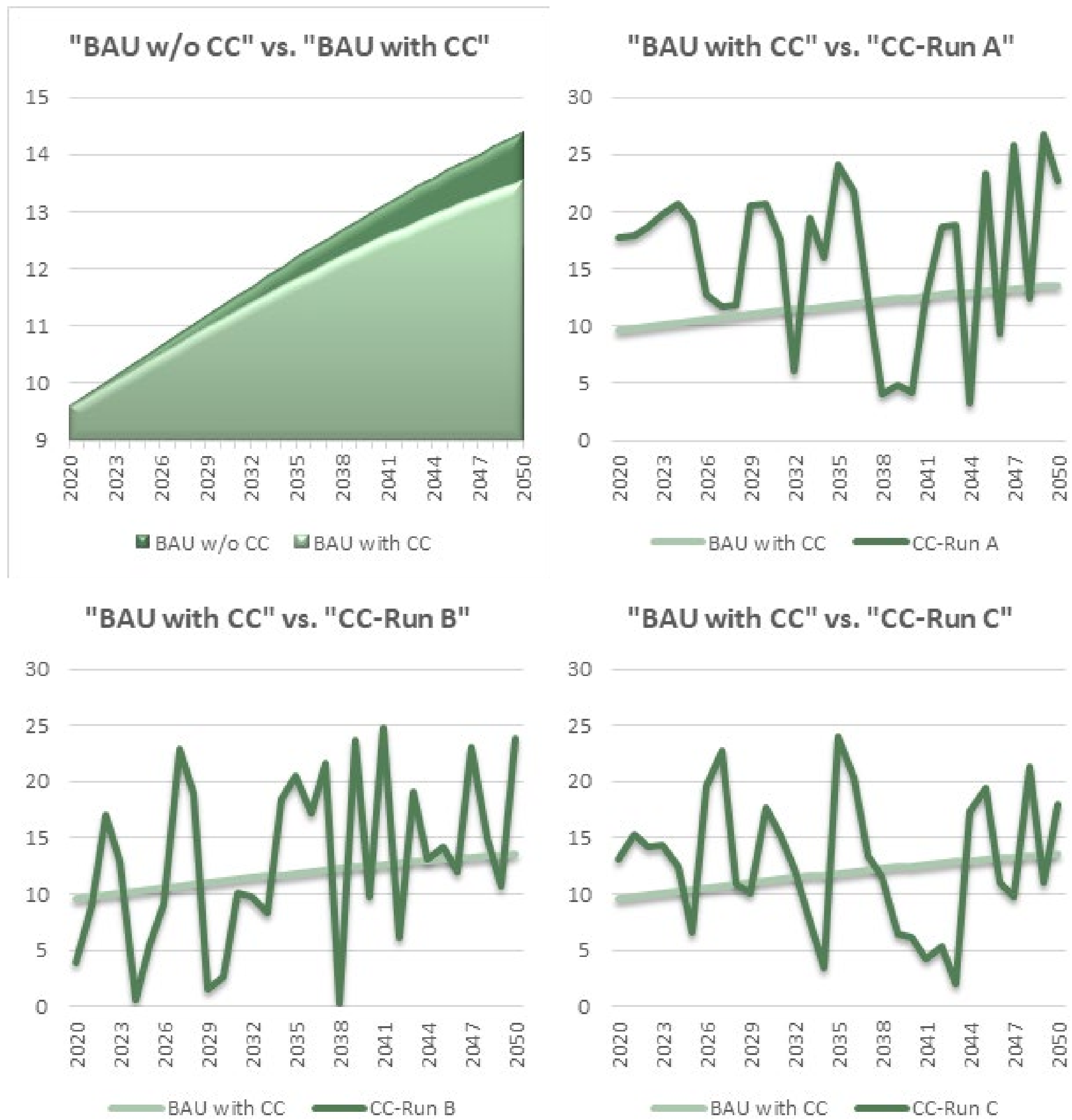
Annex E: Variations of observed yields vs. yield trends for potatoes from 2000 to 2018. *(Source: Own figure based on own calculations).*

Uvs



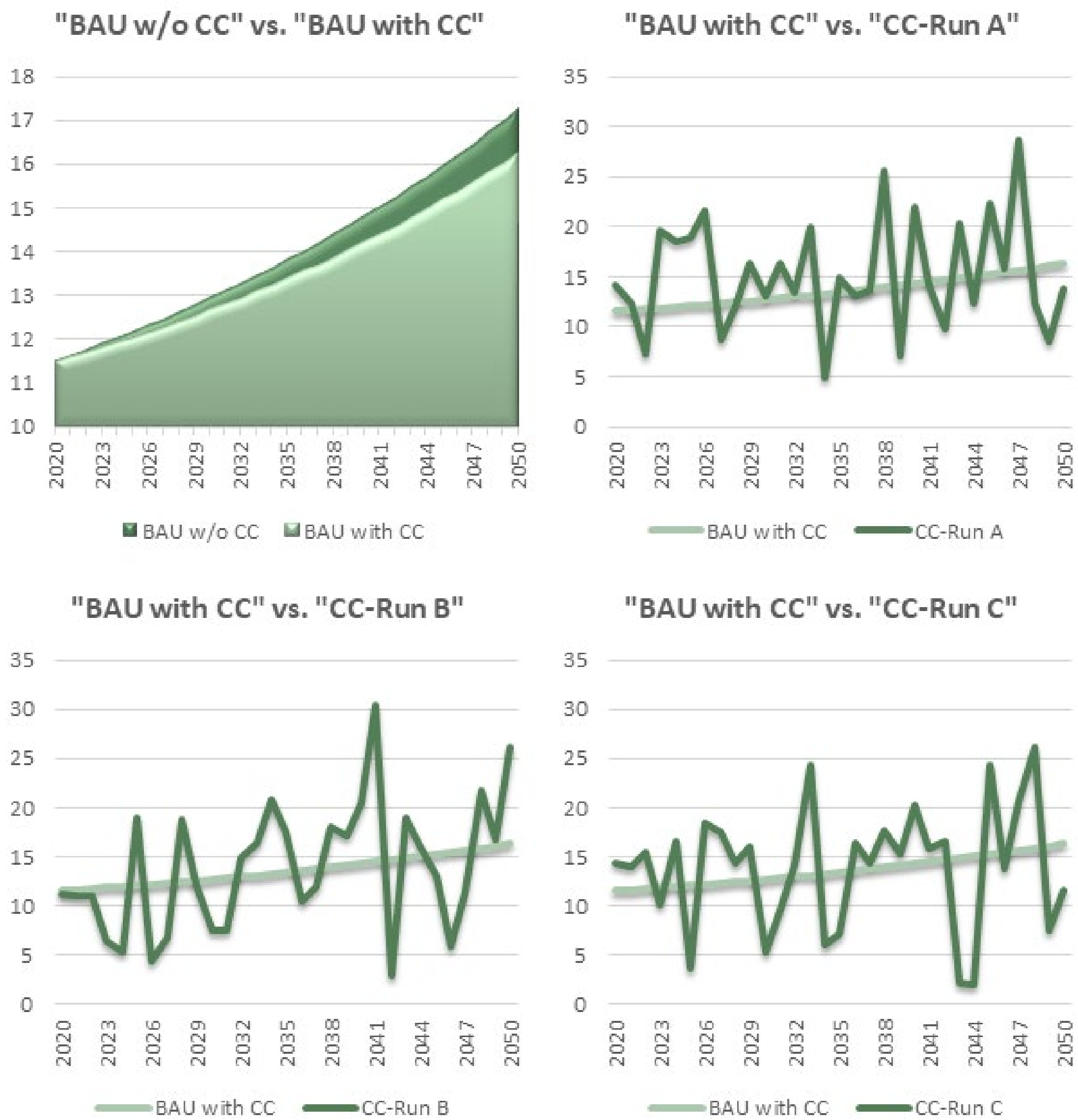
Annex F: Expected spring wheat yields from 2020 to 2050; yield trends (up-per left box) and three runs of randomized an-nual variations (in 100 kg per hectare)

Dornod



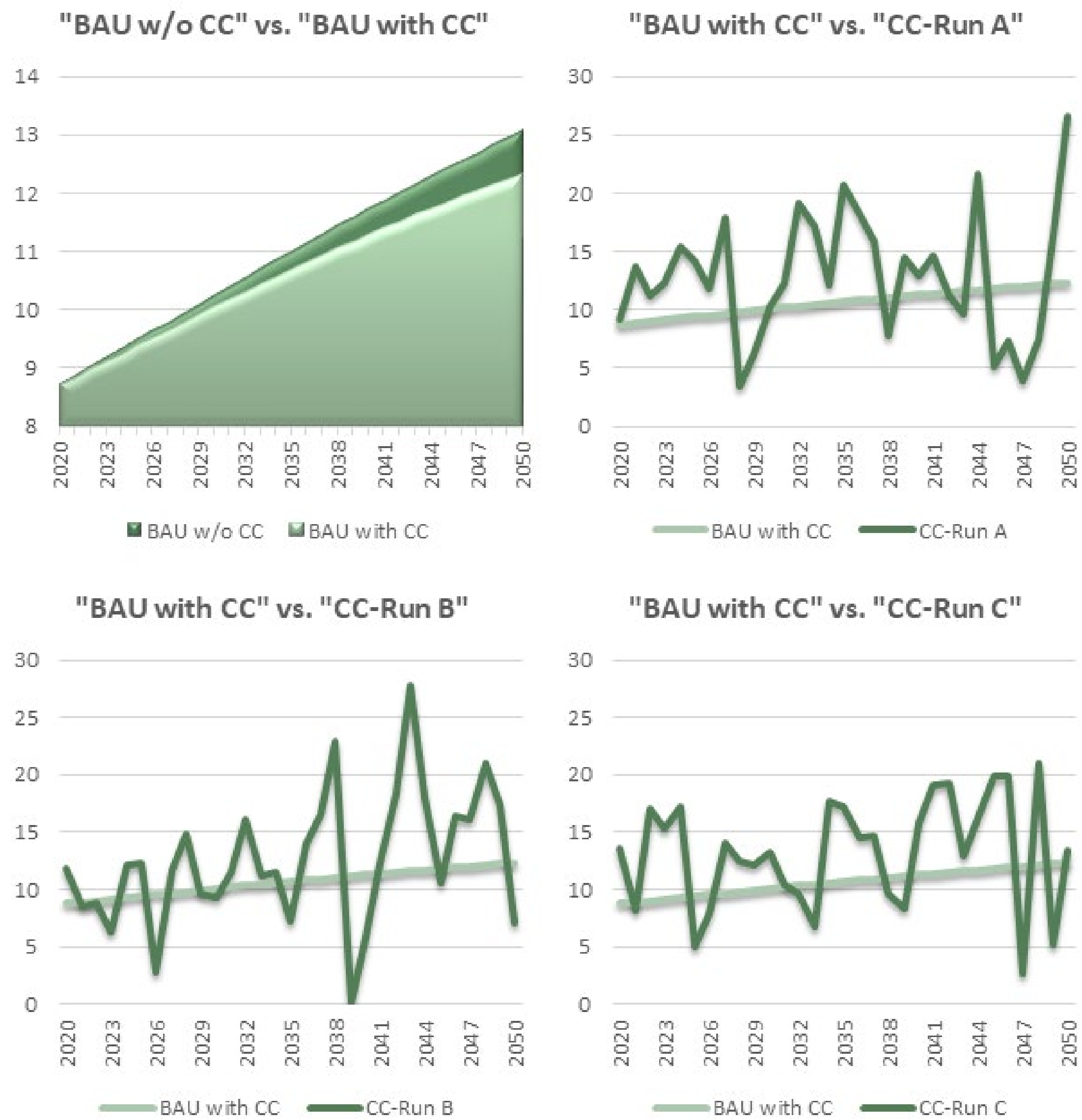
Annex F: Expected spring wheat yields from 2020 to 2050; yield trends (up-per left box) and three runs of randomized an-nual variations (in 100 kg per hectare)

Xo'vsgol



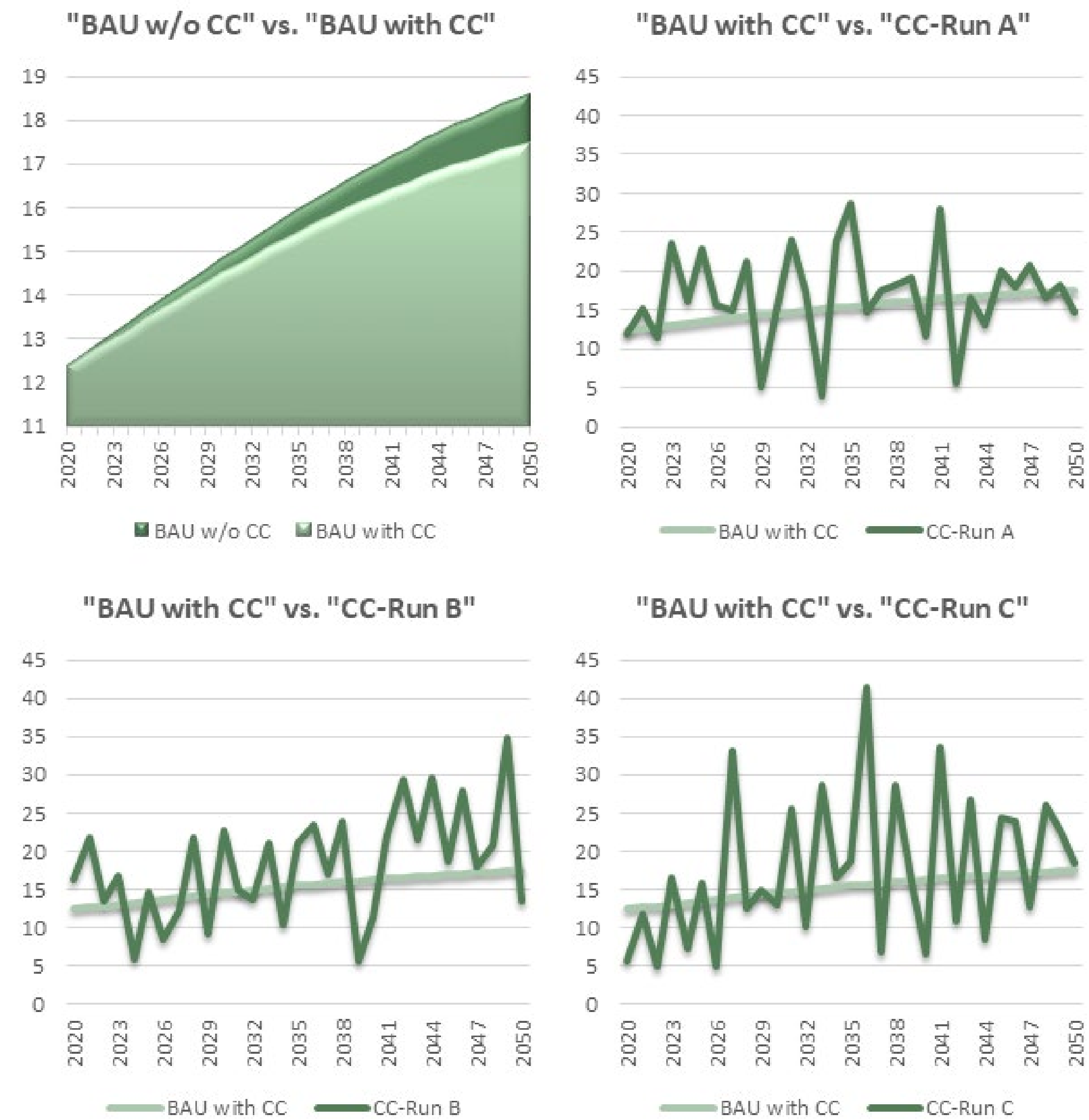
Annex F: Expected spring wheat yields from 2020 to 2050; yield trends (up-per left box) and three runs of randomized an-nual variations (in 100 kg per hectare)

Khentii



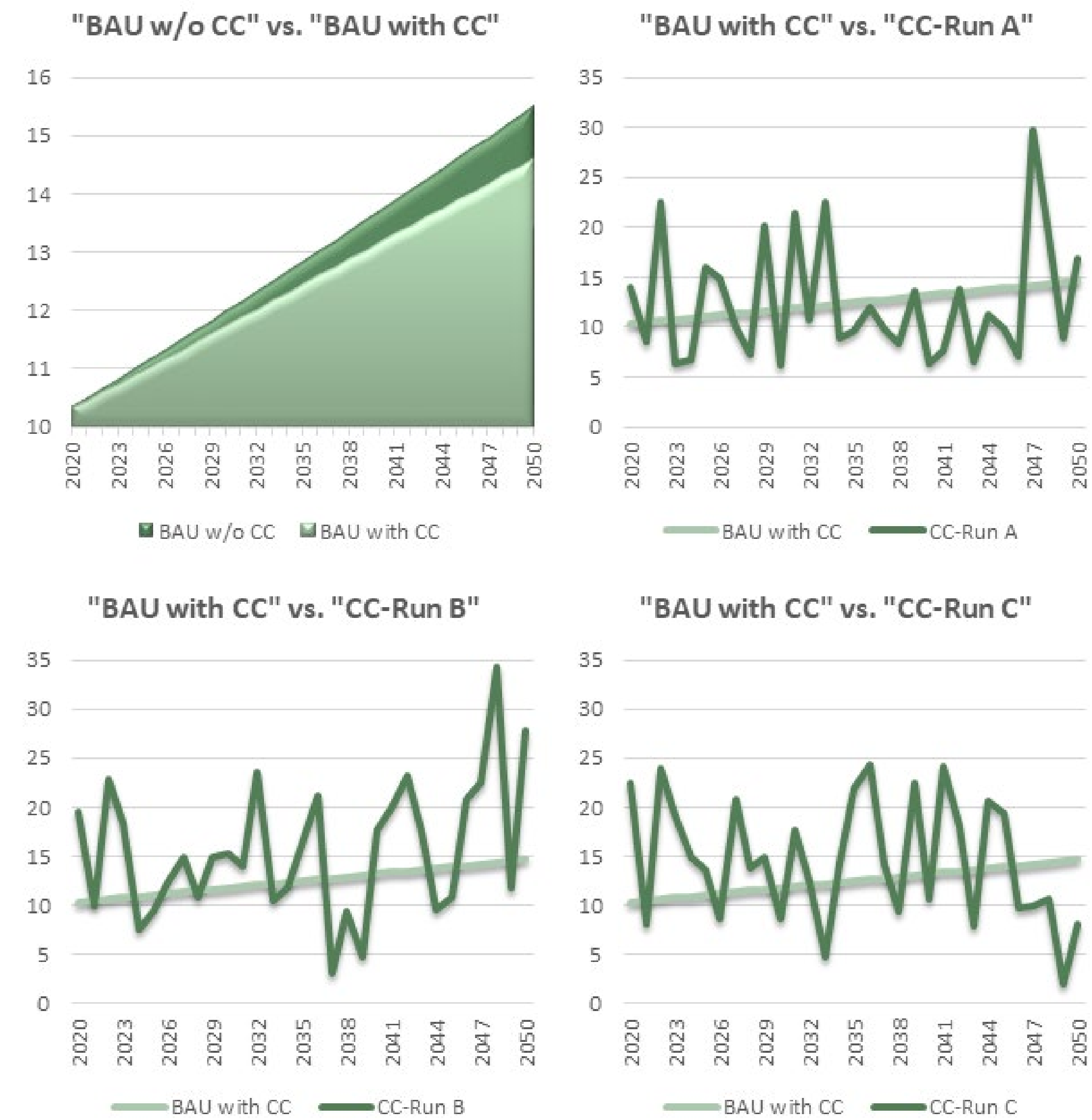
Annex F: Expected spring wheat yields from 2020 to 2050; yield trends (up-per left box) and three runs of randomized an-nual variations (in 100 kg per hectare)

Darkhan-Uul



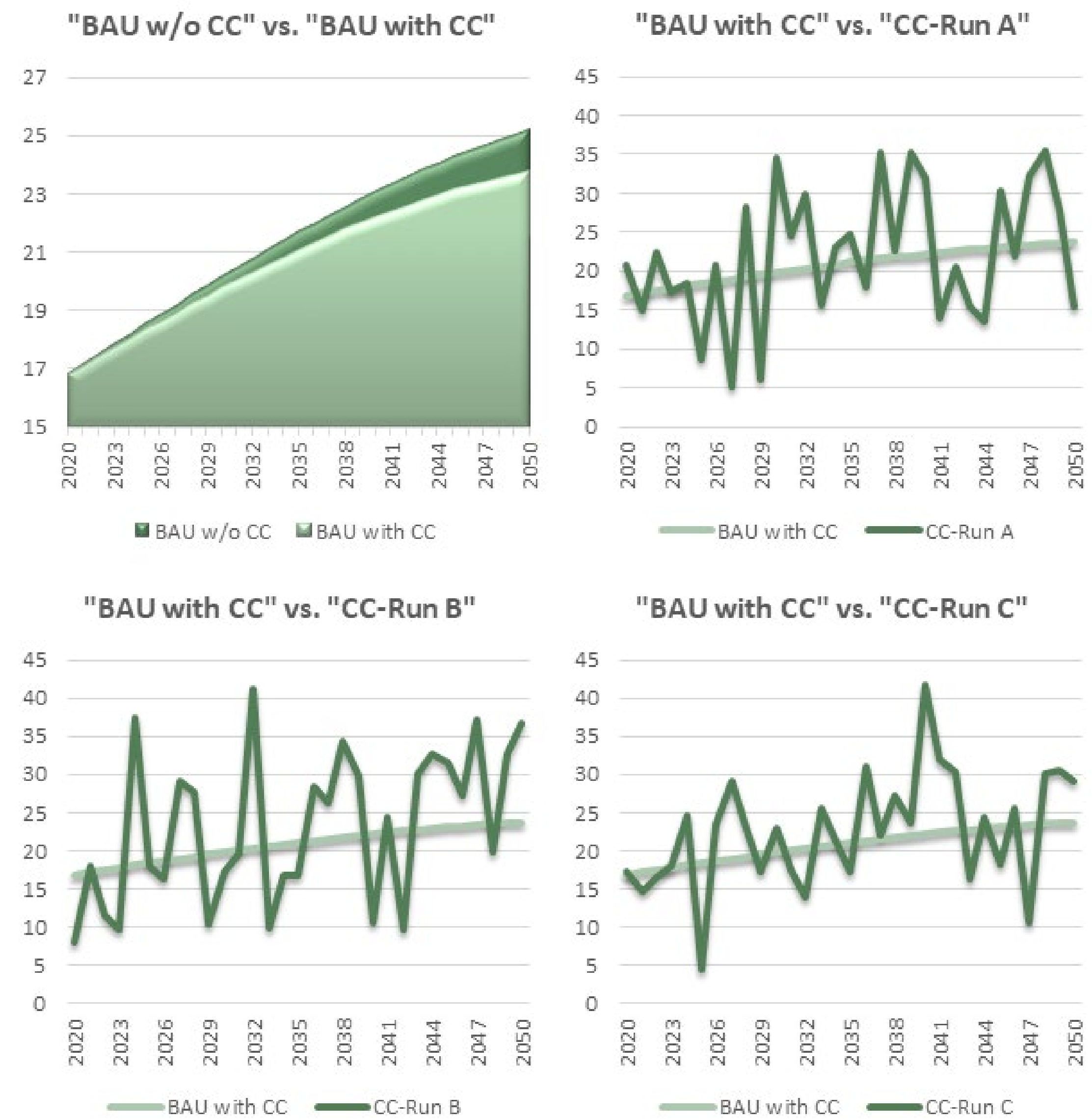
Annex F: Expected spring wheat yields from 2020 to 2050; yield trends (up-per left box) and three runs of randomized an-nual variations (in 100 kg per hectare)

Tuv



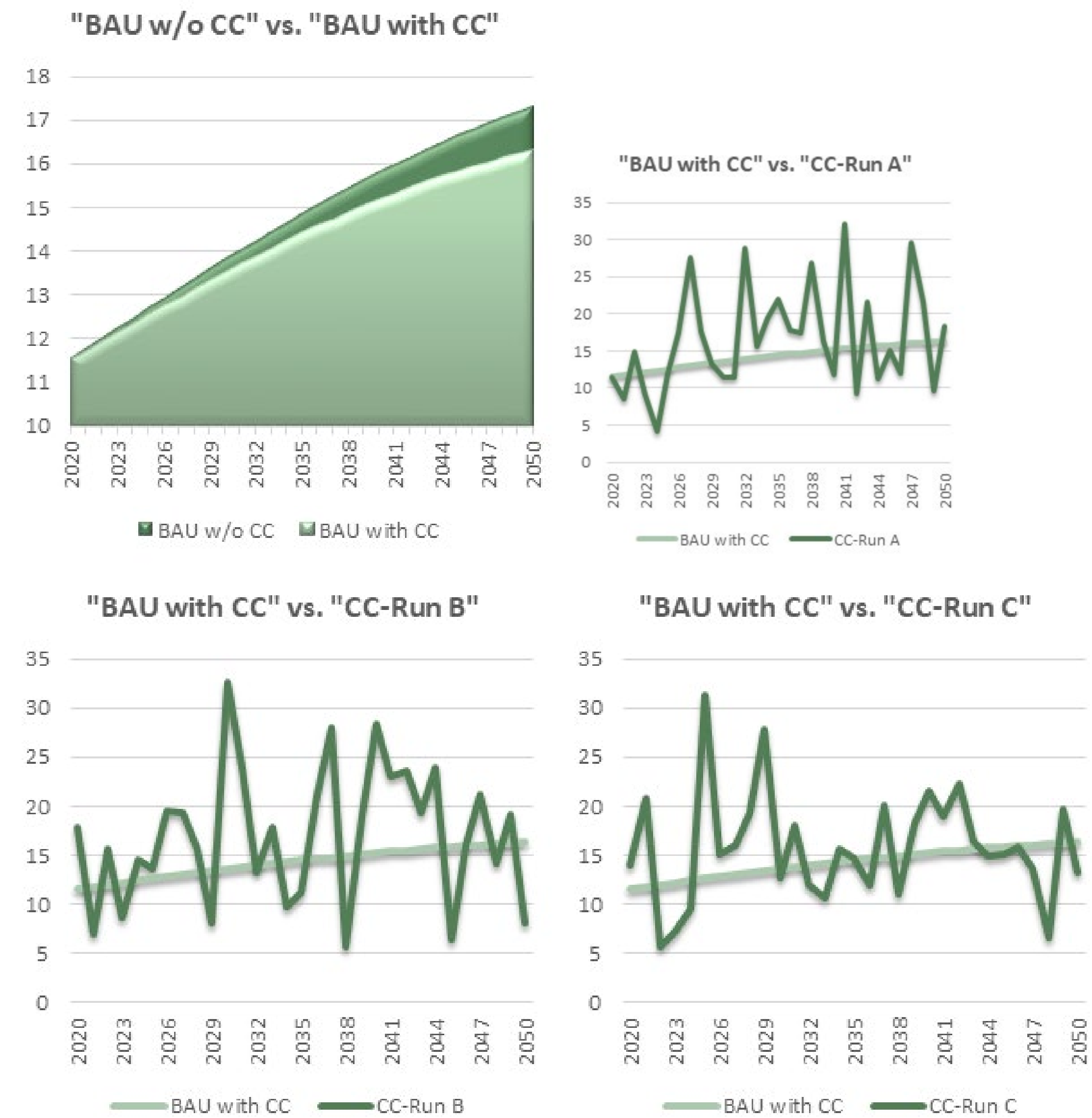
Annex F: Expected spring wheat yields from 2020 to 2050; yield trends (up-per left box) and three runs of randomized an-nual variations (in 100 kg per hectare)

Selenge



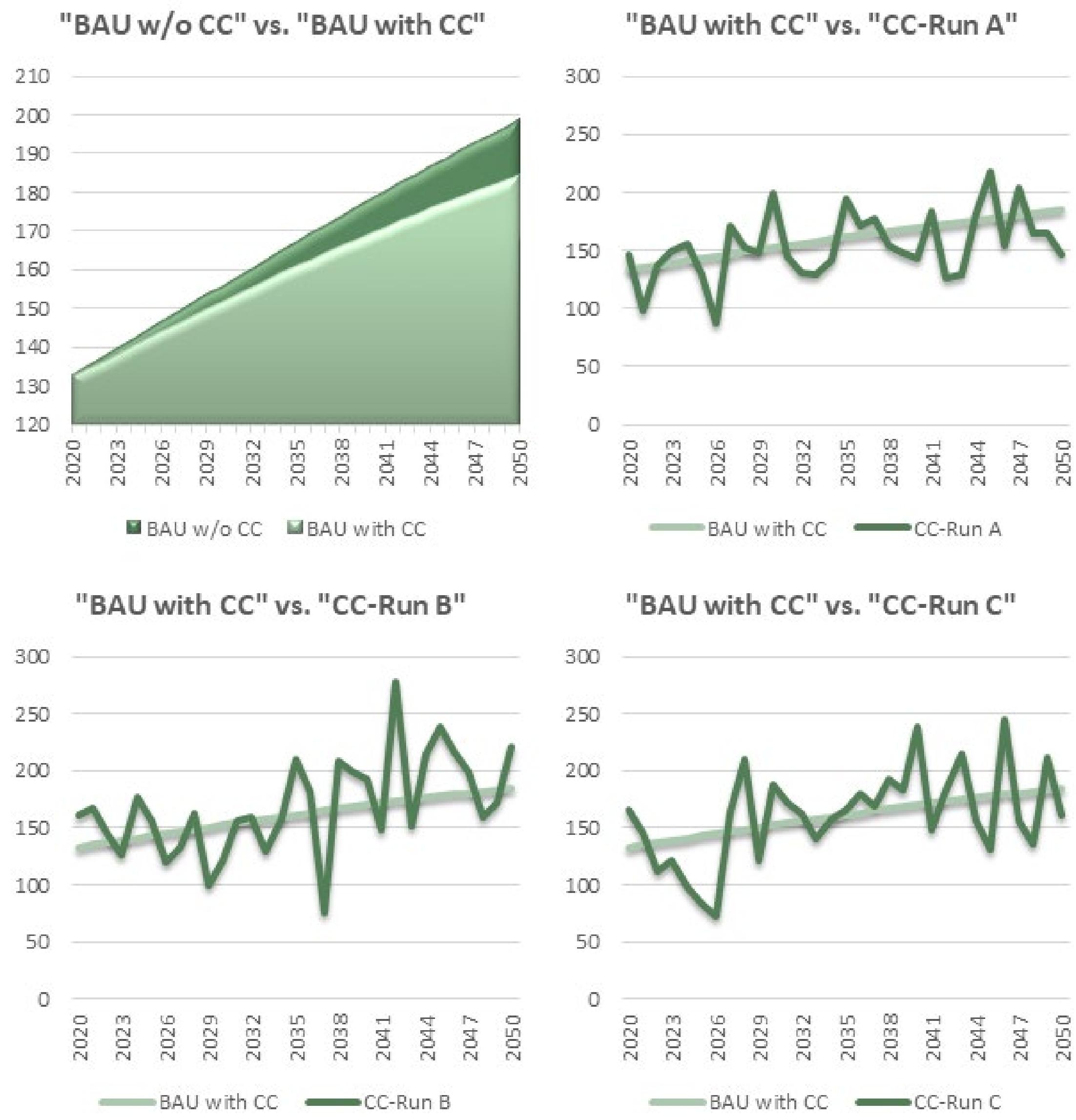
Annex F: Expected spring wheat yields from 2020 to 2050; yield trends (up-per left box) and three runs of randomized an-nual variations (in 100 kg per hectare)

Arkhangai



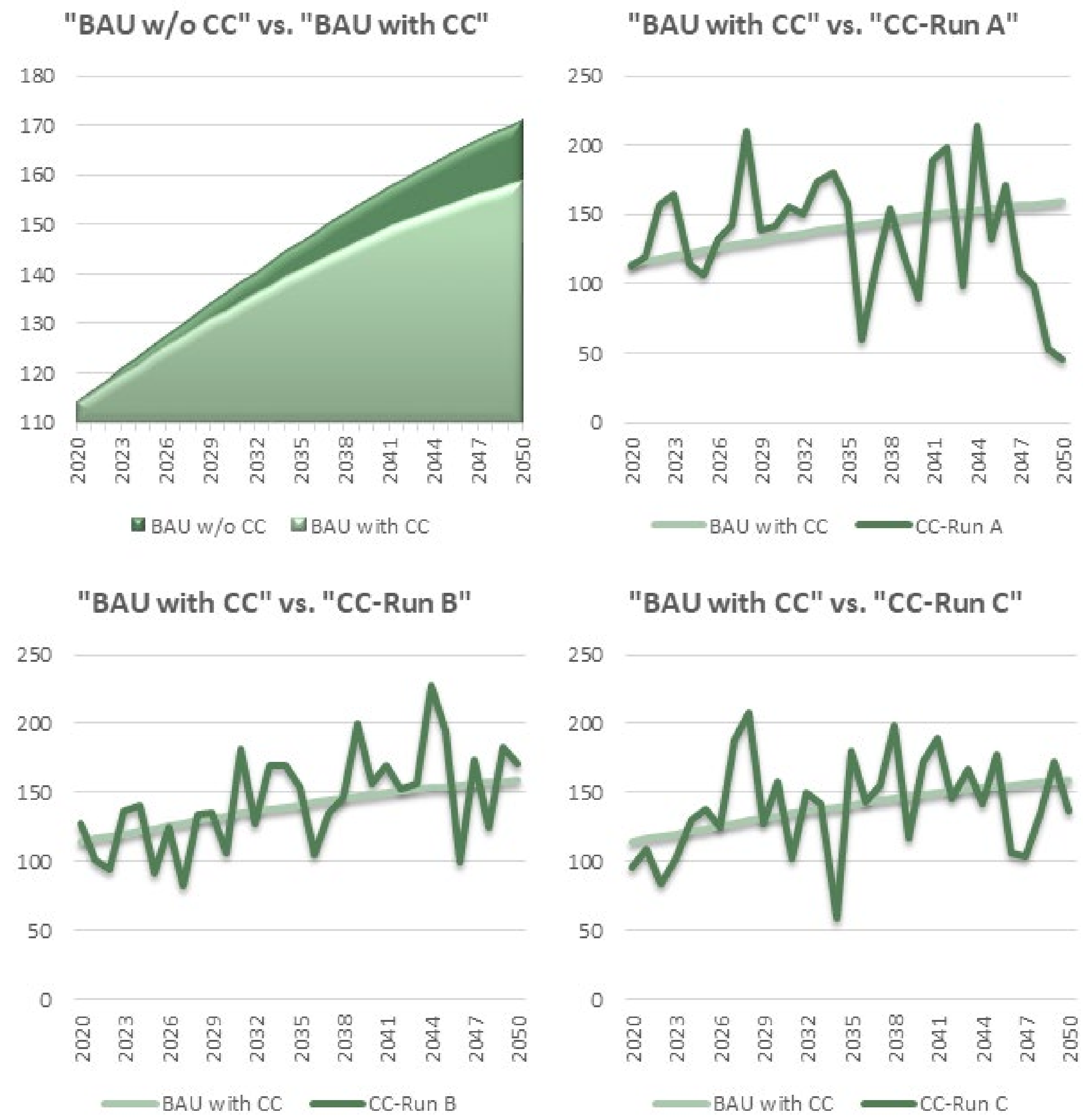
Annex F: Expected spring wheat yields from 2020 to 2050; yield trends (up-per left box) and three runs of randomized an-nual variations (in 100 kg per hectare)

Uvs



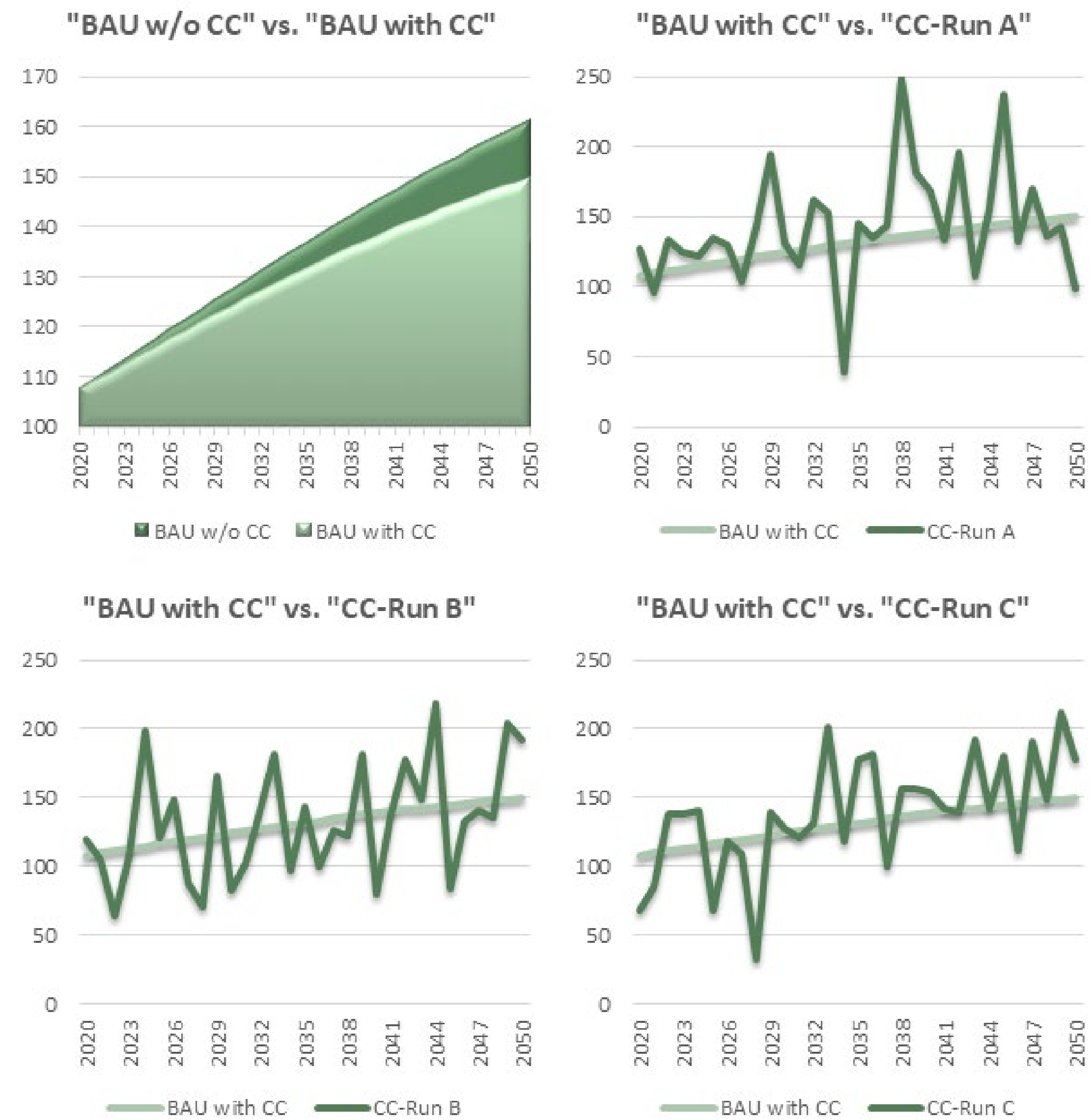
Annex G: Expected potato yields from 2020 to 2050; yield trends (upper left box) and three runs of randomized annual variations (in 100 kg per hectare)

Dornod



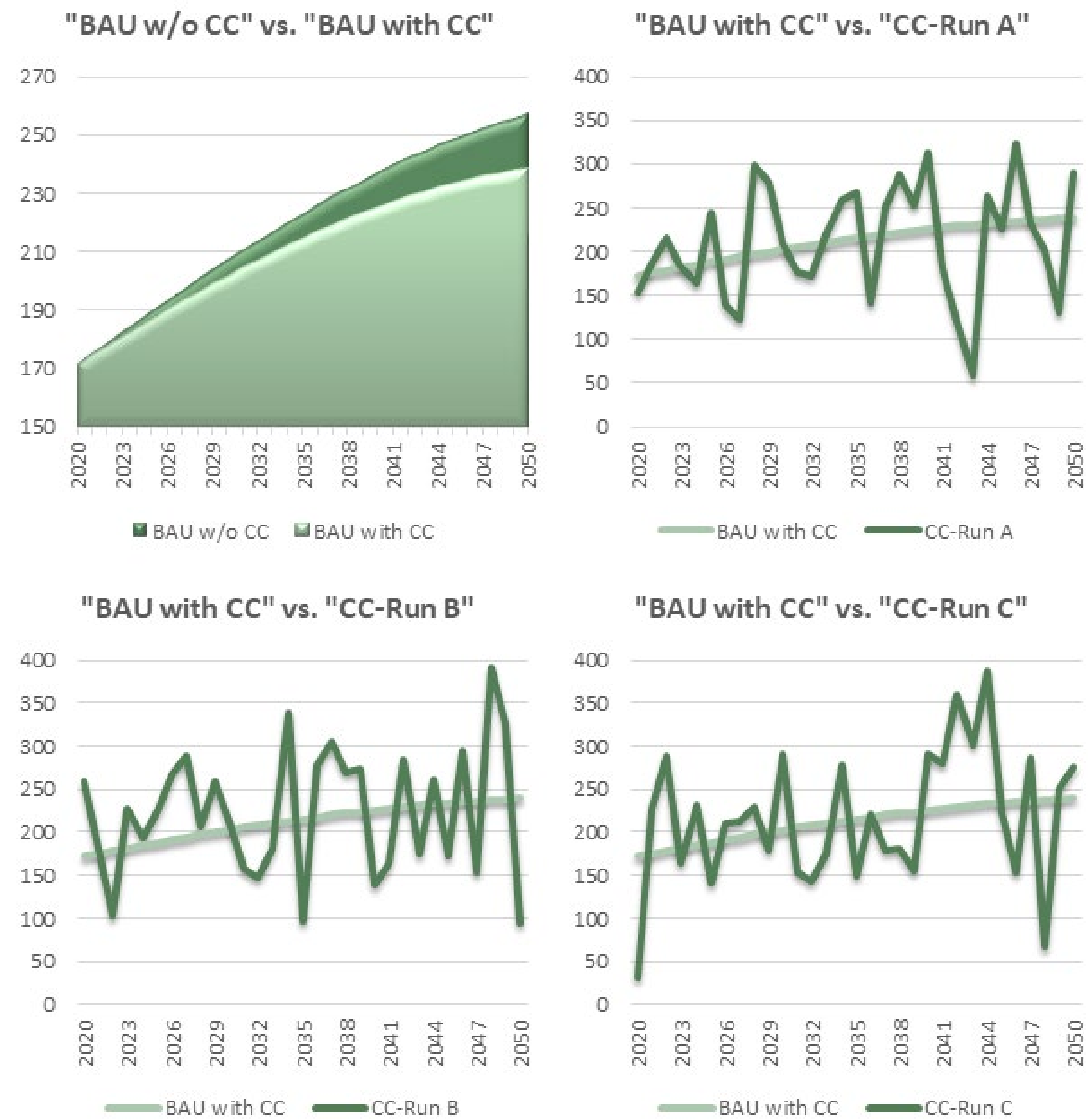
Annex G: Expected potato yields from 2020 to 2050; yield trends (upper left box) and three runs of randomized annual variations (in 100 kg per hectare)

Xo'vsgol



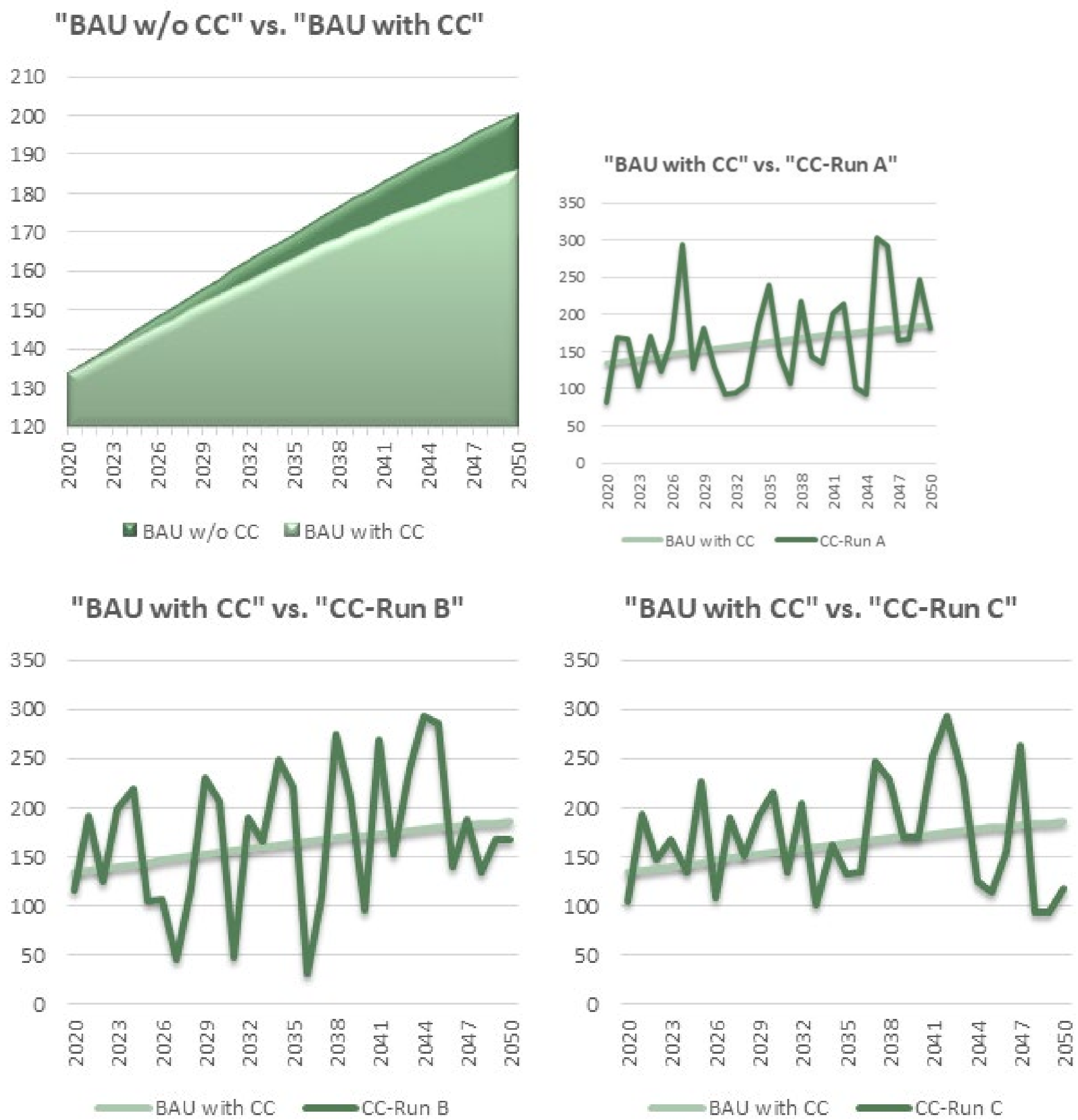
Annex G: Expected potato yields from 2020 to 2050; yield trends (upper left box) and three runs of randomized annual variations (in 100 kg per hectare)

Khentii



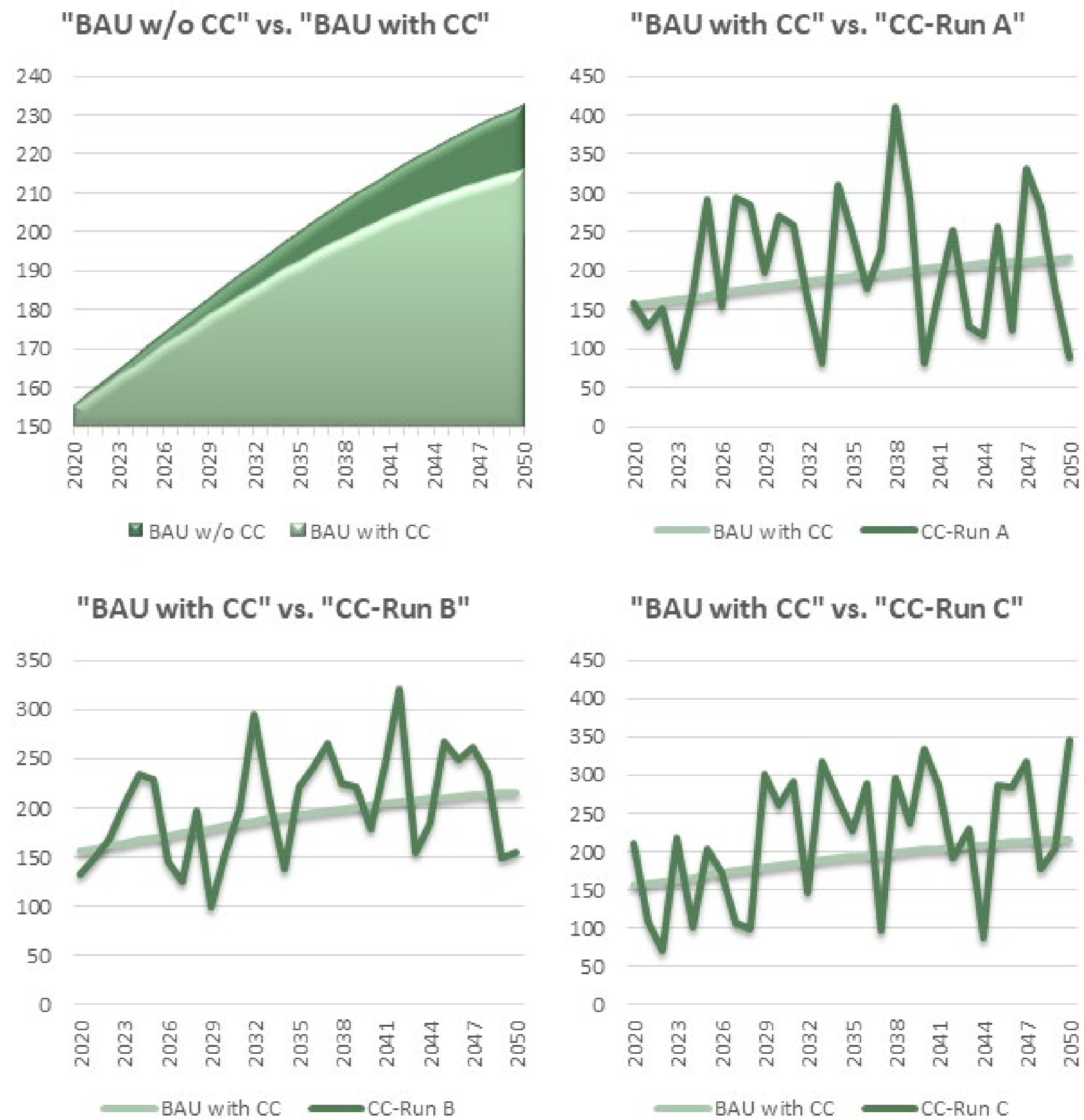
Annex G: Expected potato yields from 2020 to 2050; yield trends (upper left box) and three runs of randomized annual variations (in 100 kg per hectare)

Darkhan



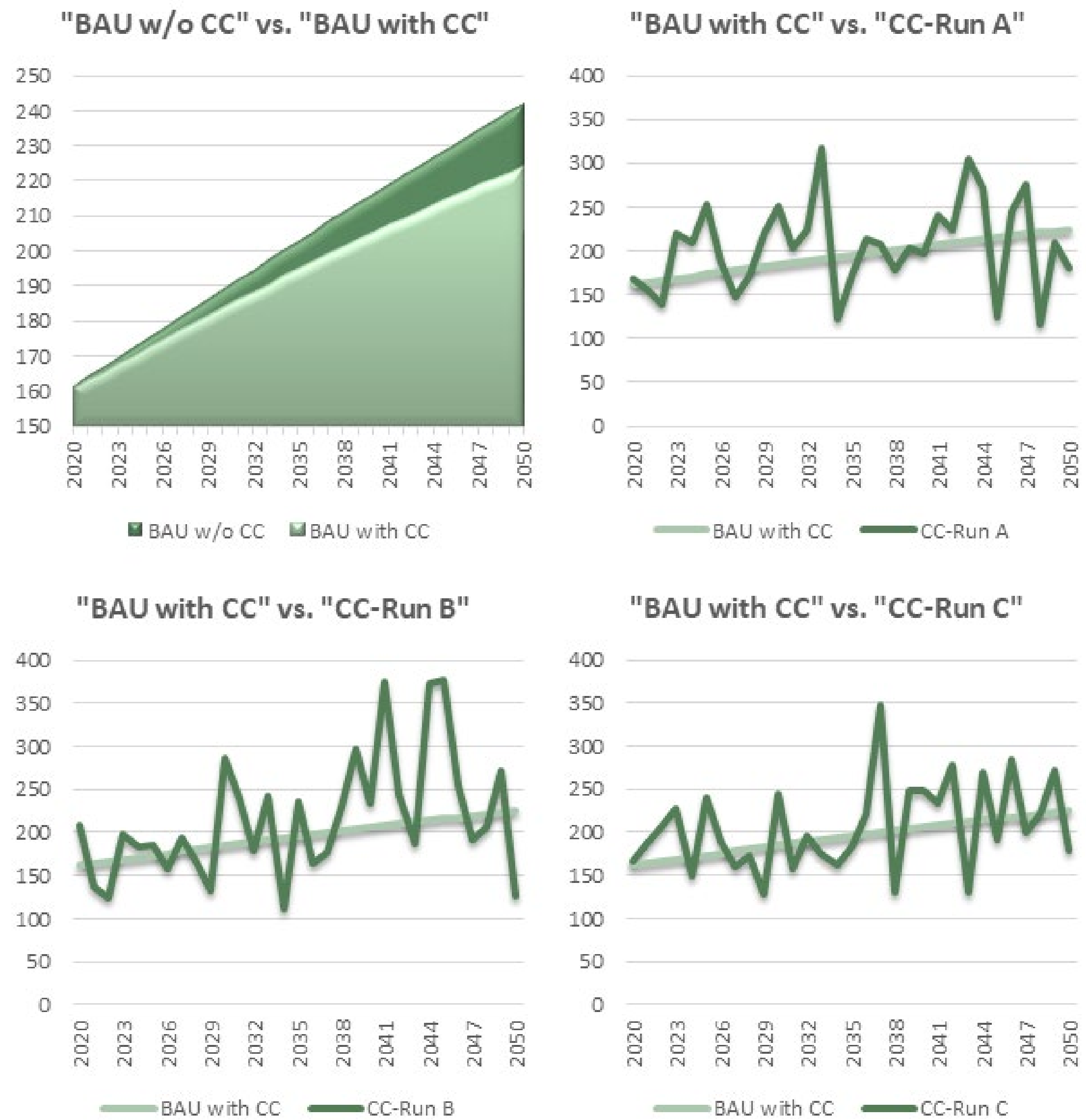
Annex G: Expected potato yields from 2020 to 2050; yield trends (upper left box) and three runs of randomized annual variations (in 100 kg per hectare)

Tuv



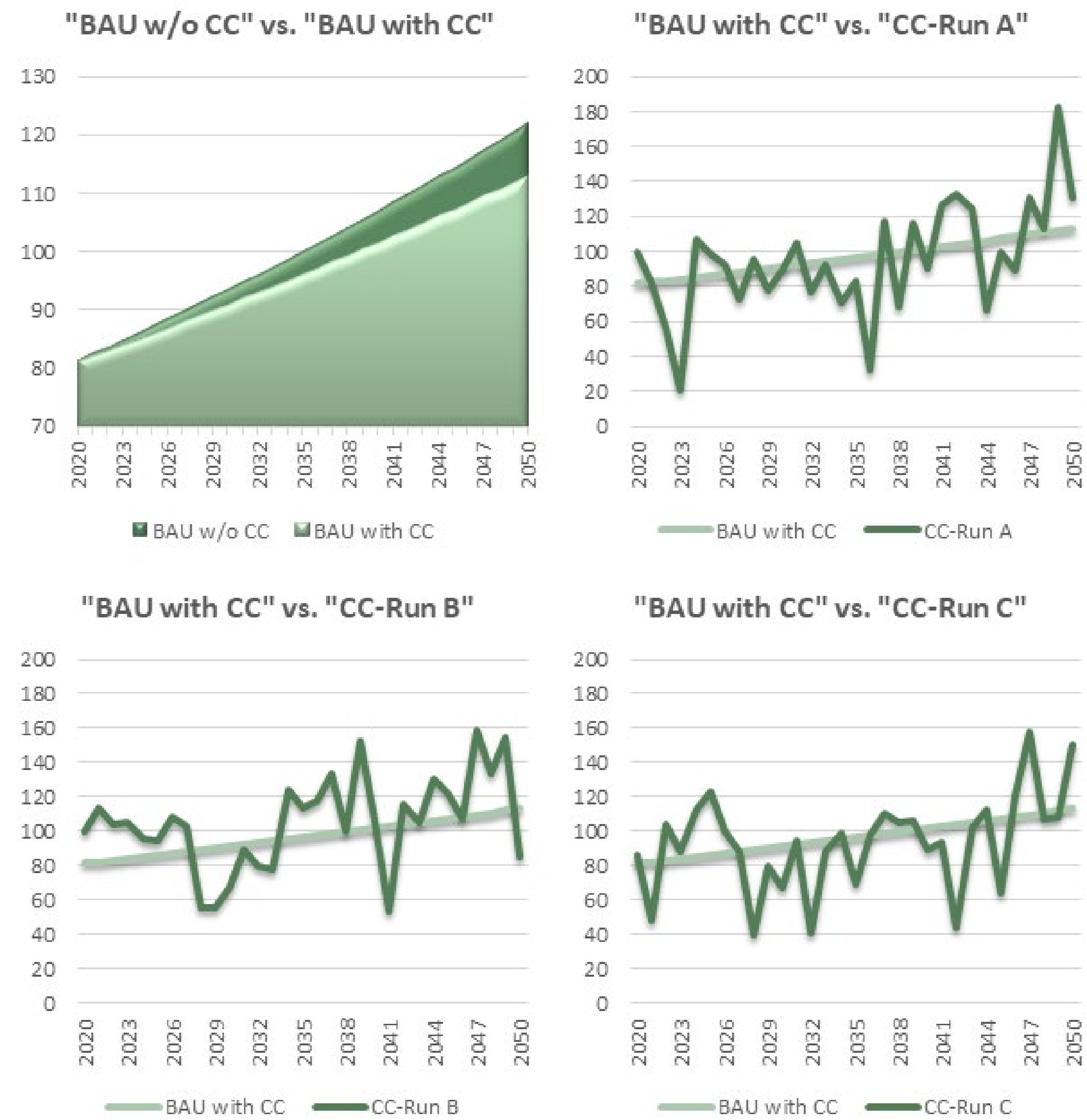
Annex G: Expected potato yields from 2020 to 2050; yield trends (upper left box) and three runs of randomized annual variations (in 100 kg per hectare)

Selenge



Annex G: Expected potato yields from 2020 to 2050; yield trends (upper left box) and three runs of randomized annual variations (in 100 kg per hectare)

Arkhangai



Annex G: Expected potato yields from 2020 to 2050; yield trends (upper left box) and three runs of randomized annual variations (in 100 kg per hectare)

INDEX-BASED CROP INSURANCE: INTERNATIONAL EXPERIENCE AND OPPORTUNITIES FOR MONGOLIA

Authored by:

Dr. Kuhn L.
Dr. Bobojonov I.
Leibniz Institute of Agricultural Development in Transformation Economies

CONTENTS

EXECUTIVE SUMMARY

Climatic conditions pose a considerable risk for the vulnerable Mongolian agricultural sector. In future, existing problems are likely to be further aggravated by climate change. Weather risk insurance may increase the coping potential of crop producers and increase investment into agricultural production. To support the development of tailored and sustainable insur-ance markets, this report reviews experience of establishing index-insurance worldwide with a special focus on transition economies like China, Kazakhstan, Mongolia, Ukraine and Uzbekistan. It discusses the suitability of international experience and approaches in designing and implementing a crop insurance that fits the Mongolian agricultural and financial system.

The pilot[1] projects discussed in this report are initiated by various actors ranging from local governments, international development agencies, NGOs, research and private enterprises. The scale of the discussed activities ranges from small pilot projects to large-scale programs with thousands of participants. Overall, long-term success - defined as programs imple-mented sustainably and beyond the pilot area in a fashion that they improve farm level risk management - does not seem to depend on the size of the initial investment, a specific in-dex or the type of implementing agency. Instead, successful projects are often characterized by a stable cooperation of private businesses and NGOs or research organizations. Further, sustainable programs were designed in a way that guarantees economic interests of business partners and takes into account the detailed demands of customers, which should be assessed in small pilot projects or consumer studies prior to the launch of large-scale programs. While governments often provided subsidies to compensate for farmers' low willingness to pay, their support in information dissemination and facilitating exchange between insurance agencies, banks and other stakeholders was at least as vital.

Overall, several lessons from other developing and transition economics could be translated into suggestions towards the establishment of a crop insurance in Mongolia. Most of these issues refer to the embeddedness of the program in national agricultural policy, coordination of interests and tasks between different stakeholders, and the setting of suitable incentives to farmers and insurance providers:

- Implementation of index insurance should be approached along small-scale pilot projects and outscaled only after gaining necessary experience with designing, distributing and servicing the product. This leaves opportunity to create a demand-based product and pre-vents the development of false expectations and damage of consumer trust. Furthermore, successful pilot farms can serve as demonstration cases for outscaling.
- Extension and information dissemination activities should be of highest priority in the policy discussion. The government can facilitate the process by organizing round tables and workshops for insurance agencies, banks, input suppliers, meteorological organiza-tions and extension agencies, where responsible parties discuss their interests and motivation towards introducing index insurance. This measure can improve understanding for the product among various stakeholders and increase coverage. Sole reliance on insur-ance companies will most likely be insufficient.
- Agricultural index insurance needs to be understood as part of the agricultural finance system and not as a standalone program. It should be integrated with credit lines and state procurement programs. However, insurance purchases should not be made mandatory. Programs have shown to be more sustainable if farmers are intrinsically motivated to buy the product, for instance due to improved credit access, lower interest rates, pref-erential input or procurement prices. Potential interests of banks and private input sup-pliers with regard to a cooperation in an index insurance program should be investigated.
- Any subsidization of the insurance sector or products should be planned such that financial support is not affected by budgetary fluctuations. Sudden withdrawal of government finances will likely lead to a breakdown of an established insurance market.
- Experience gained in the Mongolian livestock index insurance should be fully utilized in establishing index insurance for crop producers. Crop producers may be aware of the products offered for livestock producers and use it as reference information. Further research needs to be carried out on how positive spillovers from index based livestock insurance market could be transferred to crop index insurance.

[1] *Here, the term "pilot programs" refers to small-scale implementation of pilot programs in con-trolled environment.*

1. INTRODUCTION: CLIMATE RISK AND HISTORY OF LIVESTOCK INSURANCE IN MONGOLIA

1.1. CLIMATE RISKS IN MONGOLIA

Like most countries worldwide, Mongolia has witnessed a distinct change of climate over the last century. Over the last 115 years, average temperature (5-year average) increased by more than two degrees (see **Figure 1**). While more moderate temperatures in winter can contribute to longer vegetation periods, high temperatures during the vegetation period increase evaporation. In the past 20 years, Mongolia experienced several years with average tempera-tures during summer months being one to two degrees above the long-term average. High summer temperatures are particularly critical in arid regions where heat leads to a quick evaporation of scarce rainfalls.

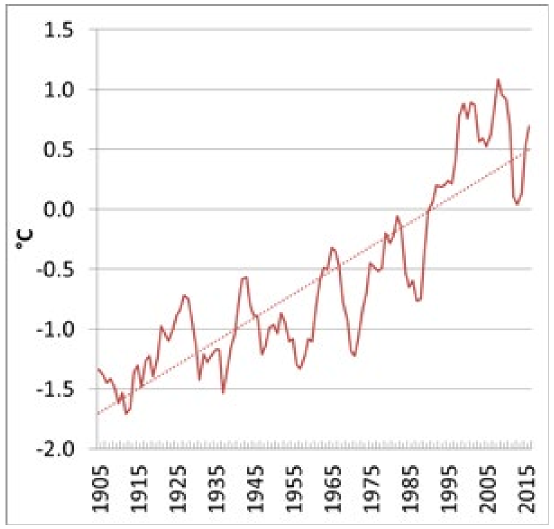


Figure 1: Temperature Mongolia (5-year averages) *(Source: Own illustration, data from Climate Change Knowledge Portal, 2019).*

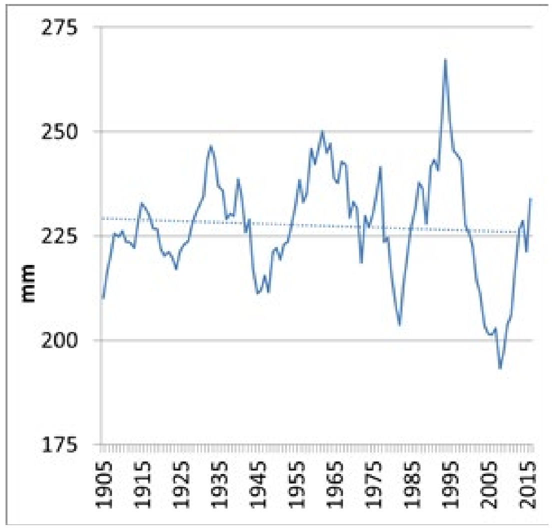


Figure 2: Precipitation Mongolia (5-year averages) *(Source: Own illustration, data from Climate Change Knowledge Portal, 2019).*

In addition to rising temperatures, the sum of annual precipitation (5-year average) has dropped by 23.8 mm (= 11 %) since 1901 in Mongo (see **Figure 2**). While decrease of rainfall is not statistically significant, existing rainfalls are subject to increasing spatial and temporal variability. According to the Third National Communication of Mongolia under the UNFCCC, precipitation in winter months is increasing due to global warming. Further, significant changes in certain parts of the country can be observed. *(Ministry of Environment and Tour-ism Mongolia 2018)*.

These changes had a strong effect on agriculture. Land without vegetation cover increased by three times between 1992 and 2006; in the same period, biomass in the rangelands decreased by 20-30 % *(Ministry of the Environment Japan 2014)*. Wheat, which is usually rain-fed in Mongolia, suffered from several drought waves over the past decades. While a general modernization of agriculture led to an increase in average yields, repeated drought waves translated into considerable yield losses, most recently in 2015 and 2017 (see **Figure 3**). This production uncertainty is not only a threat for food security, but can also affect the livelihood of crop producers and livestock farmers.

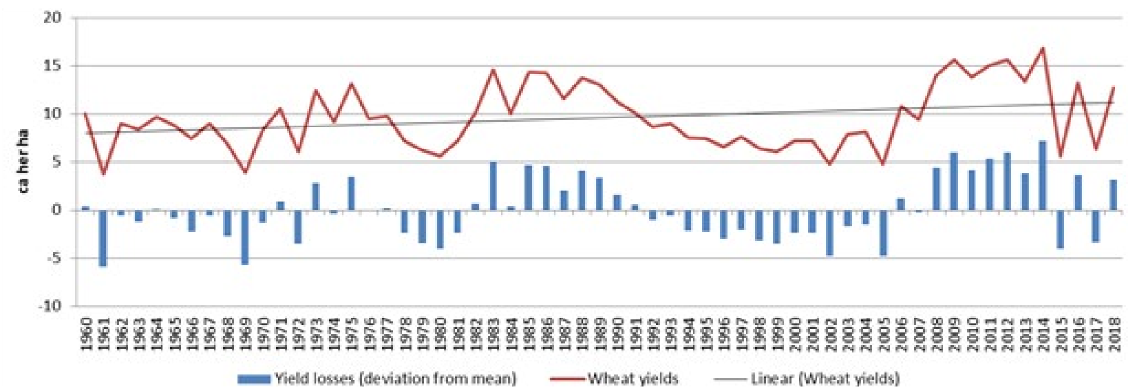


Figure 3: Wheat yields, trends and losses. *(Source: Own illustration, data from MSIS (2019)).*

The capacity of farmers to cope with volatile climate conditions crucially depends on their access to modern risk management. One option to increase coping potential is the availability of modern farming equipment and other production inputs. Irrigation, drought-tolerant varie-ties or specialized cropping techniques are examples of such production-level risk manage-ment. Second, farmers need to have access to functioning financial markets that will provide credits for above-mentioned investments or capital to compensate for income losses from yield shortfalls. Finally, yield storage can help mitigating the consequences of large price fluctuations due to volatile weather conditions *(Hardaker et al. 2015)*. In the following, we analyze Mongolia's agricultural infrastructure with regards to agricultural finance, input markets and harvest storage.

1.2. AGRICULTURAL INFRASTRUCTURE

1.2.1. AGRICULTURAL FINANCE

Mongolia's finance system is highly vulnerable to commodity price fluctuations, partially due to the heavy reliance of the country's industry on the mining sector: In 2018, 86 % of the na-tional export value came from mineral products, predominantly coal (41.3 %) and copper concentrate (30 %) *(MSIS 2019)*. In addition, the sector suffers from a large percentage of non-performing loans *(ADB 2018)*, which leads to credit rationing and strict collateral re-quirements. High collateral requirements - in the case of agricultural credit usually land, livestock, or agricultural equipment from crop producers - is regarded as one of the main credit constraints for farmers *(World Bank 2017a)*. Due to low stocks of valuable assets, they often have only poor access to financial markets, a problem which they share with the major-ity of agricultural producers in the region *(ADB 2018)*.

Nationwide, interest rates for loans in national currency range around 17 % *(MSIS 2019)*. While official statistics do not distinguish between economic sectors, examples from other countries in the region indicate that average interest rates are even higher for the agricul-tural sector. In consequence, investment in agriculture is growing only slowly, accounting for less than 3 % of national investment (see **Figure 4**). The Government of Mongolia has initiated several programs to improve access of agricultural producers to credits; yet both duration and overall budget of these programs are very limited. Consequently, studies recommend developing loan guarantee programs to back agricultural producers with low collaterals *(World Bank 2017a)*.

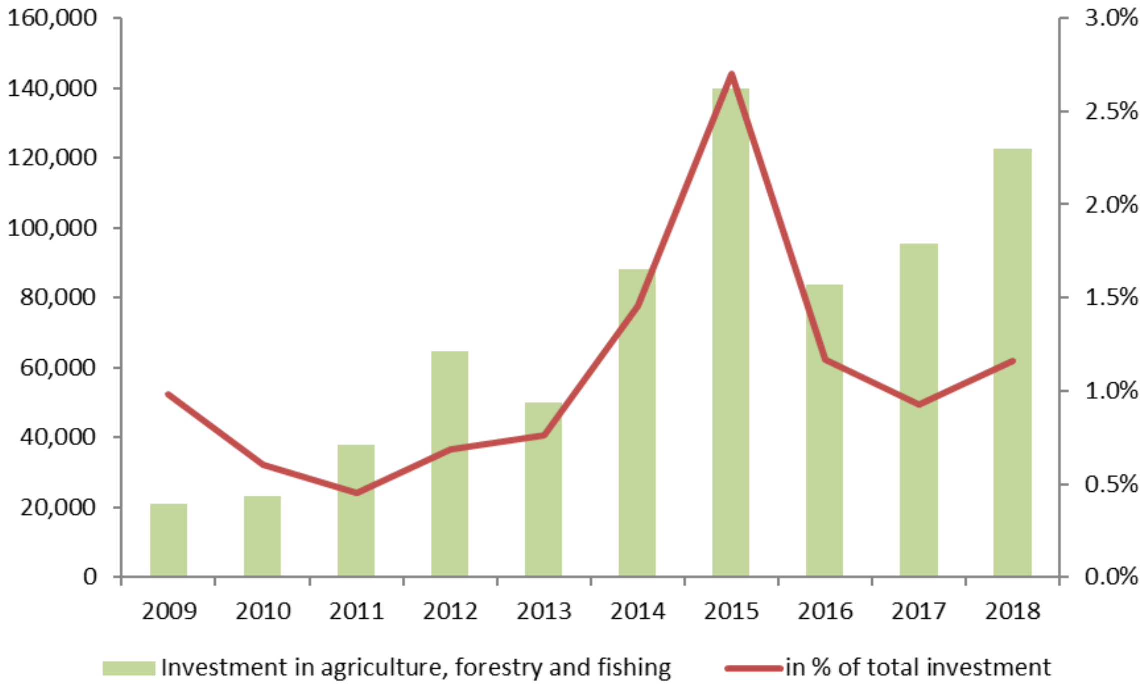


Figure 4: Investment in national currency, 2009-2018 *(Source: Own illustration, data from MSIS (2019)).*

1.2.2. INPUT FACTOR MARKETS AND STORAGE

Input distribution in Mongolia is implemented by private as well as international organizations *(FAO 2017)*. Still, only a limited number of input suppliers are active in the Mongolian market. According to World Bank *(2017a)*, in 2010 only 44 input suppliers in the livestock and crop sectors were operating in the whole country.

According to the World Bank *(2019)*, fertilizer use increased from 5.9 kg per hectare to almost 40 kg per hectare between 2002 and 2016. Due to rising labor costs, the use of pesticides and herbicides as well as expanding the area of minimum tillage technologies are becoming essential. However, in 2010 only 22 % of the cropland was treated with fertilizer, application of chemical fertilizer being more common in commercial farms than in household farms. Although the Government of Mongolia provides price support for chemical fertilizer, current prices are still too high for many farmers *(World Bank 2017a)*. Concerning irrigation, the state promotes financial support towards the construction of reservoirs, head gates and pipelines. The government also provides loans without interest for irrigation equipment up to three hectares and up to three years. Despite the subsidies, irrigation facilities are still very costly; thus, irrigation is only used for high value crops such as vegetable, fruits, alfalfa, and seed grains.

Finally, the state is actively involved in the seed sector via the State Seed Reserve Fund, providing soft loans and subsidization of equipment in order to facilitate modernization *(World Bank 2017a)*. The Fund on Supporting Crop Farming (FSCF), which provides most of the support and subsidies in crop production, operates grain storages and procures grain from farmers at guaranteed prices. FSCF is the largest supplier of fertilizer, chemicals, seeds as well as an important provider of machinery. Farmers obtaining inputs from FSCF can also pay for their bill with obtained yields after the harvest.

While input provision is certainly improving welfare and risk-coping mechanisms in the short run, World Bank *(2017a)* recommends decreasing the involvement of the Government of Mongolia in input supply activities to improve commercial supply of inputs. In other countries, commercial input suppliers are often taking on important roles in agricultural extension services and provision of other agricultural services, a role which shall be discussed more in detail in the country cases.

2. LOSS-BASED CLIMATE INSURANCE

Another important risk management option is the insurance of agricultural production against climatic risk. The next section discusses opportunities and constraints observed in climate insurance programs worldwide, with a particular focus on transformation economies like Mongolia.

2.1. WORLDWIDE COVERAGE

Over the past few decades, yield insurance has been becoming one of the important tools to manage risks in production and marketing. In particular, traditional loss-based weather in-surance is a very established instrument across the world. Mahul and Stutley (2010), the most recent comprehensive study on the topic, found an estimated sum of agricultural insurance premiums of 13.5 billion $US in 65 countries worldwide. For the developing world, Hess and Hazell (2016) found insurance programs covering 0.5 million hectares in Africa, 174 million hectares in Asia, and 3.3 million hectares in Latin America and the Caribbean.

Transition economies such as China, Kazakhstan, Russia, Ukraine and Uzbekistan are among the countries with the longest history of traditional crop insurance. Still under political sys-tems of planned economy, the governments of these countries payed particular attention to the development of agricultural markets and were actively involved in setting up insurance systems. In most of the cases, the provision of subsidies played an important role in increas-ing the coverage of insured area[2]. In Mongolia, crop insurance exists only for seed producers; wider dissemination is challenged by problems that are also observed in many other coun-tries and shall be discussed below.

2.2. GENERAL CHALLENGES

Despite the general success of agricultural insurance, worldwide market penetration in 2010 reached only 0.9 % *(Mahul and Stutley 2010)*. Several challenges have so far prevented a faster and more comprehensive spread of insurance systems in developing countries:

First, damage assessment is typically costly due to the high geographic dispersion of custom-ers in the countryside and a high information asymmetry between customer and insurance agency. To avoid this problem, insurance companies are forced to send evaluators for expensive and time-intensive field inspections or find other ways to verify yield information. For commercial products, this costly process typically results in high premiums. Unfortunately, farmers' ability to pay high premiums is low, especially in regions of high climatic risk. Therefore, market-based products often fail to cover large parts of the production and exclude small and marginal producers. The second challenge is the lack of transparency of loss-assessment and payout processes. Under loss-based

[2] Detailed information about the market development in these countries is provided in Section 3.

insurance, both insurance companies and producers have to rely on subjective processes of field inspection. Area-yield insurance meanwhile relies on official yield statistics whose accuracy may be subject to reporting bias or explicit manipulation.

3. INDEX-BASED INSURANCE - EXISTING EXPERIENCE

Index-based insurance attempts to avoid the above-mentioned problems by basing payouts not on damage assessment via field inspection but instead on various weather or vegetation indices featuring high correlation with yields and yieldlosses. In addition to reduced transaction cost, this method also promises higher transparency and speed of case settlement. Meanwhile, poorly developed programs easily suffer problems of basic risk, which arise when actual harvest default is not identical with estimated values based on which insurance is providing outputs. Accurate index design, including the choice of data, critical growth periods, appropriate area aggregation and other technical details are therefore of utmost importance.

Systemic risks occur when weather events affect large areas, triggering a large number of indemnity payments at a time, which is a problem for both loss-based and index-based insurances. In such an event, national insurance companies might not be able to handle the large amount of outstanding compensation requests, resulting in payout delays or shortfalls. Re-insurance by international insurance companies can solve this dilemma but is usually not available for traditional loss-based insurance: Due to the geographical distance, loss assessment procedures via direct field inspection are hardly transparent for international re-insurers, raising issues of moral hazard. The availability of unmanipulable and easily accessible information used by weather and vegetation indices meanwhile allows the negotiation of re-insurance contracts.

In the following, we will introduce the state of implementation in Mongolia and compare it with international experience and country-specific challenges of index-based insurance. Most attention is given to piloting activities in transition economies with similar economic and agricultural systems as in Mongolia.

3.1. GENERAL OVERVIEW OF COMMERCIAL AND NON-COMMERCIAL IMPLEMENTATION ACTIVITIES

Worldwide, we can observe a considerable number of projects aiming at the implementation of index-based insurance. Table A1 in the appendix provides a list of large-scale implementation and small-scale piloting activities, which were compiled from various sources for this report. Most of the pilot projects in emerging economies are implemented by governments in cooperation with private companies and/or research institutions and rather technical support by NGOs. In high-income countries such as USA and Canada, implementation activities are usually carried by the national government in cooperation with private companies. In almost all projects in developing countries, international development and donor agencies played the leading role in initiating piloting activities. Most recently, large international re-insurance companies (e. g. Swiss Re, Munich Re and Hannover Re) played a very active role in initiating piloting activities in developing countries and emerging economies like China, Kazakhstan and Indonesia.

National government initiated programs. The Index Insurance Initiative in Canada is one example, where a national government took the leading role in an implementation project. The provincial government of Ontario initiated a program of production insurance

for various crops. Since 2014, the Forage Rainfall Plan has offered index-based insurance against drought and excess rainfall. The government bears all administrative costs and also provides about 60 % subsidy towards premiums. The developed weather index triggers when cumulative rainfall drops below 85 % of the long-term mean. Rainfall data stems from 350 weather stations and is provided by AgriCorp insurance, a state-owned company under the Agricultural Ministry of Ontario. In 2018, 1094 farmers with nearly 100,000 insured hectares participated in the Forage Rainfall Plan, leading to a total sum insured (i. e. insured amount of production) of nearly $45 million. Premiums (i. e. price of insurance) amounted to $47 per hectare on average. Due to widespread drought in 2018, claims were approved for nearly half of the contracts. Claims for the Fodder Rainfall Plan reached $11 million, accounting for 9 % of total production insurance claims *(Agricorp 2019)*.

Donor initiated projects. Since 2011, the World Food Program and Oxfam America have been establishing index insurance programs in Ethiopia, Senegal, Malawi and Zambia via the Rural Resilience Initiative *(World Food Programme and Oxfam 2019)*. The employed index is based on rainfall data available from satellites *(World Food Programme 2018)*. One of the particular characteristics of this type of insurance programs is that poor farmers can pay for insurance premiums with their labor. In addition to the WFP and Oxfam, also other stakeholders are involved in the project implementation, most prominently government agencies, for instance the Swiss Agency for Development and Cooperation, Government of Flanders International Cooperation Agency and DFID (United Kingdom), who contribute with substantial funding *(World Food Programme 2018)*. World Bank also initiated and supported estab-lishing index insurance markets in Mongolia and Ukraine, which will be discussed more in detail in the next chapter.

Private initiatives. There are only very few examples where private companies launched an index insurance program without considerable support by local governments, donors or other NGOs. However, especially in high-risk environments, input suppliers and procurement com-panies are aware that they have to support farmers to secure stable returns of investment. In some cases, they therefore launch insurance initiatives or create incentives for farmers to insure their production. For instance in 2007, food and beverage corporation PepsiCo intro-duced an index-based insurance for Indian farmers. Polices are sold by ICICI Lombard, one of the leading private sector general insurance companies in India, and are managed through the private consultancy company Weather Risk Management Services (WRMS), which is responsible for product design and installation of weather stations. In detail, PepsiCo offers farmers higher procurement prices when they cover their production by index insurance, the price advantage being equivalent to approximately 50 % of insurance premiums. In parallel, PepsiCo developed a routine of distributing weather information and important farming information via smartphone apps *(PepsiCo 2017)*. In 2016, ICICI Lombard GIC Ltd. initiated the PMFBY program, which covered 1.5 million farmers by the season 2017/2018 and reportedly replaced all earlier insurance schemes. The high coverage stems from substantial government subsidies; further, all farmers applying for Seasonal Agricultural Operations loans from financial institutions are covered by the insurance scheme compulsorily. For damage assess-ment, the program uses a mix of area-yield data provided by regional government and satellite-based vegetation indices *(ICICI Lombard 2018)*.

3.2. MONGOLIA - THE STATUS QUO

The Mongolian Index-based Livestock Insurance (IBLI) is one of the very few successfully commercialized index insurance programs in transition economies, but also one of the few sustainably out-scaled programs among developing countries. With support of World Bank and other international donors, IBLI has been developing since 2001 to protect herders from weather risks, especially harsh winters known as dzud. Piloting activities began in 2006 in three provinces of Mongolia and were stepwise scaled up to national levels until 2012. In 2014, all activities were transferred to private insurance companies and one re-insurance company based on public-private ownership *(Bertram-Huemmer and Kraehnert 2015)*. Insur-ance payments are based on district level livestock mortality rates. Insured herders receive indemnity payments when district level mortality drops beyond the predefined trigger *(Bobojonov 2017)*.

Similar to other countries, also the Mongolian government provides subsidies to make market-based premiums more affordable to farmers. In this case, we observe an indirect subsidization of premiums. This is implemented by dividing the indemnity payment into two levels. At the first level, losses up to 30 % of production value (in some extremely risky regions 20 %) are covered under market conditions. This means that re-insurance of the losses by interna-tional re-insurance companies is covered only by the premiums collected from insured herd-ers. Meanwhile, the price for re-insurance of losses over 30 % (or 20 %) of production value are subsidized by the state. Thus, the overall price of the product remains affordable to the Mongolian herders. Insurance can be selected for specific livestock and set at various levels of livestock value. While herders can insure between 1-100 % of the value of the livestock, on average 30 % of the livestock value is insured *(AgRe 2015)*.

In 2015 season, about 5.1 % of the 51.98 million livestock in Mongolia were insured, mostly small ruminants *(AgRe 2015)*. In total, about 7 % of Mongolian herders were insured in 2016 *(IBLI 2015)*. In 2015, agricultural insurance employed 180 agents working in 1101 branches belonging to different insurance companies in 21 provinces of Mongolia *(AgRe 2015)*. Participation of herders in the IBLI is voluntary and based on their interests in risk management. In addition to intrinsic interest in risk management and the premium subsidies from the state, another motivation to purchase insurance is that insured herders can receive a 2 % reduction in interest rate for commercial agricultural credits. According to interviews of the authors with AgRe (currently Mongolian Re), banks have started to act as brokering agents with a certain brokerage fee since 2017, leading to a further increase in insurance coverage.

A recent study found a positive impact of indemnity payments on asset recovery of insured households *(Bertram-Huemmer and Kraehnert 2018)*. In fact, the program was viewed as so successful by the World Bank that the IBLI concept was later outscaled to Kenya and Ethiopia.

3.3. CHALLENGES AND BEST PRACTICES IN TRANSITION ECONOMIES - FOUR COUNTRY CASES

While there are typical challenges shared by all of these pilot initiatives, transition economies may feature problems and requirements different from those in traditionally market-based economies. The following chapter will provide more detailed information on the characteristics of existing index insurance pilots in transition countries.

3.3.1. CHINA: POOLING REINSURANCE AND EXPERIMENTING WITH MULTIPLE PPP INITIATIVES

In the past 50 years, China has witnessed an increased prevalence of droughts in its northern areas, one of the major grain producing areas of the country *(Zou et al. 2005)*. In reaction, the Chinese government undertook several attempts to introduce traditional loss-based agricultural insurance. While these programs were heavily subsidized and reached high coverage, indemnity payments (payments to cover the losses) were very low in absolute terms and in relation to actual losses. Therefore, these programs failed to have meaningful effect on the disaster-coping capability of insured farmers *(Wang et al. 2011)*.

Since these first, rather unsuccessful attempts, several pilot programs of index-based climate insurance have been introduced on a regional level and for rather specific products. Most of these programs were introduced with involvement of reinsurer Swiss Re (see **Table 1**). At the onset, index insurance products were not eligible for state subsidies, as the China Insurance Regulatory Commission (CIRC) feared to lose the trust of consumers in case of basis risk and instead insisted on a physical verification of losses. To remedy this lack of stakeholder dia-logue, the German GIZ conducted several successful measures: Increased efforts in measur-ing risk exposure in cooperation with the China Meteorological Administration (CMA) provid-ed the necessary knowledge base. Stakeholder discussions with participation of regulators aimed at building trust and were disseminated in the format of studies to support evidence-based policy making. In the end of the process, the CIRC introduced the Agriculture Insurance Ordinance and henceforth started to approve also index-based insurances *(GIZ 2019)*. Since the inclusion into state subsidy programs, subsidization of agricultural insurance in China has reached levels of 80 % of premiums.

Meanwhile, several factors still impact the developments of index insurance markets beyond small-scale pilots. Foremost, the coverage of the Chinese pilot projects depends on the ex-tremely high level of subsidies which may communicate wrong incentives and are a major budgetary burden that many countries might find difficult to carry. Another essential aspect is the distribution of premium subsidies, which generally suffers from transparency issues and misallocation, spurring government to strengthen efforts to prevent fake underwriting and misallocation of subsidies. Due to their rather recent implementation, detailed systematic evaluations of specific programs do not exist up to now. Jin et al. *(2016)* evaluate the 2009 pilot for rice in Anhui, finding take-up by about 50 % among sample farmers. Lack of cover-age was mostly due to price aspects (44 %), but also lack of trust in payouts (18 %) and lack of information or understanding of the offered product (24 %). The subsidization worked well in promoting insurance take-up; 30 % of the insured farmers mentioned government subsidiza-tion as the main reason for joining the pilot. Also due to this subsidization, the rice-insurance project in Anhui province was cheaper than traditional loss-based insurance. However, main problems apparently were pricing risk and basis risk, which could not be resolved by the product *(China Re and P&C 2014)*. Generally, the capacity of local insurance companies for index development was reported to be inadequate. Furthermore, demand was limited through lack of coordination with banks and other relief programs *(IFAD 2010)*.

As mentioned, earlier loss-based insurances failed to have a meaningful impact due to the low level of transfers, which considerably decreased the interest of farmers in purchasing insurance *(Wang et al. 2011)*. Indeed, the sum insured reached on average only a third of actual production cost (see **Table 1**). Another important issue is the low trust of farmers in insurance companies. Previous negative experiences with settlement processes can seriously harm trust in current programs, even in cases that date back several decades *(Wang et al. 2011)*. New pilots still did not seem to have solved existing problems of process transparency *(Agroinsurance 2017)*.

In RMB / mu	Sum insured	Production cost covered		Total production cost	
		Value	SI / Cost	Value	SI / Cost
Rice	349.1	449.7	77.5%	1,151.1	30.3%
Wheat	337.0	407.3	82.7%	914.7	36.8%
Corn	273.8	350.0	78.2%	1,012.0	27.1%
Soybean	190.4	193.0	98.7%	625.9	30.4%

Table 1: Production cost vs. sum insured (2014) *(Source: PeakRe 2017).*

For a long time, the massive size of Chinese agricultural production made risk sharing a major challenge. In order to solve this issue, the China Agricultural Reinsurance Pool (CARP) was established in 2014. Insurance companies that are members of CARP contribute with roughly half of their insurance premiums to the pool. The managing agency China Re P&C negotiates reinsurance terms with their members *(Krychevska et al. 2017)*. Even though 23 direct insurers are contributing to the pool, in 2018 China Re paid the majority of contributions (80 %) *(IMF 2017)*. The increased activity of international reinsurance companies meanwhile provided real alternatives of risk sharing under the condition of data transparency and reliability of underwriting and settlement processes.

Featuring mixed results, these pilots are likely to be only first steps in Chinese agricultural risk management. In future, the Chinese insurance market is to be complemented with an effective price-insurance product. Despite government incentives and several official notes pressing for a development of the insurance market, the introduction of a target price insurance so far was too unattractive to insurance companies. Previous studies therefore urged for institutional reforms to support new policies on the development of insurance markets with necessary market incentives, for instance effective price signaling by futures markets. *(Kenderdine 2018)*.

3.3.2. KAZAKHSTAN: COMMERCIAL PROJECTS INITIATED BY AN INTERNATIONAL RE-INSURANCE AND LOCAL INSURANCE COMPANIES

With its vast land resources, Kazakhstan is one of the largest grain producers and exporters worldwide. Despite its critical role for grain world markets, grain production in the country is very volatile. Serious droughts, like witnessed in the years 2002, 2010 and 2012, are a serious threat to agricultural production. Agricultural insurance is perceived as an important instrument to deal with risk also by the Kazakh government. Crop insurance

was thus made mandatory in 1997 and has been subsidized since 2004.

Agricultural Insurance in Kazakhstan is offered by commercial insurance companies and mu-tual insurance societies. Producers have the opportunity either to buy the insurance policies in an insurance company or be a member of mutual insurance societies. The distribution of subsidies is implemented by the joint-stock company "KazAgroGarant", which reimburses 50 % of the paid claims. Due to relatively high levels of subsidies and legislative pressure, a high insurance coverage was achieved until 2008, when 84 % of the national crop area was insured. However, popularity of the insurance program has declined since then, with having reached only 42 % coverage by 2018. This decline in coverage can be explained by the country's high systemic risk, leading to incidents when rightful claims were not disbursed and subsequent distrust of customers in any further insurance programs. Further, premiums remain high despite strong subsidization, making the product rather unattractive, even for the large commercial farms.

The state has recognized those development challenges and convinced itself of the importance of index insurance to tackle these issues. In 2014, the government therefore opted to create a conducive environment to establish and develop index insurance markets in Kazakhstan *(UNDP 2016)*. The first practical implementation of index insurance was in 2016. Since then, an index insurance product has been offered via the agency QOLDAU (the former Minagro) in cooperation with Swiss Re. The product and payouts are based on a soil moisture index generated from satellite data provided by Vandersat *(QOLDAU 2019)*. According to the information of QOLDAU *(2019)*, the correlation of yield and soil moisture index is 81 %. Indemnity payments are set between 2.43 % and 4.8 % of the sum insured. Insurance indemnity payments are provided in two or three stages depending on the crop (e. g. two stages for hay and fodder, 3 stages for cereals). More than 10 thousand hectares of crop area were insured in the pilot regime in the Kostanay, Akmola and North Kazakhstan regions in 2018 *(Inbusiness 2018b)*. The insurance is marketed via traditional distribution channels, but also on emerging online platforms for input supplies, procurement, weather information and other extension services. Due to the hitherto short running time, empirical data on the impact of the program on farm incomes is yet missing.

3.3.3. UKRAINE: A NEW START WITH SMALL-SCALE PRIVATE INITIATIVES

In Ukraine, the main risk for agricultural production is drought, followed by frost and winter kill. According to survey results, 85 % of Ukrainian farmers identify drought as a cause for production uncertainties *(Swiss Re, 2010b)*. In order to support the development of insurance markets, the government provided a 50 % premium subsidy during the years 2005-2008, leading to a surge in insurance coverage. However, in 2009 the subsidies were eliminated due to budget deficits, leading to a drop of insurance coverage to 8-18 % of the crop area, depending on the region *(IIF 2017)*. Additionally, credit institutes became reluctant to accept traditional harvest insurance as collateral since they doubted the fairness and accuracy of its payment mechanisms *(Swiss Re, 2010b)*.

In parallel to loss-based insurance, several attempts were made with support by international organizations (mainly the World Bank) to introduce index insurance in Ukraine. With first pilots dating back to 2002, the country was the first among the former Soviet republics to attempt to introduce index based insurance *(Skees et al. 2002)*. Piloting activities were implemented following an initiative of the International Finance

Corporation (IFC) Agribusiness Development Project in cooperation with Credo-Classic Insurance Company and the Com-modity Risk Management Group (CRMG) of the World Bank. Products offered to farmers are based on indices incorporating moisture (lack of rainfall) and temperature stress. In addition to the weather indices, field visits are supposed to cross-check that payouts corresponded with losses of insured production. However, the scope of this program remained small; only two farmers were insured in the scope of this activity *(IFAD 2010)*. One reason for this low performance was the timing of the pilot which had to compete with the cheaper state-subsidized multiple-peril product mentioned above. Second, field inspections make the evalu-ation process of the pilot very complex *(Shynkarenko 2007)*. Third, according to IFAD (2010), the insurance company involved in piloting failed to conduct sufficient information dissemination to truly popularize the product and gain trust of potential customers. In 2015, World Bank and IFC partnered with the private company CelsiusPro AG, a provider of weather indices *(Artemis 2015)*, so far, however, with no published results.

In 2016, Syngenta launched the pilot program MeteoZakhyst in collaboration with the local insurance PZU, covering 100,000 hectares of wheat and corn in 2016 and 420,000 hectares in 2018. Farmers purchasing Syngenta products were offered the insurance for free. If the in-surance index is triggered, insured farmers receive compensation for the funds spent on Syn-genta products within five days after the weather event *(Destinations UA 2018)*. In detail, seed and diesel cost are reimbursed up to 60 euros and additional 30 euros for other inputs. The product covers yield losses due to lack of rainfall (cumulative precipitation), heat (max. temperature) and floods (more than 10 mm) *(Syngenta 2019)*.

Overall, the most recent initiative shows the urge to make insurance schemes less dependent on fluctuating government subsidies by introducing non-price incentives to farmers. The success in solving other problems like trust, knowledge dissemination and pricing of pilot schemes meanwhile has yet to be tested.

3.3.4. UZBEKISTAN: CAREFUL EXPLORATION OF OPPORTUNITIES FOR MARKET-BASED INDEX INSURANCE

The agricultural insurance market started to develop in Uzbekistan in 1997 with the estab-lishment of the specialized state joint-stock insurance company "Uzagrosugurta". From 1998 to 2001, the company received a substantial amount of budgetary subsidies. Over this period, about 25 % of indemnities were subsidized by the state. Since subsidies have been abolished in 2002, the agricultural insurance market is working under market conditions. Until 2014, 3-60 % of cotton and 2-37 % of wheat areas were insured, depending on the region *(Muradullayev et al., 2015)*. Thus, Uzbekistan is the single country in the former Soviet Union where agricultural insurance is functioning without state subsidies. The main reason for the successful functioning of the insurance market is the existence of subsidized credits for cotton and wheat production. Banks providing such credits often request the purchase of MPCI insurance to guarantee that farms will remain able to serve their loan installments even under drought conditions.

The first and so far only pilot of index insurance in Uzbekistan was launched in 2019 as part of a Research-to-Business (R2B) project KlimALEZ by Leibniz Institute of Agricultural Development in Transition Economies (IAMO) *(Bobojonov and Kuhn 2019a)* which is active also in Kyrgyzstan. The project is implemented in cooperation with local universities, local insurance companies and the reinsurance company Hannover Re. So in Uzbekistan, the

project is im-plemented in cooperation with Tashkent State Economic University and the local company GROSS Insurance. The main characteristics of this project are its strong focus on research in terms of index product development and considerable efforts into demand analysis implemented under real farming conditions. The aim of the project is that the developed product is accepted by insurance companies as a ready-to-market product and at the same time fits the demand of agricultural producers.

At the first stage, the project developed a simple index based on cumulative rainfall data obtained from remote sensing information systems. A marketable product was designed in cooperation with insurance and re-insurance companies involved in the project. In the further stages, the project team conducted several interactive seminars with farmers in order to investigate their subjective assessments of the risks and demand for the insurance product. In 2019, a small number of index insurance contracts were sold in Zomin districts of Djizzah province, one of the main rainfed wheat production districts in Uzbekistan *(Bobojonov and Kuhn 2019b)*. Test piloting activities and interactive seminars revealed several areas for improving the beta product version: First, farmers pointed out the need for an index combining both rainfall and temperature information since recent droughts were caused not only by lack of rainfall but also high temperatures that increased the water demand of plants. Furthermore, farmers indicated the need to increase transparency of settlement processes by insurance companies. This need for higher transparency can be explained by several negative experiences with local insurance companies that failed to provide indemnity payouts even though crop losses had occurred.

In the second half of 2019, several policy changes occurred in Uzbekistan that could impact the further development of agricultural insurance markets. First, the government announced the introduction of a 20 % subsidy towards the loss payments of the state-owned "Uzagrosu-gurta" insurance company when they insure subsidized bank loans. This measure might reduce the overall premiums of that company and thus increase participation rates among farmers. Second, a presidential decree recommended setting up an index-insurance development program in Uzbekistan, which might lead to the allocation of further resources towards the establishment of index-based insurance markets both by the government and na-tional and international insurance companies *(Bobojonov and Kuhn 2019c)*. The implementa-tion of further reforms is expected in the upcoming years.

So far, the ongoing KlimALEZ project led to following conclusions concerning various technical aspects and involvement of stakeholders along the value chain:

- In terms of index design, satellite information showed promising potentials to make up for limitations in terms of land-based data availability. Many weather stations in the region were discontinued in the 1990s, leaving most countries with a network that is not dense enough to reduce basis risk for insurers. Farmlevel weather stations are one alternative, but financially feasible only for large-scale farms. While various indices were tested in the scope of the project's index design, many of them ultimately rely on the same temperature and rainfall raw data. However, various challenges are identified in terms of applying temperature and precipitation based indices in mountainous areas and irrigated land. Therefore, application of other indices such as Vegetation Indices and Soil Moisture Indices need to be considered as potential measure for such farming systems.

- Science-business cooperation has shown to be a good practice to consider interests of farmers as well as insurance industry. Furthermore, the cooperation between local insurance company and international reinsurance company is of crucial importance. In addition to their financial backing to cope with systemic drought, reinsurance companies also provide know-how in terms of institutional agreements, contracting and other administrative items from their global experience.
- Comprehensive insurance cover based on market rates leads to low take-up among farmers, regardless of the farm size. Insurance premiums can be reduced by subsidies which however need to be carefully balanced to avoid biases in terms of market competition. Recent policy measures in Uzbekistan so far only support a state-owned insurance company, but omit smaller private insurance companies.
- Higher insurance take-up can be achieved by a stronger cooperation with banks and input suppliers. So far, these stakeholders show general interest in cooperating with insurance agencies but require several conditions in order to make the product suitable for their needs. Negotiations with banks providing agricultural credits are ongoing.
- Experience from scientific experiments with farmers and extension seminars indicate the need for extensive trust-building measures to increase the take up rate. To fix trust issues originating from earlier negative experience with insurance agencies and settlement processes, information seminars have shown to be successful. These sem-inars should be conducted in close cooperation with local agricultural offices, but also involve other stakeholders like local agronomists or extension agents. In particular, they should be conducted in participatory fashion that leaves room for comments and questions by farmers. Considering the rising digitalization among Uzbek farmers, information dissemination for instance via social media or chat groups are so far underutilized opportunities.

4. SUMMARY AND POLICY RECOMMENDATIONS FOR MONGOLIA

Case studies on piloting and dissemination activities discussed in this study provide a broad overview of opportunities and challenges of piloting and outscaling index insurance products. Several lessons could be learned and analysis made on opportunities and challenges for Mongolia, which will be discussed below.

4.1. LESSONS LEARNED

While small-scale implementation of index insurance is taking place in many countries worldwide, we identified a wide range of issues which constrain the large-scale dissemination of such an innovative product. First, the employment of weather or vegetation indices for loss evaluation and payments could not solve the ever-pressing price problem. Although index insurance is supposed to be relatively cheaper than traditional insurance products, commercial prices are often still above the willingness to pay of farmers. This is particularly the case if the risk of new market entries and lack of historical yield data are priced into the products and added to the fair premiums by both national insurers and international reinsurance com-panies. Projects achieving a large coverage in short time initially offered lower premiums close to the fair premium for a faster market entry. Also, pilots with development character offered premiums below usual market rates through their project funding which can be regarded as indirect subsidization.

In the long run, most piloting activities regard subsidies or other types of state support towards product price as necessity, in particular for fully commercial products that have to be sustainable beyond the scope of a short development project. State subsidies for insurance projects are meanwhile somewhat ambivalent: Based on the experience from transition economies, we can conclude that very high dependency on subsidies does not only provide wrong incentives to involved stakeholders but is also problematic if the state budget is unstable. Like stated initially, many transition economies are highly dependent on few export goods or sectors and thus subject to strong budget fluctuations. In the cases of Russia, Ukraine and Kazakhstan, highly subsidized insurance products suffered a very high fluctuation in in-surance coverage depending on the level of state support. Considering the significant vulner-ability of Mongolia's agricultural finance system (see **Section 1.2.1**), a heavy reliance on state subsidies might therefore not be ideal.

Another requirement for a successful piloting and outscaling (dissemination of implementation activities from pilot activities to regional or nationwide ones) is an extensive dissemination of information to improve the understanding of farmers for the settlement process. Out-scaling may fail unless piloting and dissemination is combined with extension activities, as was the case with many of the listed pilots. Very large campaigns in form of extension activities are necessary to provide knowledge and information and prevent farmers from developing wrong expectations. In the case of China, faulty communication and extremely high subsidized premiums led farmers to treat agricultural insurance as yet another input subsidy instead of understanding it as part of their risk management. Another issue is lack of trust: While index-based agricultural insurance can solve problems of information asymmetries in damage assessment, information dissemination helps to reduce trust issues in terms of underwriting and payout processes which are of vital importance for customers and insurance agencies. In many countries with a history of default of indemnity payments like Uzbekistan, Kazakhstan or China, rebuilding farmers' trust is of particular importance. Often, involved insurance companies are expected to conduct these activities, as for instance in the case of Ukraine where insurance companies were criticized for their lack of respective information campaigns (see **Section 2.3.3**). However, one should be careful to raise too high expectations concerning the activities of private insurance companies. Based on our experience, insurance and re-insurance companies view extension and information dissemination activities as development work which also benefits other competing insurance companies. Therefore, they are hesitant to allocate too many resources to information dissemination and extension services for new products.

4.2. RECOMMENDATIONS

First, any early policy debates on index market development and outscaling in the country should discuss in advance who should implement extension activities. It was shown that previous efforts by insurance agencies are often not effective enough in providing sufficient information and building trust among farmers. Meteorological agencies should also be involved in such extension activities and, at the same time, should serve as index providers. Information campaigns by state extension agencies or companies for agricultural inputs might improve knowledge and trust among farmers, thus leading to higher acceptance and coverage and possibly complementing or even replacing additional price subsidies.

Second, once sufficient ground for extension activities is secured, governments should tackle the question of subsidization. Under any circumstances, governments should set the subsidization rate at a level that is sustainable in the long run and not vulnerable to sudden budget fluctuations. However, ambitious policies neglecting the commercial interests of the implementing agency might not lead to a successful implementation in the long run. The Chinese case showed that only if incentives are set right for insurance companies which distribute the product, policy targets can be successfully implemented.

Third, the presented country cases provided examples of a successful combination of index insurance with input supply or procurement contracts. Farmers who had purchased index insurance received higher procurement prices and/or lower input prices, thus setting clear incentives to insure the production, while at the same time guaranteeing a more steady revenue for the involved companies.

A fourth suggestion is the combination of agricultural insurances with other agricultural financial services. In particular, linking the product to credits can contribute to disseminating the index insurance products. Since credit access is one of the challenges in Mongolia (see **1.2.1**), the acceptance of agricultural insurance as collateral might not only increase the cov-erage of agricultural insurance but also improve the credit access of small farmers through-out the country. To facilitate the cooperation with banks and insurance companies, it is recommended to set up round tables and workshops to discuss interests and requirements of involved stakeholders in the various stages of supply chains. However, for launching such round-table discussions though the initiative of government organizations, NGOs or scientific institutions is required.

Fifth, all planned reforms related to index insurance need to be based on experience gained from small-scale piloting activities with strong involvement of research institutes, as in the case of the Uzbek pilot. Previous experience in other countries showed that large initiatives without consideration for regional needs and structures are likely to fail. Insurance companies should cooperate with research institutes and international donors to test new products and explore the demand of crop producers, as currently implemented in the **KlimALEZ** project.

Sixth, experience gained in index-based livestock insurance in Mongolia need to be considered also in the establishment of a similar system for crop producers. The project featured a successful partnership between state actors and private business, which would decisively support the establishment of a similar insurance pilot in crop production. Detailed research on how to transfer this experience from the livestock insurance market to the crop insurance market is required.

5. PUBLICATION BIBLIOGRAPHY

ADB (2018): Mongolia. Finance Sector Fact Sheet. Available online at https://www.adb.org/sites/default/files/publication/450161/fact-sheet-mongolia-finance-sector.pdf, checked on 9/29/2019.

AgRe (2015): Products - Index-Based Livestock Insurance. Available online at http://agreinsurance.mn/index.php?lan=en&page=products, checked on 9/29/2019.

Agricorp (2019): Production Insurance Sales and Claims Reports as of May 21, 2019. Available online at https://www.agricorp.com/en-ca/AboutUs/Pages/OpenData.aspx, checked on 10/3/2019.

Agroinsurance (2017): AgriculturalInsurance in China. History, Development and SuccessFactors. Available online at http://agroinsurance.com/wp-content/uploads/2017/04/Agricultural-insurance-in-China-Agroinsurance-International.pdf, checked on 9/29/2019.

Ali Akhter (2013): Farmers' willingness to pay for index based crop insurance in Pakistan. A case study on food and cash crops of rain-fed areas. In Agricultural Economics Research Review 26 (347-2016-17088), pp. 241–248.

Artemis (2015): CelsiusPro & World Bank partner on Ukraine weather-index insurance. Available online at https://www.artemis.bm/news/celsiuspro-world-bank-partner-on-ukraine-weather-index-insurance/, checked on 9/30/2019.

Bertram-Huemmer V., Kraehnert K. (2015): Does Index Insurance Help Households Recover from Disaster? Evidence from IBLI Mongolia. Deutsches Institut für Wirtschaftsforschung. Available online at https://www.diw.de/documents/publikationen/73/diw_01.c.518175.de/dp1515.pdf.

Bertram-Huemmer V., Kraehnert K. (2018): Does Index Insurance Help Households Recover from Disaster? Evidence from IBLI Mongolia. In American Journal of Agricultural Economics 100 (1), pp. 145–171.

Bobojonov I. (2017): Development of index based crop insurance market in Mongolia. Edited by German-Mongolian Cooperation Project Sustainable Agriculture. Available online at https://kooperationsprojekt-mng.de/de/studien.html, checked on 9/26/2019.

Bobojonov I., Kuhn L. (2019a): KlimALEZ - Increasing climate resilience via agricultural insurance - Innovation transfer for sustainable rural development in Central Asia. Available online at www.klimalez.org, checked on 9/29/2019.

Bobojonov I., Kuhn L. (2019b): Piloting index insurance in Uzbekistan. Available online at https://www.klimalez.org/home/news-details/piloting-index-insurance-in-uzbekistan-1/, checked on 9/29/2019.

Bobojonov I., Kuhn L. (2019c): Reform on subsidizing cotton and wheat insurance in Uzbekistan. Available online at https://www.klimalez.org/home/news-details/reform-on-subsidizing-cotton-and-wheat-insurance-in-uzbekistan/, checked on 10/3/2019.

Chantarat S., Mude A.G., Barrett C.B., Carter M.R. (2013): Designing index-based livestock insurance for managing asset risk in northern Kenya. In Journal of Risk and Insurance 80 (1), pp. 205–237.

China Re and P&C (2014): The Development of Agricultural Insurance in China (CAS Reinsurance Seminar May 2014). Available online at https://www.casact.org/education/reinsure/2014/handouts/Paper_3229_handout_2138_0.pdf, updated on 8/21/2019.

Cole S., Giné X., Tobacman J., Topalova P., Townsend, R., Vickery, J. (2013): Barriers to household risk management. Evidence from India. In American Economic Journal: Applied Economics 5 (1), pp. 104–135.

Cole S., Stein D., Tobacman J. (2014): Dynamics of demand for index insurance. Evidence from a long-run field experiment. In American Economic Review 104 (5), pp. 284–290.

Destinations UA (2018): Syngenta: Pioneering Agroinsurance in Ukraine. Available online at https://destinations.com.ua/business/trends-innovations/651-syngenta-pioneering-agroinsurance-in-ukraine, checked on 9/30/2019.

FAO (2017): Mongolia. A review of the agricultural research and extension system. Available online at http://www.fao.org/3/a-i6571e.pdf, checked on 9/29/2019.

FCIC (2019): Commodity Year Statistics for 2018. Available online at https://www3.rma.usda.gov/apps/sob/current_week/crop2018.pdf, checked on 10/4/2019.

Fonta W.M., Sanfo S., Kedir A., Thiam D.R. (2018): Estimating farmers' willingness to pay for weather in dex-based crop insurance uptake in West Africa. Insight from a pilot initiative in Southwestern Burkina Faso. In Agricultural and Food Economics 6 (1), pp. 1–20.

Gaurav S., Cole S., Tobacman J. (2011): Marketing complex financial products in emerging markets. Evidence from rainfall insurance in India. In Journal of marketing research 48 (SPL), S150-S162.

Giné X., Yang D. (2009): Insurance, credit, and technology adoption. Field experimental evidencefrom Malawi. In Journal of development Economics 89 (1), pp. 1–11.

GIZ (2019): China: Enabling Policy Environment. Available online at https://www.indexinsuranceforum.

org/resilience-document/china-enabling-policy-environment, checked on 8/21/2019.

Hardaker J. B., Lien G., Anderson J.R., Huirne R.B.M. (2015): Coping with risk in agriculture. Applied decision analysis: CABI.

Hess U., Hazell P. (2016): Innovations and emerging trends in agricultural insurance. How can we transfer natural risks out of rural livelihooods to empower and protect people? Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit.

IBLI (2015): Index-Based Livestock Insurance Project. Available online at https://www.shareweb.ch/site/EI/Documents/To%20SORT/Themes/PSD/7F-06642.02-Report%20-%20Index%20Based%20Livestock%20Insurance%20-%202005-2015-en.pdf.

ICICI Lombard (2018): Pradhan Mantri Fasal Bima Yojana (PMFBY) Crop Insurance Details & Benefits. Available online at https://www.icicilombard.com/crop-insurance#, checked on 9/29/2019.

IFAD (2010): The Potential for Scale and Sustainability in Weather Index Insurance. for Agriculture and Rural Livelihood. Rome. Available online at https://www.ifad.org/documents/38714170/40239486/The+potential+for+scale+and+sustainability+in+weather+index+insurance+for+agriculture+and+rural+livelihoods.pdf/7a8247c7-d7be-4a1b-9088-37edee6717ca, checked on 9/10/2019.

IIF (2017): Index Insurance in Ukraine: Opening Doors for Agribusiness. Available online at https://indexinsuranceforum.org/publication/index-insurance-ukraine-opening-doors-agribusiness, checked on 9/29/2019.

IMF (2017): People's Republic of China Financial Sector Assessment Program. Detailed Assessment of Observance of the Insurance Principles. Available online at https://www.imf.org/~/media/Files/Publications/CR/2017/cr17402.ashx2Fcr17402.ashx&usg=AOvVaw3G9D76h5gA7pTVn9MiRCw7, checked on 8/21/2019.

Inbusiness (2018a): Index Agrarversicherung in Kasachstan eingeführt. Available online at https://inbusiness.kz/ru/last/indeksnoe-agrostrahovanie-vnedreno-v-kazahstane, checked on 10/4/2019.

Inbusiness (2018b): Index agricultural insurance introduced in Kazakhstan. Available online at https://inbusiness.kz/ru/last/indeksnoe-agrostrahovanie-vnedreno-v-kazahstane, checked on 9/11/2019.

Isaboke H.N., Qiao Z., Nyarindo W.N., Ke W. (2016): Explaining The Perception Of Smallholders Towards Weather Index Micro-Insurance Alongside Risks And Coping Strategies. In International Journal of Food and Agricultural Economics (IJFAEC) 4 (1128-2016-92109), pp. 59–67.

Janvry A., Ritchie E.R., Sadoulet E. (2016): Weather index insurance and shock coping. Evidence from Mexico's CADENA Program: The World Bank.

Jensen N.D., Mude A.G., Barrett C.B. (2018): How basis risk and spatiotemporal adverse selection influence demand for index insurance. Evidence from northern Kenya. In Food Policy 74, pp. 172–198.

Jin J., Wang W., Wang X. (2016): Farmers’ Risk Preferences and Agricultural Weather Index Insurance Uptake in Rural China. In International Journal of Disaster Risk Science 7 (4), pp. 366–373. DOI: 10.1007/s13753-016-0108-3.

Kenderdine, T. (2018): Insurance Plus Futures. Agricultural Commodity Price Reform in China. In Asia & the Pacific Policy Studies 5 (2). DOI: 10.1002/app5.226.

Krychevska, L., Shynkarenko, I., Shynkarenko, R. (2017): Agricultural Insurance in China. History, Development and Success Factors. Edited by Agroinsurance. Available online at http://agroinsurance.com/wp-content/uploads/2017/04/Agricultural-insurance-in-China-Agroinsurance-International.pdf, checked on 8/21/2019.

Mahul, O., Stutley, C.J. (2010): Government Support to Agricultural Insurance. Challenges and Options for Developing Countries. Edited by The World Bank. Washington D.C. Available online at http://documents.worldbank.org/curated/en/%20698091468163160913/pdf/538810PUB0Gove101Official0Use0Only1.pdf, checked on 9/6/2019.

Ministry of Environment and Tourism Mongolia (2018): Third National Communication of Mongoloa. Under the United Nations Framework Convention on Climate Change. Ulanbaatar. Available online at https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/06593841_Mongolia-NC3-2-Mongolia%20TNC%202018%20print%20version.pdf, checked on 11/4/2019.

Ministry of the Environment Japan (2014): Climate Change in Mongolia. Outputs from GCM. Available online at https://www.env.go.jp/earth/ondanka/pamph_gcm/gcm_mongolia_en.pdf, checked on 9/29/2019.

MSIS (2019): Statistics. Available online at www.1212.mn, checked on 9/29/2019.

PeakRe (2017): China’s drive for food self-sufficiency. The role of agricultural insurance (Peak Insights 2017). Available online at https://www.peak-re.com/wp-content/uploads/2017/09/Peak-Insights-2017.pdf, checked on 8/21/2017.

PepsiCo (2017): PepsiCo Contract Farming. At a Glance. Available online at https://indexinsuranceforum.org/sites/default/files/Factsheet_PepsiCo%20Contract%20Farming_India.pdf, checked on 9/29/2019.

QOLDAU (2019): Index insurance based on soil moisture. Online insurance service “Agroinsurance. Available online at https://agro-insurance.qoldau.kz/ru/insurance-help/page/index-start-slides.

Shynkarenko, R. (2007): Introduction of Weather Index Insurance in Ukraine - Obstacles and Opportunities. Available online at https://ageconsearch.umn.edu/record/9244, checked on 9/29/2019.

Sibiko, K.W., Veettil, P.C., Qaim, M. (2018): Small farmers’ preferences for weather index insurance. Insights from Kenya. In Agriculture & Food Security 7 (1), p. 53.

Skees, J.R., Hess, U., Ibarra, H. (2002): Crop Disaster Assistance in Ukraine: Issues, Alternatives, and Consequences. Available online at http://siteresources.worldbank.org/INTCOMRISMAN/Resources/ukrainecropdisastercopy.pdf, checked on 9/29/2019.

Stoeffler, Q., Wouter, G., Catherine, G., Michael, C. (2016): Indirect protection. The impact of cotton insurance on farmers’ income portfolio in Burkina Faso.

SwissRe (2015): Swiss Re China protects cotton farmers' yields in cold weather: first programme launched. Available online at https://www.swissre.com/our-business/public-sector-solutions/thought-leadership/swiss-re-china-protects-cotton-farmers-yields.html, checked on 8/21/2019.

SwissRe (2016): Ramping up natural disaster insurance in China. Available online at https://reports.swissre.com/corporate-responsibility-report/2016/cr-report/solutions/strengthening-risk-resilience-2016-highlights/ramping-up-natural-disaster-insurance-in-china.html, checked on 8/21/2019.

Syngenta (2019): Meteozahist. Available online at https://www.syngenta.ua/meteozahist, checked on 9/29/2019.

Tafere, K., Barrett, C.B., Lentz, E., Ayana, B. (2017): Insuring Well-Being? Buyer's Remorse and Peace of Mind Effects from Insurance. Available online at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3078349, checked on 9/11/2019.

The World Bank (2005): Managing Agricultural Production Risk. Innovations in Developing Countries. Available online at http://siteresources.worldbank.org/INTARD/Resources/Managing_Ag_Risk_FINAL.pdf, checked on 9/29/2019.

UNDP (2016): UNDP moves on to pursue indemnity and index insurance to secure Kazakh farmers. Available online at http://www.kz.undp.org/content/kazakhstan/en/home/presscenter/pressreleases/2016/05/03/undp-moves-on-to-pursue-indemnity-and-index-insurance-to-secure-kazakh-farmers.html, checked on 9/29/2019.

Wang, M., Shi, P., Ye, T., Liu, M., Zhou, M. (2011): Agriculture insurance in China. History, experience, and lessons learned. In International Journal of Disaster Risk Science 2 (2), pp. 10–22.

Ward, P.S., Makhija, S. (2018): New modalities for managing drought risk in rainfed agriculture. Evidence from a discrete choice experiment in Odisha, India. In World development 107, pp. 163–175.

World Bank (2017a): Agricultural Productivity and Marketing in Mongolia. Available online at http://documents.worldbank.org/curated/en/277781468195567857/pdf/101087-WP-P130366-PUBLIC-Box393257B-Agricultural-Productivity-and-Marketing-in-Mongolia-Feb-18-FINAL-with-pictures.pdf, checked on 9/25/2019.

World Bank (2017b): Index insurance market profile: Senegal. Available online at http://documents.worldbank.org/curated/en/491731490706300014/pdf/113754-BRI-SN-CountryProfiles-Senegal-PUBLIC.pdf, checked on 9/29/2019.

World Bank (2019): Fertilizer consumption (kilograms per hectare of arable land). Available online at https://data.worldbank.org/indicator/AG.CON.FERT.ZS, checked on 9/29/2019.

World Food Programme (2018): Weather insurance boosts the resilience of Malawian farmers. Empowering communities to manage climate risks and tackle hunger. Available online at https://insight.wfp.org/weather-insurance-boosts-the-resilience-of-malawian-farmers-485949556ef5, checked on 9/29/2019.

World Food Programme, Oxfam (2019): R4 Rural Resilience Initiative. Quarterly Report Avaiable online at https://docs.wfp.org/api/documents/WFP-0000107879/download/?_ga=2.142553202.1958119698.1568200101-404284012.1568200101, checked on 9/11/2019.

Zou X., Zhai P., Zhang Q. (2005): Variations in droughts over China. 1951–2003. In Geophys. Res. Lett. 32 (4). DOI: 10.1029/2004GL021853

APPENDIX: SELECTED PILOTS OF INDEX-BASED WEATHER INSURANCE

Country	Year	Responsible Institution	Participants	Insured value (in $US)	Product type	Main crops / animals	Source
Brazil	2007	Programa Seguro Agricola Basico (government), AgroBrasil	14893	11,914,000			IFAD 2010
Burkina Faso	2014	Sofitex, Planet Guarantee	8,281		crop	cotton, maize	Stoeffler et al. 2016; Fonta et al. 2018
Canada	2018	Government	1,094	33,550,404	crop	forage	Agricorp 2019
China	2008	Anxin Insurance Company			crop	watermelon	Agroinsurance 2017
China	2009	Guoyuan Agricultural Insurance Company	500	56,000	crop	rice	IFAD 2010
China	2013				livestock	pig	China Re and P&C 2014
China	2015	SwissRE		1,200,000	crop	cotton	SwissRe 2015
China	2016	SwissRE, Sunlight Agriculture Mutual Insurance Company		1,380,000	crop	various	SwissRe 2016
Ethiopia	2009	Adi-Ha,Oxfam/IFRC	200	9,000			IFAD 2010
Ethiopia	2012	USAID, CGIAR, Australian Development Research Awards Scheme, CCAFS and Dryland Systems	550		livestock	camel, cow	Tafere et al. 2017
Ethiopia, Senegal, Kenya, Malawi, Zambia	2019	Nyala Insurance, WB, WFP	57000	6,600,000	crop	maize, sorghum	World Food Programme and Oxfam 2019
India	2006	Self-Employed Women's Association	19,882				Cole et al. 2014
India	2008	NBFC agricultural loan portfolios	5000				IFAD 2010
India	2008	PepsiCo, ICICI Lombard	4575	3,812,000	crop	Potato, others	IFAD 2010
India	2009	Microinsurance Innovation Facility of ILO, USAID, Harvard Business School	900		crop		Gaurav et al. 2011
India	2009	MicroEnsure and Kolhapur District Central Cooperative Bank (KDCCB)	4770	480,000			IFAD 2010
India	2019	ICICI Lombard (private insurer)	1,540,820	1,356,735,149	crop	food grain and oilseed	ICICI Lombard 2018
India	2009	IFFCO-Tokio (private insurer)	70000		crop	various	IFAD 2010
India	2009	AIC (public ag insurer)	1088313	371,000,000			IFAD 2010
India	2009	BASIX (MFI)		5,000,000			IFAD 2010
India	2016	USAID, Bill and Melinda Gates Foundation	2,160		crop		Ward and Makhija 2018
India	2006	SECO, World Bank CRMG, Bill and Melinda Gates Foundation	660		crop		Cole et al. 2013
Indonesia	2009	Munich RE, TATA, GTZ	500	13,000			IFAD 2010
Jamaica	2008	JP Foods, Private insurer	1050	1,080,000			IFAD 2010
Kazakhstan	2016	Swiss Re, VanderSat	Ca. 12		Crop	cereals, oilseed	Inbusiness 2018a, authors' own research,
Kenya	2009	Syngenta Foundation	200	7,000			IFAD 2010
Kenya	2014	Kenyan National Commission for Scicence, Technology and Innovation (NACOST) and the German Research Foundation (DFG)	386		crop	wheat, maize	Sibiko et al. 2018

Kenya	2009	USAID, CGIAR, Australian Development Research Awards Scheme, CCAFS and Dryland Systems	42		livestock		Chantarat et al. 2013
Kenya	2009	USAID, World Bank, CGIAR, UK Department for International Development, the Australian Department of Foreign Affairs and Trade, Agriculture and Rural Development Sector of the EU	832		livestock	camels, cattle, sheep, goats	Jensen et al. 2018
Kenya	2015	University of Embu, Kenya	401		crop	maize	Isaboke et al. 2016
Malawi	2006	World Bank (CRMG)	800		crop	maize, groundnut	Giné and Yang 2009
Malawi	2006	World Bank, Opportunity International	1710	150,000	crop	tobacco	IFAD 2010
Malawi	2008	World Bank, MicroEnsure	2587	300,000	crop	tobacco	IFAD 2010
Mexico	2005	UK Department for International Development, World Bank	4,311		crop		Janvry et al. 2016
Mongolia	2009	World Bank, government	3281	5,000,000	livestock		IFAD 2010
Nicaragua	2009	World Bank	9	2,211,000			IFAD 2010
Pakistan		Government, Pakistan Poverty Alleviation Fund	531		crop		Ali 2013
Peru	2008	La Positiva	51	67,000			IFAD 2010
Philippines	2009	MicroEnsure	500				IFAD 2010
Rwanda	2009	MicroEnsure and Ministry of Agriculture (MINAGRI)	500	32,000			IFAD 2010
Senegal	2014	CNAAS, Swiss Re, World Bank	4,035	399,391	crop,	groundnut seed, maize millet	World Bank 2017b
South Africa		Investec (Investment bank) – coop					IFAD 2010

Tanzania	2009	MicroEnsure	339	101,000			IFAD 2010
Thailand	2008	BAAC (ag bank)	388	300,000			IFAD 2010
Thailand	2009	Government					IFAD 2010
Ukraine	2004	Credo-Classic (Insurer)	2	200	crop	winter wheat	IFAD 2010; The World Bank 2005,
USA	2009	Government, private companies	39332		Crop	forage, apiculture	FCIC 2019
Uzbekistan	2019	IAMO, Hannover Re, Gross Insurance			crop	wheat	Bobojonov and Kuhn 2019a

Note: Some countries featured piloting activities in two different years that possibly were part of the same overarching program. However, as long as our sources did not provide evidence for a clear connection, the activities were listed as two different pilots.

MONGOLIA'S POLICIES AND INSTITUTIONAL APPROACHES FOR CLIMATE CHANGE ADAPTATION IN CROP FARMING

Authored by:

***Prof. Dr.* Dagvadorj D.**

National Consultant
Climate Change and Development Academy

CONTENTS

INTRODUCTION: THE NEED OF THE CROP SECTOR TO MITIGATE AND ADAPT TO THE IMPACTS AND RISKS OF CLIMATE CHANGE

The activities and products of the non-irrigated crop farming sector of Mongolia are completely dependent on the overall climate and weather conditions throughout the years. In other words, it is only possible to harvest adequate yields that meet the local demand if the required amount of preserved moisture was present during the seed-sowing season in the spring, sufficient rainfall was seen during the seed ripening period, and there were no overheated days throughout the vegetation period. With low rainfall and dry and prolonged drought conditions, there is a high risk of a complete loss of yield. This dependence of the crop farming sector on weather and climate conditions is severely affected by the already intensifying climate change nowadays. Nonetheless, crop farming is one of the most important sectors of the country's food supply.

Therefore, under the current circumstances, an essential requirement of sustainable crop farming development is to adapt integrated activities to the changing climate conditions. Recent research clearly indicates that the changes in the climate of our country are beginning to produce both positive and risk-increasing negative impacts on the crop farming sector. The consequences of the overall warmer climate, such as the occurrence of early spring and late autumn conditions, longer vegetation periods and increased plant heat accumulation, may provide, to a certain extent, favorable conditions for the crop farming industry. However, in the Mongolian situation, the crop farming sector is also harshly affected by the consequences of a range of adverse effects resulting from global climate change, such as: reduction of precipitation during the warm season; occurrence of prolonged dry and hot weather; degradation of natural ecosystems and soil quality; displacement of the natural zones by shift or expansion of the dry Gobi desert region to the north; depletion of water resources; loss of soil moisture regime; decrease of the groundwater level; and increase in the frequency and intensity of natural disasters.

Therefore, to ensure the efficient and sustainable development of the crop farming sector and food safety of the country in the future, it is imperative to elaborate and implement a climate-smart model for the crop sector development. The key objective of this model will be to overcome and adapt to the impacts, risks and additional effects of climate change. The prerequisite for the development of a climate-smart crop farming model is to create legal frameworks and the necessary institutional environment for the matter. This report summarizes an assessment of how the issue of climate change adaptation is reflected in the crop sector's policies and programs, and what institutional settings are currently available for the implementation.

SECTION 1. OBJECTIVES AND MEASURES REGARDING CROP FARMING IN THE POLICY DOCUMENTS ON DEVELOPMENT AND CLIMATE CHANGE OF MONGOLIA

Mongolia has well-established policies, implementation programs, and action plans regarding climate change. These documents, to a certain extent, specify crop farming adaptation and its related actions. This is due to the fact that crop farming is the most affected sector of climate change as its activities and products are directly dependent on the weather and climate conditions. Therefore, crop farming adaptation measures have been evaluated based on the impact of climate change on crop production, growth, and operations and on the risk assessment conducted.

The following section discusses how crop farming adaptation is presented in the Mongolian climate change policies and programs.

1.1. NATIONAL ACTION PROGRAM ON CLIMATE CHANGE

This program was first approved by the State Parliament in 2000 and amended in 2011. The program is a key document of state and government policies and actions on climate change, which will be implemented in coordination with the Government's main activities, sector programs, and annual action plans.

The purpose of this program is to maintain environmental balance, to develop the economic and social sectors in accordance with climate change whilst decreasing their vulnerability and risks, to increase production efficiency and productivity by reducing greenhouse gas emissions, and to support the implementation of green economic development and growth policies.

By 2021, at the end of the program, it is planned that Mongolia will have the ability to adapt to climate change and provide the basic conditions for a green economy. Among the five main strategic goals placed for the program, the following two are directly related to climate adaptation in the crop farming sector:

i. Build national capacity to adapt to climate change, achieve environmental balance and gradually reduce economic and social vulnerabilities and risks.

As the fifth objective of the program is a general provision for all relevant stakeholders, it applies to the implementation of adaptive measures necessary for the crop farming sector.

v. Support and encourage the population to provide information regarding climate change to the public and to actively participate in activities and events organized against climate change.

The program will be implemented in two stages from 2011 to 2021: stage one, from 2011 to 2016, involves mitigating climate change, strengthening national capacity for adaptation, establishing legal framework, structure, organization, and management system and increasing public participation; while stage two, from 2017 to 2021, includes implementing climate change adaptation measures and launching sustainable efforts to reduce greenhouse gas emissions.

The following actions, presented in the second goal of the strategy to "build national capacity for adaptation to climate change, maintain environmental balance and gradually

reduce economic and social vulnerabilities and risks", are directly related to crop production:

. . .

- To expand the constructions of pools and reservoirs for the storage of water resources accumulated from rivers, streams, rain, snow and melting glaciers;
- To determine the water resources of climate sensitive areas in detail and to integrate them with sector development policies and plans;

. . .

- To mitigate land degradation and desertification, and increase the capacity of pasture and soil to absorb greenhouse gases;

. . .

- **To develop irrigated crop farming based on water saving and soil conserving technologies adapted to drought conditions;**

. . .

- To implement projects and programs to improve living standards, reduce poverty and create green jobs.

Stage two (2017-2021)

- ... to expand the constructions of pool and reservoirs to store rain and snow water;
- To expand the measures to mitigate land degradation and desertification;
- **To expand irrigated crop farming based on water saving and soil conserving technologies adapted to drought conditions.**

In the agricultural sector, measures are being taken to increase irrigated farming and reduce crop production fluctuations by 20 % for grains and by 40 % for vegetables by 2015 in comparison with the fluctuations of 2005-2010. In addition, activities to reduce water consumption by 50 % using water-efficient irrigation technologies by 2021 are being implemented in the sector. However, no reports on the implementation of these measures have been made available to the public.

The Ministry of Environment and Tourism conducts a general assessment of the implementation of the activities covered by the National Program on Climate Change, but there is lack of evaluation reports on their implementation in the agricultural sector.

1.2. MONGOLIA'S INTENDED NATIONALLY DETERMINED CONTRIBUTION (INDC) TO MITIGATING CLIMATE CHANGE, 2015

Prior to Mongolia's accession to the Paris Agreement, this document was submitted in 2015 to the Secretariat of the Framework Convention on Climate Change. The following summarizes the climate change adaptation activities– a main focus of the document – to be implemented in the crop farming sector.

Sector	Adaptation goals	Outcome	Requirement		
			Capacity building	Technology	Financial requirements in million USD
Crop Farming	Increase irrigated farming, reduce evaporation of soil moisture and carbon dioxide emissions	Reduce the proportion of bare fallow to less than 30 %, introduce rotations of 3 to 5 crops with 3 to 4 circles, and increase irrigated farming by 2 to 2.5 times	Establish soil protection regulations (soil structure, nutrients and moisture)	- Introduce zero and reduced tillage technology - Increase crop varieties and increase the number of rotation circles - Reduce water consumption by 2.5 to 5 times through introduction of efficient crop irrigation technology	150.0

Table 1: INDC, 2015: Requirement for Adaptation (2021-2030) *(Source: INDC, 2015).*

1.3. TECHNOLOGY NEEDS ASSESSMENT (VOLUME 1) – CLIMATE CHANGE ADAPTATION IN MONGOLIA, 2013

A detailed report by the Ministry of Environment and Tourism was published in English in 2013 regarding the technological requirements needed for climate change adaptation for vulnerable sectors. Among the reported 36 impacts of climate change on the economic and social sectors, the possible effects of climate change on the crop farming sector have been evaluated in the following table.

Climate change indicator	Impact	Consequences for crop farming
Decreased summer precipitation	Decrease in soil moisture content	Decrease in crop yield
Intensity of precipitation increased during the vegetation period	Unstable soil moisture content	Unstable crop production
Higher average temperature during the warm season	Vegetation period is lengthened and early sowing/planting of crops	Cultivation of crops suitable for warmer climates and expansion of arable land
Early melting of stable snow cover	Dry soil during sowing period	Early sowing opportunities are limited
Increase in soil moisture evaporation	Unstable soil moisture content	Reduced crop yields; need for irrigation
Increased frequency of hot spells	Slower rate of photosynthesis in crops; increased/intensified periods of drought	Heat stress causes reduced yield; decrease in harvests
Increase of heat accumulation during the vegetation period	Increase of crop diseases and pests	Reduced crop yields
Reduced precipitation and increased temperature	Unstable soil moisture content	Reduced soil fertility; reduced organic carbon and nitrogen levels in soil

Table 2: The main impacts of climate change on crop farming. *(Source: Technology Needs Assessment Volume 1- Climate Change Adaptation in Mongolia, 2013).*

According to the decision making multi-criteria assessment on the risks and harms of climate change, the crop and livestock farming sectors were identified as the most vulnerable sectors. The main risk to the crop farming sector was considered to be the increase in dry and drought conditions due to climate change. As a result, it is expected that crop yield will decrease causing significant economic, social and environmental damages.

Based on the results of this multi-criteria decision making assessment, technologies suitable for climate change adaptation to be used in the crop farming sector were determined.

№	Technology	Adaptive effects
1	Plastic film cover cultivation	- Soil moisture retention - Limit the growth of weeds - Reduce the leakage of soil nitrogen and other nutrients - Reduce soil compaction
2	Irrigated vegetable farming (drip irrigation)	- Efficient use of water - Reduce water demand and evaporation losses - Efficient fertilizer application - Reduce dependence on wind and rain

3	System of wheat intensification through conservation tillage	- Protect soil fertility - Reduce soil erosion - Soil moisture retention
4	Establish windbreaks on cultivated land	- Reduce wind erosion - Biodiversity conservation
5	Breeding and cultivation of new varieties and use of marker assisted selection	- Cultivate new crops that are resistant to drought and disease and suitable to local climate conditions - Faster success in breeding
6	Introduction of proper crop rotation system	- Protect soil fertility - Limit prevalence of diseases, pests and weeds - Reduce land degradation
7	Integrated Nutrient Management	- Protect soil fertility - Increase consumption of environment-friendly fertilizers

Table 3: Technologies for climate change adaptation in the crop farming sector. *(Source: Technology Needs Assessment Volume 1- Climate Change Adaptation in Mongolia, 2013).*

Based on the results of the multi-criteria decision making assessment, the following technologies were determined to be most effective in the crop farming sector.

i. System of wheat intensification (SWI): This system combines the fallow protection measures with general crop management to create favorable conditions for sustainable crop production. This system will provide the integrated management of crops, soil and fertilizers and will allow for the reduction of soil erosion.

ii. Vegetable production system (VPS) with drip irrigation: This water conserving technology utilizes drip irrigation to increase vegetable yield. It allows for the proper usage of fertilizers, pesticides, and soil management. This technology will be particularly appropriate in the case of water limitation due to climate change in Mongolia.

iii. Potato seed production system (PSPS): This system comprises the creation, storage and distribution of elite, high-yield potato seed stocks. In addition to cultivation of potatoes, this technology creates the opportunity to obtain a high yield and to save significant amounts of time, money and labor.

1.4. MONGOLIA'S NATIONALLY DETERMINED CONTRIBUTION (NDC) TO MITIGATING GLOBAL CLIMATE CHANGE, 2019[1]

Within the Nationally Determined Contribution (NDC) of 2019 which will be approved by the Government of Mongolia in the near future, the following objective and goals have been proposed upon discussion with the Ministry of Food, Agriculture and Light Industry (MoFALI) regarding climate change adaptation in the crop farming sector and reduction of its related risks. The measures to be taken for the implementation will be identified and placed into action.

Crop farming

Objective:

Create conditions for the sustainable supply of safe food products for the population, feed for livestock, and raw materials for the light industry by optimizing the positive effects and mitigating the negative effects of climate change on the crop farming sector.

Goal 1. Introduce plastic film covers and drip and infiltrating irrigation technologies to conserve water and save irrigation labor for the cultivation of potatoes, vegetables, fruits and berries,

Goal 2. Introduce plastic film covers and drip and infiltrating irrigation technology to reduce water and irrigation costs for the cultivation of potatoes, vegetables, fruits and berries,

Goal 3. Cover the field of non-irrigated crops, such as grains, fodder and industrial crops, with straw mulch and build fences to reduce moisture evaporation and soil overheating and protect from soil erosion due to wind and water,

Goal 4. Introduce zero tillage technology.

It is considered that the implementation of these goals and its relevant actions will ensure the proper and conservative use of water resources, protect soil fertility, ensure the sustainable operation of the crop farming sector, create conditions to fully meet the domestic demand for crop products, and guarantee the food safety of the entire population.

The MoFALI is responsible for the implementation of these tasks as of 2020. This will require specific action plans at the sector level. In addition, project proposals should be developed to request support from international organizations, in particular the Green Climate Fund.

1.5. MONGOLIA'S SUSTAINABLE DEVELOPMENT VISION 2030, 2016

The following goals are proposed in this document (Table 2).

As part of the implementation of these goals, the reduced tillage technology was utilized on 130 thousand hectares in 2017 and 145 thousand hectares in 2018 and is planned to be introduced on 160 thousand hectares in 2019.

[1] *This document is expected to be discussed at the Government's Session scheduled for the third week of November 2019.*

Indicators	2016-2020	2021-2025	2026-2030
Introduce zero tillage technology in the grain fields (percentage)	70	85	90
Irrigated farming field (thousand hectares)	65	100	120
Fertilizer supply (percentage)	50	70	100
Supply of acclimatized elite varieties (percentage)	75	90	100

Table 4: Goals proposed in Mongolia's Sustainable Development Vision 2030 regarding crop farming *(Source: Mongolia's Sustainable Development Vision, 2016)*

1.6. "GREEN DEVELOPMENT POLICY" OF MONGOLIA (2014-2030)

The Green Development Policy specifies the following measures to be implemented for the crop farming sector:

"To meet the domestic demands for grains, potatoes and vegetables, to rehabilitate and reuse at least 70 % of fallow land by increasing soil fertility, introducing advanced, cost saving, efficient agrotechnical and irrigation technologies for soil cultivation, and reducing land degradation due to crop farming by creating windbreaks."

The execution of these tasks will have a significant impact on the implementation of climate change adaptation goals.

SECTION 2. REPRESENTATION OF CLIMATE CHANGE ADAPTATION IN CURRENT CROP FARMING POLICIES AND PROGRAMS

2.1. CLIMATE CHANGE ADAPTATION IN THE SECTOR'S POLICIES AND LEGAL DOCUMENTS

Currently, there are no coherent policies, strategies, and action plans on adapting to and mitigating the adverse effects of climate change in the crop farming sector.
However, some guidelines and actions that are in some way related to the mitigation and adaptation relating to climate change in the current policies and programs of the crop farming sector are discussed below.

a) "State Policy on Food and Agriculture" 2015

There are a number of long-term objectives proposed by the government on mitigation and adaptation relating to climate change. The following objectives are covered in the "State Policy on Food and Agriculture 2015" regarding climate change issues:

- Promote predominance of pastoral animal breeding activities that preserve traditional techniques and adapt them to climate change, develop productive and intensive farming activities near populated cities, suburban areas, and crop farming regions;
- Increase and support the sustainable development of crop production activities that are adapted to climate change using advanced technologies;
- Ensure the sustainable supply of safe, nutritious food to the population through processing raw materials and natural resources from livestock and crop farming based on traditional and advanced technologies;
- Sustainably develop agricultural production based on scientific knowledge, introduce innovative technologies and increase productivity;
- Train and strengthen the sector's human resources, enhance the production management team and create comfortable living and working conditions.

b) Law on Crop Farming

The amended Law on Crop Farming in Mongolia was approved by the State Parliament in January 2016. The law is the industry's key regulatory document that establishes arable land and governs the proper use of the land whilst protecting and improving its soils. However, the law does not specify measures on how to adapt to climate change. Still, the following articles, in general, may relate to climate change adaptation:

Article 12. Protective windbreaks for cultivated land

12.1. The protective windbreaks shall be a strip of trees and shrubs that have been established to protect the cultivated land against erosion and damage caused by wind.
12.2. The protective windbreaks shall belong to the owner of the cultivated land.

Article 18. Machinery and technology renovations in crop production

18.1. For grain production, reduced and zero tillage technologies shall be implemented to protect soils.
. . .
18.3. Crop production technology shall comply with the requirements for: protecting soil from erosion and damage, preserving soil fertility, reducing evaporation of soil moisture, creating economically efficient and safe working conditions, and maintaining the ecological balance.

Article 25. Measures for soil protection and fertility improvement

25.1. The following activities shall be implemented to protect and improve soil fertility of cultivated land:
25.1.1. Unless otherwise stated within this law, soils shall be treated with reduced and zero tillage technologies for grain production;
25.1.2. Fencing of arable land;
25.1.3. Development of windbreaks;
25.1.4. Cover cultivated field with straw mulch;
25.1.5. Use disease, pest, weed, and drought resistant and locally acclimatized varieties;
25.1.6. Introduce legumes into crop rotation circle;
25.1.7. Develop and implement comprehensive measures to protect minerals, organic fertilizers and plants;
25.1.8. Comply with irrigation regimes;
25.1.9. Record all soil protective measures taken on cultivated areas.

c) Mongolian Government Action Program 2016-2020, 2016

Within the context of the continuation of "Virgin land 3 campaign":

4. Establish comprehensive plant protection measures, protect cultivated land from erosion and damage, improve soil fertility, and introduce proper crop rotation and zero tillage technology in phases;
5. Develop and rehabilitate irrigation systems based on water exploration research, support the introduction of advanced irrigation technologies and increase the number of irrigated fields each year;
9. Develop the legal environment required for crop insurance.

d) "Virgin land 3 campaign" program

The "Virgin land 3 campaign" program was approved by the 70th Resolution of the Government of Mongolia in 2018. The main purpose of the program was to protect and restore soil fertility, intensify the renovation of seed varieties and technologies to substitute imported products, and ensure the sustainable development of export-oriented crop farming.

The following activities are planned to be implemented through this document: "Supply the domestic demand for wheat flour, potatoes and vegetables through domestic production by re-cultivating abandoned arable land (about 940 thousand ha) and transforming it into a crop rotation system."

e) "Vegetable" National Program

The "Vegetable" national program was approved by the 278th Resolution of the Government of Mongolia in 2017 in order to be implemented from 2018 to 2022. The goal of the program is to develop the vegetable production industry and ensure the sustainable supply of the domestic vegetable demand throughout the year by supporting household growers and other private vegetable production entities and corporations.

The program has the following objectives related to climate change:

- ***Objective 2.2.2: Promote irrigated vegetable farming and increase vegetable production through the introduction of advanced techniques and technologies.***

f) "Fruits and Berries" National Program

The "Fruits and Berries" National Program was approved by the 223rd Resolution of the Government of Mongolia in 2017 in order to be implemented from 2018 to 2022. The purpose of the program is to increase the varieties and production of fruits and berries by enhancing seabuckthorn cultivation to 10 thousand hectares and other types of fruits to 2 thousand hectares, to sustainably supply the population with natural and nutritious fruits and berries, to reduce imported products and to increase export revenues by improving the products' competitiveness.

The program does not include specific clauses on climate change.

g) State Policy on Food and Agriculture

The policy states the following objectives which are closely related to climate change adaptation.

- ***Objective 3.1.3:*** Fully implement soil cultivation by zero tillage technology with phases
- ***Objective 3.1.4:*** Increase the number of crop rotation circles and reduce the amount of bare fallow

h) The UN Food and Agriculture Organization's handbook and recommendations on "Climate-resilient smart-agriculture"

This handbook defines climate-resilient smart agriculture as:

- established on quality and productivity
- rational usage of natural and other resources
- resistant to natural disasters and risks
- maintaining a sustainable production and revenue

From this, it can be understood that a climate-smart agriculture must be established on quality and productivity, must use its resources rationally, must be resistant to natural disasters and risks, and must maintain a sustainable production and revenue.

From the point of view of developing climate-smart crop farming it is important to conduct crop production in such a way as to reduce the adverse effects and risks of climate change and be fully adapted to the changing climate conditions, to cultivate crops and varieties that require less water and are resistant to drought and other natural disasters that may occur in our country, and to do business with a focus on increasing productivity.

In Mongolia, however, the abovementioned requirements have not been met due to lack of focus on quality, an excessive use of natural resources, an extreme vulnerability to risks, and an unstable production and revenue. Thus, there is an urgent need to develop and implement a crop farming policy that is climate-resilient and smart.

2.2. GAPS IN THE CROP FARMING SECTOR POLICIES AND PROGRAMS REGARDING CLIMATE CHANGE ADAPTATION

- As can be deduced from the above, the policies and programs related to the crop farming sector have very limited provisions that specifically address climate change adaptation.
- Some general provisions that address the improvement and refinement of crop farming technologies and activities and their adaptation to climate change have been found.
- Some general provisions related to the sustainable development of crop farming activities include the improvement of farming technology to better suit climate change, the cultivation of varieties suitable for hot and dry conditions, the cultivation of new crops, and the improvements in water management and soil protection activities.
- The mechanisms, institutions, and financial resources which are relevant for implementing climate change mitigation and adaptation have not been adequately identified.
- The criteria for evaluating the implementation and the outcome to be achieved are unknown.
- Thus, it can be concluded that the issue of climate change adaptation in crop production has been neglected in the sector's legal documents, policies and operational programs.

2.3. THE INSTITUTIONAL ENVIRONMENT FOR RESEARCH ON ADAPTATION OF CROP FARMING TO CLIMATE CHANGE

a) Research organizations in the field of climate change adaptation in Mongolia

i. Information and Research Institute of Meteorology, Hydrology and Environment

This institute is the only state organization in Mongolia to conduct research on meteorology, hydrology, and climate change and its impact. The institute conducts comprehensive research on the related topics, funded by the Mongolian Science and Technology Foundation with the support of other foreign institutions, universities and international organizations.

The impact of climate change and the vulnerability of crop farming by the exposure to climate change have been extensively evaluated in recent years by the institute. Research in this area includes:

- Study on the current and future trends of climate change;
- Study on the climate conditions of cultivated crops and their changes;
- Assessment of the impacts of climate change on crop growth and yield; research is conducted with widely-used "climate – crop growth and yield" models (Centure, DSSAT, SPUR, etc.);
- Study on weather and natural disasters;
- Development of climate change adaptation approaches for economic and social sectors (including crop farming).

The results of these studies provide a basis for Mongolia's climate change policies and programs, and reports prepared for international organizations.

ii. Climate Change and Development Academy

This organization is an independent non-profit organization that conducts research on climate change and development, implements project programs and advises other domestic and foreign organizations. The organization is conducting the following activities:

- Development of climate change policies and the basis for a legal framework, preparation of documents, conducting evaluations and providing consultations,
- Integrating findings of the relevant sectors and applied research and determining their connections, and developing recommendations on aligning the results with national and sectoral policies and strategies,
- Creating a smart and carbon-free development model adapted to climate change,
- Preparing and publishing brochures, articles, and reports on climate change,
- Giving lectures and recommendations on climate change to government agencies, research institutes, university researchers and students as well as to the related ministries, local governments, the citizens and the public.

iii. International project implementation units on climate change

Project implementation units have been set up to implement climate change projects and programs supported by international organizations in Mongolia. The units are performing the following functions:

- Implementing international climate change projects and programs, conducting research and preparing reports,
- Ensuring the implementation of the United Nations Framework Convention on Climate Change and the Paris Agreement and preparing reports,
- Conducting the Mongolian Greenhouse Gas inventory and preparing the reports according to international methods.

iv. The applied mathematics and meteorology department of the School of Engineering and Applied Sciences at the National University of Mongolia

- Providing university education in meteorology and hydrology, and preparing and training highly qualified personnel,
- Conducting joint research with foreign universities.

b) Ministry for the crop farming sector, research and education institutions

The Ministry of Food, Agriculture and Light Industry, relevant agencies and foundations The Ministry of Food, Agriculture and Light Industry (MoFALI) is the central administrative body with a primary responsibility to ensure the rational usage of raw materials, to substitute imported products, to develop value chains of export-oriented production, to ensure the sustainable growth of the sector's economy by increasing production income, productivity and competitiveness, to create conditions for supplying the population with healthy, safe and nutritious food, hygienic products, clothing and consumables through the accurate identification and implementation of sectoral policies. The Ministry's priorities include:

. . .

- Organizing and coordinating the implementation of activities for an increased water supply and the proper use, protection and restoration of agricultural arable lands;
- Promoting a sustainable development and intensification of crop production, increasing crop yields, introducing crop rotation, improving and protecting soil fertility, and implementing comprehensive plant protection procedures;
- Introducing new advanced technologies and innovations into the production industry of the sector;
- Creating conditions for the supple of healthy and safe food for the population, increasing food supply and access, ensuring that food safety requirements are met, and formulating and coordinating the domestic trade policy;
- Establishing a knowledge-based economy by developing new high-tech sectors and developing and implementing effective policies and regulations for public-private partnerships.

Within these priorities, crop farming related issues were determined. Particularly, the issue of adaptation to climate change is well formulated, which is illustrated in detail below:

Prevent and reduce the risks of natural disasters and climate change for agricultural production.

Since the Ministry's prioritized activities clearly outlined the risks and impacts of climate change, the MoFALI is responsible for taking specific actions and measures in this area.

Within its role of monitoring the implementation of policies and activities in the agricultural and crop farming sectors, the General Agency for Specialized Inspections shall also oversee the implementation of climate change adaptation measures in the crop farming sector and play an important role in accelerating their execution.

Although the Crop Support Fund is responsible for supporting the crop farming sector, introducing new technologies, and providing support for the prevention of natural disasters, there is currently no clear information on the Fund's activities relating to climate change adaptation and protection against potential risks.

Research and educational institutions of the sector

i. Mongolian University of Life Sciences:

MULS is the only agricultural university in Mongolia. The university consists of five core schools and four research institutions.

Affiliated schools:

1. School of Veterinary Medicine
2. School of Animal Science and Biotechnology
3. School of Engineering and Technology
4. School of Agroecology
5. School of Economics and Business

In addition to these affiliated schools, there is also the Graduate School.

Research Institutions:

1. Institute of Veterinary Medicine
2. Research Institute of Animal Husbandry
3. Plant Science and Agricultural Institute
4. of Plant Protection Research Institute

Local research and training units are also affiliated with the MULS.

In addition to training and educating agricultural professionals at the schools and institutes of the Mongolian University of Life Sciences, they also conduct detailed research on issues facing the agricultural sector. Although recent studies have been focusing on the integration of these studies with climate change issues, there are few specific projects or programs on this subject.

ii. School of Agroecology and Business of the MULS in Darkhan

The School of Agroecology and Business of the MULS is a nation-wide organization that carries out basic and applied research in agriculture, develops new technologies in crop production, produces primary seeds of acclimatized varieties of various crops, defines and implements agricultural development policies.

In recent years, the school has conducted research on developing new varieties and production technologies that are adaptable to the changing climate conditions.

iii. Department of Meteorology of the MULS in Darkhan

- Providing education in meteorological engineering,
- Conducting agro-climate research and providing farmers with the required information and recommendations.

SECTION 3. RECOMMENDATIONS FOR ACCELERATING THE ADAPTATION OF THE CROP FARMING SECTOR

3.1. IMPROVING THE LEGAL ENVIRONMENT FOR CROP FARMING ADAPTATION AND COORDINATING THE IMPLEMENTATION OF THE SECTOR'S POLICIES, STRATEGIES AND PROGRAMS

- The laws and regulations of the agricultural and crop farming sectors do not address the issue of adaptation to climate change. Therefore, more attention should be paid to including this issue in the sectoral laws and regulations.
- **Amendments to the Law on Crop Farming.** Although the 2016 revision of the Law on Crop Farming sets out to develop crop farming, improve its technologies, identify and properly use arable lands, and protect and improve soils, the law does not specify how to adapt to climate change and what actions should be taken. Therefore, a special clause must be added to the law on how to address this issue.
- As the current policies and programs of the agricultural and crop farming sectors have insufficiently addressed mitigation options and the adaptation to climate change, measures should be taken to clearly incorporate this issue into new developmental policies, strategies and programs.
- Integrate the goals and measures for climate change and adaptation in the crop farming sector, which are presented in the policies, programs, and documents related to the development and the climate change in Mongolia, into the sector's policies, strategies, and programs and implement them.
- Implement the objectives and measures to adapt the crop farming sector to climate change in conjunction with the policies and programs discussed in subsection 2.1, and if possible, include additional details for their implementation.
- As the national development policies, strategies and programs for climate change are intersectoral, with the relevant sectors and ministries being responsible for implementing them, it should be noted that the relevant provisions of the objectives and measures set forth in those documents shall be considered and implemented in the crop farming sector.

3.2. DEVELOPING AND IMPLEMENTING SPECIAL PROGRAMS FOR A CLIMATE-SMART ADAPTATION OF THE CROP FARMING SECTOR

It is important for the MoFALI, together with the Ministry of Environment and Tourism and other relevant ministries and research organizations, to develop and implement the National Program for the "Climate-smart development of the crop farming sector". Or, the issue could be addressed within the scope of the general program on the agricultural sector's adaptation to climate change. The program may cover the following topics:

- Conducting a detailed study of the impacts and risks of climate change on the crop farming sector and its crops;
- Taking full advantage of the positive impacts of climate change, researching the possibility of overcoming the negative impacts, and developing variations of adaptation measures and evaluating their effects;
- Identifying strategies and methods (necessary technology, financing mechanisms, capacity building, etc.) of implementing adaptation measures in the crop farming sector;

- Determining how to integrate these objectives and measures in the policies and activities of the sector;
- Some measures to reduce greenhouse gas emissions from the soil and crop farming sector may also be included.

3.3. IMPROVING AND STRENGTHENING THE INSTITUTIONAL ENVIRONMENT

- Strengthen and enhance the correlation between the organizations, universities and institutes of the crop farming sector, which are responsible for the climate change issue, and develop and implement joint projects;
- Provide training and knowledge for staff of crop farming organizations, universities and research institutes on climate change, and regularly hold meetings and discussions on the topic;
- Ensure that crop farming professionals are actively involved in climate change projects and programs;
- Specialists and researchers in the field of climate change and crop farming should initiate and develop projects and programs and collaborate with international organizations;
- Develop project proposals and project documentation on the adaptation of the crop farming sector to climate change with funding from the International Green Climate Fund, initiate works to submit project proposals to the Fund, and cooperate with the UN Food and Agriculture Organization and other specialized agencies;
- The affiliated schools of the Mongolian University of Life Sciences and the Research Institute will each be involved in the development and implementation of science and technology projects on "crop and climate change" which may be financed by the Mongolian Science and Technology Fund.

3.4. ENHANCING THE INSTITUTIONAL CAPACITY TO FACILITATE CLIMATE CHANGE ADAPTATION IN THE CROP FARMING SECTOR

It is particularly important to improve the working relationships and expand the cooperation between organizations of all levels, including public administrations, research and educational institutions as well as scientific institutions, to reduce the impacts and risks of climate change, and to implement climate change adaptation measures in national and sectoral policies and legal documents.

The institutional structure and interrelations of administrative bodies, research organizations, private-sector and non-governmental organizations as well as relevant international organizations, and funding mechanisms aimed at solving the issues of concern are outlined in **Figure 1**.

3.5 PROVIDING INFORMATION REGARDING CLIMATE CHANGE AND CAPACITY BUILDING FOR CROP FARMING SECTOR SPECIALISTS AND DECISION MAKERS

- Provide information for agricultural and crop farming professionals and conduct trainings and seminars;
- Provide information to researchers of the agricultural and crop farming sector schools and research institutions and conduct trainings and seminars;
- Conduct regional trainings for the local farmers and provide information on the

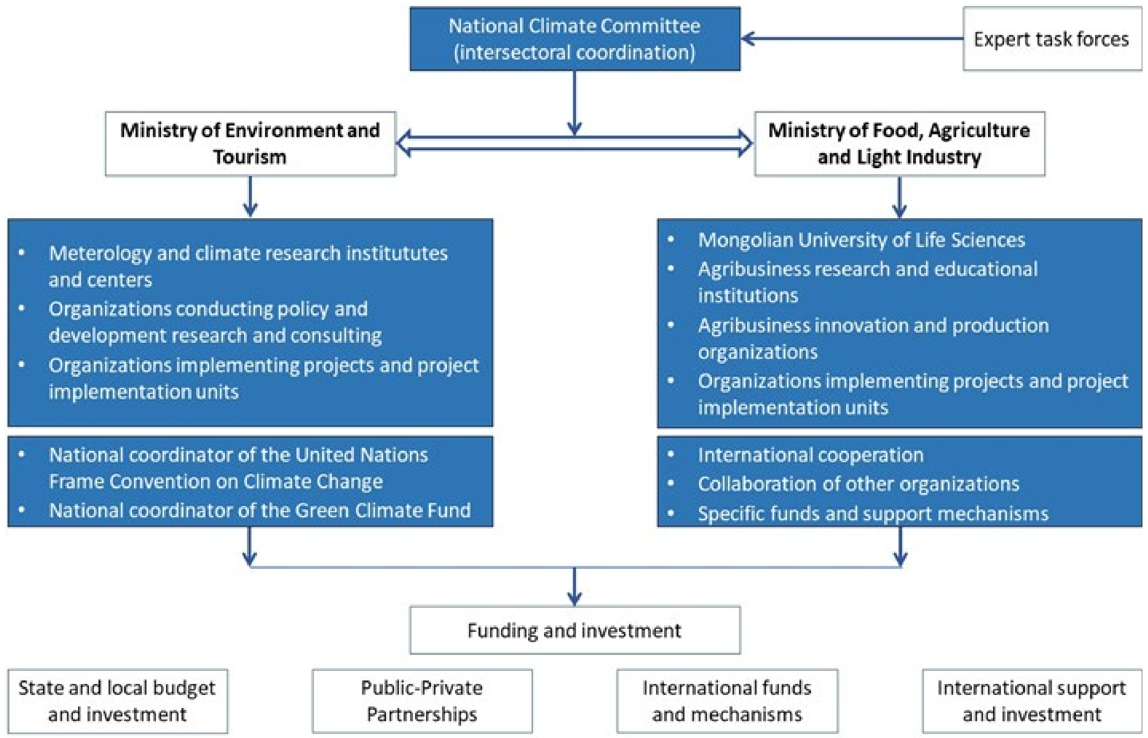


Figure 1: General outline of the institutional structure to support climate change adaptation in the crop farming sector *(Source: own illustration)*

implementation of climate change adaptation;

- Prepare and distribute brochures and manuals to the related parties on the effects, risks and adaptations of climate change in the crop farming sector.

REFERENCES

Climate Change and Development Academy (2019) www.ccd-academy.com (Last access 10.12.2019)
FAO (Food and Agriculture Organization of the United Nations) (2013): Climate-Smart Agriculture - Sourcebook, FAO, Rome
Information and Research Institute of Meteorology, Hydrology and Environment (2019) www.irimhe.namem.gov.mn (Last access 10.12.2019)
MEGD (Ministry of Environment and Green Development of Mongolia) (2013): Climate Change Coordination Office: Technology Needs Assessment for Climate Change, Volume 1: Climate change adaptation
MEGDT (Ministry of Environment, Green Development and Tourism of Mongolia) (2015): Mongolia's Intended Nationally Determined Contribution (INDC)
MET (Ministry of Environment and Tourism of Mongolia) (2019): Mongolia's Nationally Determined Contribution to mitigate global climate change (NDC),
MULS (Mongolian University of Life Sciences) (2019) http://www.muls.edu.mn (Last access 10.12.2019)
School of Agroecology and Business of the Mongolian University of Life Sciences, http://www.sab.edu.mn/about-us/overview/ (Last access 06.12.2019)
Secretariat of State Great Hural (2008): "Virgin Land 3 campaign" program, http://www.parliament.mn/n/1rcy (Last access 2019)
Secretariat of State Great Hural (2011): Mongolian National Program on Climate Change http://www.parliament.mn/n/femo (Last access 04.12.2019)
Secretariat of State Great Hural (2015): State Policy on Food and Agriculture http://www.parliament.mn/n/uyey (Last access 06.12.2019)
Secretariat of State Great Hural (2016): "Green Development Policy" of Mongolia 2014-2030 http://www.parliament.mn/n/rony (Last access 03.12.2019)
Secretariat of State Great Hural (2016): Mongolian Government Action Program 2016-2020 http://www.parliament.mn/n/ahty (Last access 04.12.2019)
Secretariat of State Great Hural (2016): Mongolia's Sustainable Development Vision 2030
Secretariat of State Great Hural (2016): Revised Law on Crop Farming of Mongolia http://www.parliament.mn/n/qceo (Last access 05.12.2019)
Secretariat of State Great Hural (2017): "Vegetable" National Program http://www.parliament.mn/n/xbgy (Last access 04.12.2019)
Secretariat of State Great Hural(2017): "Fruits and Berries" National Program, http://www.parliament.mn/n/qigy (Last access 03.12.2019)
Secretariat of State Great Hural, (2015): State Policy on Food and Agriculture http://www.parliament.mn/n/uyey (Last access 05.12.2019)

NOTE

NOTE

Published by:

GERMAN-MONGOLIAN COOPERATION PROJECT "SUSTAINABLE AGRICULTURE" (MNG 19-01)

SUBPROJECT: EXPERT DIALOGUE ON AGRICULTURE FOR CLIMATE CHANGE ADAPTATION OF THE MONGOLIAN CROP SECTOR (MNG 19-02)

Government Building IXa
Enkhtaivan Avenue 16a
13381 Ulaanbaatar, Mongolia

Mail: **project.mn@iakleipzig.de**
Website: **www.dmknl.de**

Print production by "Info Consulting" LLC