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AFGHANISTAN'S

AGRO-ECOLOGICAL ZONING ATLAS

PART 2

Agro-ecological assessments

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PART 2 / *Agro-ecological assessments*

A study of the International Institute for Applied Systems Analysis (IIASA) in collaboration with FAO

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Foreword

Agriculture is crucial for the national economy of Afghanistan and in particularly so for the agriculturally dependent population which is constituting 60% of the total population.

Adoption of new strategies for agriculture monitoring, rural land use planning and land management are urgently required to reduce hunger and poverty among rural population and to assure sustainable food and feed production for future generations. The availability of reliable information on natural resources and agriculture for its monitoring and analysis is indispensable to development and implementation of such strategies. However, productivity in the agricultural sector has been relatively low. Afghanistan has the potential to increase its output of cereals, fruits and vegetables.

For this purpose, the project "Strengthening Afghanistan Institutions' Capacity for the Assessment of Agriculture Production and Scenario Development" (GCP/AFG/087/EC), funded by the European Union (EU), is implemented by the Ministry of Agriculture, Irrigation and Livestock (MAIL) and the Food and Agriculture Organization of the United Nations (FAO).

Among the project objectives are improving the understanding of the country's national resources endowment and limitations as well as assessing agricultural production capacities under current climatic conditions and likely impacts of climate change. Within the context of this project the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) support and implement a National Agro-Ecological Zoning activity in Afghanistan (NAEZ) which assesses quality and availability of land resources and identifies crop cultivation potentials - suitable area, production and attainable yield - under prevailing soil and terrain conditions and for given current or future agro-climatic conditions.

One of the outputs of the NAEZ activities is this Agro-Ecological Zones Atlas which is based on applications of the FAO/IIASA National Agro-Ecological Zoning system for current and future climates.

The Atlas provides two distinct parts, namely:

- Part 1: Agro-Climatic indicators
- Part 2: Agro-Ecological assessments

Acknowledgements

The publication of the agro-ecological zoning atlas of Afghanistan is the result of the great joint efforts of many institutions and individuals working in close partnership.

The publication of the atlas was made possible by the contributions (financial and in-kind) of the partner organizations involved in the Afghanistan programme: the Government of the Afghanistan, the Food and Agriculture Organization of the United Nations (FAO) and the European Commission (EC), which funds the Programme.

FAO Afghanistan greatly acknowledges the initiative taken by the Ministry of Agriculture, Irrigation and Livestock (MAIL) for delegating the study on national agro-ecological zoning.

Significant valued management for this work was provided by Rajendra Aryal. Guidance, support, and oversight in his role as FAO Representative/Country Director is highly appreciated. Special thanks are expressed to the current FAOR, Mr. Richard Trenchard for his great leadership and continuous support to this Atlas development.

The collaboration and assistance of the International Institute for Applied System Analysis (IIASA) and its experts (Gunther Fischer and Harrij van Velthuizen) are acknowledged in implementation of the national agro-ecological zoning (NAEZ) system for Afghanistan including data collection/verification, database creation, coding and scenario analysis, soil/crop/climate results classification and map production.

For in-country and international consultations, technical guidance, formal and informal peer reviews, local knowledge, and insights, thanks are due to: Moeen Uddin Siraj (Head of Operations - FAO Afghanistan) for the original conceptualization, Mohammad Aqa (Assistant FAOR – FAO Afghanistan), Douglas Muchoney (Project Lead Technical Officer, FAO-NSL), Sayed Omar Dost (GIS/RS Officer, FAO Afghanistan), Rabia Nemati (GIS/RS Officer, FAO Afghanistan), Inayatullah Mangal (Admin and Finance Officer, FAO Afghanistan), and Muhammad Ishaq Safi (National Project Manager – FAO Afghanistan).

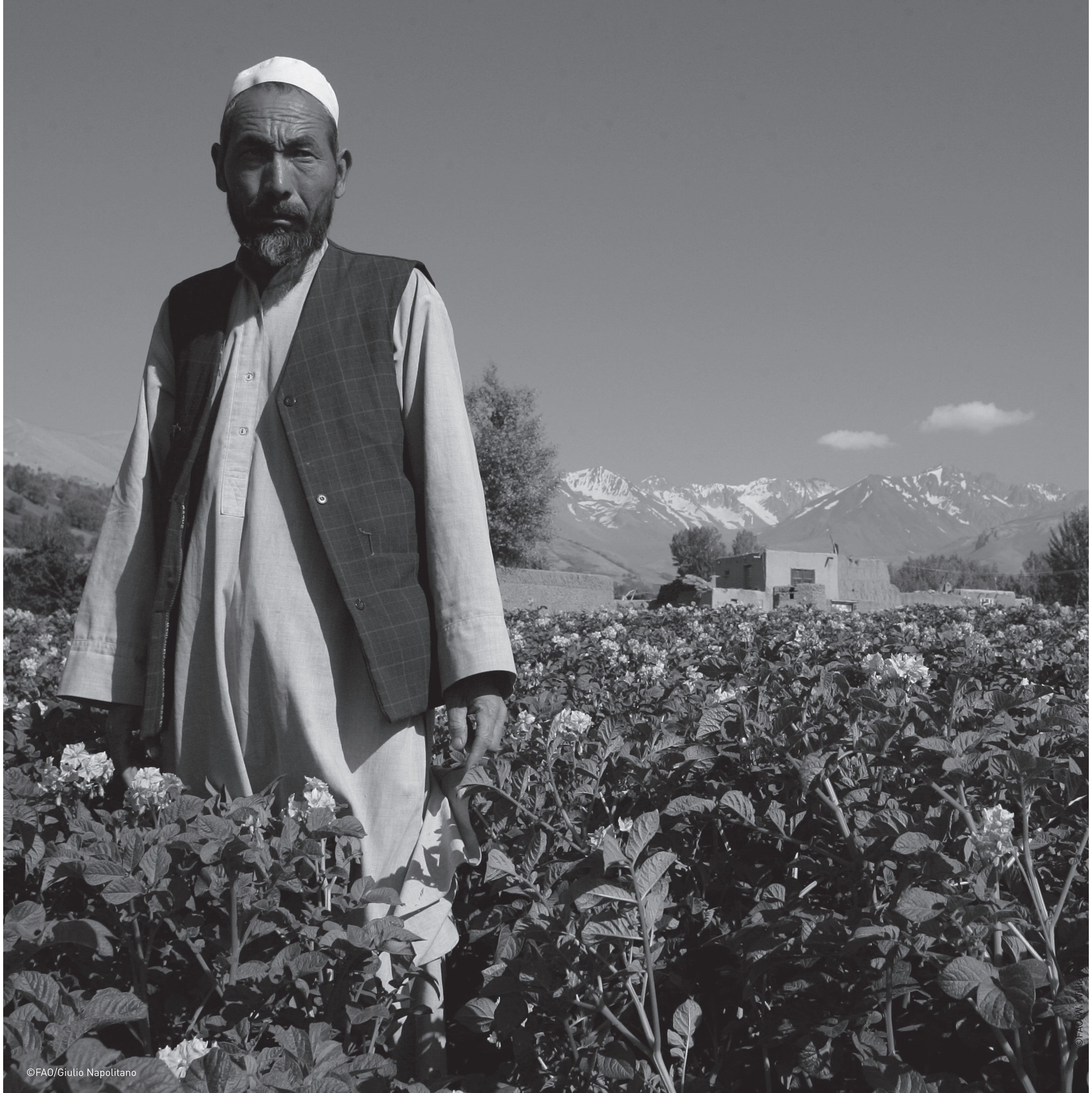
We acknowledge the keen interest, support provided and graphic designs developed by Shane Anthony Cruise (Graphic Designer, FAO Afghanistan). In addition, we also thank the technical interactions and inputs of all colleagues in FAO and many other individuals and partners agencies at all administrative levels of Afghanistan.

Abbreviations and acronyms

AEZ	Agro-ecological zones
AFGHSD	Afghanistan Harmonized Soil Database
AR5	IPCC Fifth assessment report, 2014
AWC	Available soil water capacity
BADC	British Atmospheric Data Centre
CRU	Climate Research Unit at University of East Anglia, UK
CMIP5	Coupled Model Intercomparison Project Phase 5
Ensemble mean	Mean value of multi-model ensembles
ERA-40	Re-analysis of meteorological observations from September 1957 to August 2002 produced by the European Centre for Medium-Range Weather Forecasts (ECMWF)
ESM	Earth System Model
ETo	Reference potential evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Corporate Database for Substantive Statistical Data
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory Earth System Model 2
GPCC	Global Precipitation Climatology Centre
HadGEM2	Hadley Centre Global Environmental Model 2 – Earth System
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IPSL-CM5A-LR	Institut Pierre Simon Laplace Earth System Model for the 5th IPCC Report
ISI-MIP	Intersectoral Impact Model Intercomparison Project
LCCS	Land Cover Classification System
LCDA	Land cover database of Afghanistan
LGP	Length of growing period
LGPt	Length of temperature growing period
LUT	Land utilization type
MAIL	Ministry of Agriculture, Irrigation and Livestock
MIROC-ESM-CHEM	Earth system model developed by Japan Agency for Marine-Earth Science and Technology and Centre for Climate System Research / National Institute for Environmental Studies, Japan
NAEZ	National agro-ecological zoning
NorESM1-M	Norwegian Earth System Model
RCP	Representative Concentration Pathway

Abbreviations and acronyms

SI	Suitability index
SMU	Soil mapping unit
SQ	Soil quality
SRTM	Shuttle Radar Topography Mission
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WATCH	Water and Global Change project
WRB	World Reference Base for Soil Resources



1. Description of selected AEZ input data

1.1 Climate data

For the agro-ecological zones historical assessment time series data were used from three main sources, the Climate Research Unit (CRU) at the University of East Anglia, the Global Precipitation Climatology Centre (GPCC), and the EU WATCH Integrated Project.

Climatic Research Unit (CRU) TS v3.21 (time-series) datasets (Harris *et al.*, 2014) were obtained from British Atmospheric Data Centre (BADC). These are month-by-month variations in climate over the last century. CRU TS v3.21 data used in NAEZ-Afghanistan are mean monthly temperature, diurnal temperature range, cloud cover, vapor pressure and wet day frequency.

For monthly precipitation the GPCC Full Data Reanalysis Product Version 6 is used (Schneider *et al.*, 2011). In the current version of NAEZ-Afghanistan the gridded historical precipitation data cover the period from 1961 to 2010.

Global sub-daily meteorological forcing data were provided in WATCH[1] for use with land surface- and hydrological-models. The data are derived from the ERA-40 and ERA-Interim reanalysis products via sequential interpolation, elevation correction and monthly-scale adjustments based on CRU (temperature, diurnal temperature range) and GPCC (precipitation) monthly observations.

Historical climatic data analysis was undertaken year-by-year for 1961 to 2010 and time series data were used to compile three 30-year baseline data sets, for respectively the periods 1961–1990, 1971–2000 and 1981–2010.

1.2 Climate scenarios

IPCC AR5 climate model outputs for four Representative Concentration Pathways (RCPs) are used to characterize a range of possible future climate distortions for the 2020's (period 2011–2040), the 2050's (period 2041–2070) and the 2080's (period 2070–2099).

RCPs are a set of four greenhouse gas concentration trajectories developed for the climate modeling community as a basis for long-term and near-term modeling experiments adopted by the IPCC for its fifth Assessment Report (AR5).

The four RCPs together span the range of year 2100 radiative forcing values found in the open literature, i.e., from 2.6 W/m^2 under stringent emission mitigation measures to 8.5 W/m^2 associated by-and-large with 'business as usual' development assumptions. The four RCPs – RCP2.6, RCP4.5, RCP6.0, and RCP8.5 – are named after a future level of radiative forcing values in the year 2100 (2.6, 4.5, 6.0, and 8.5 W/m^2, respectively). These concentration pathways are documented in a special issue of Climatic Change (van Vuuren et al., 2011), and climate model simulations based on them were undertaken as part of the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2011).

Multi-model ensembles for each of the climate forcing levels of the RCPs were analyzed based on spatial data from the IPCC's AR5 CMIP5 process, data bias-corrected and downscaled to 0.5 degree as used in the Intersectoral Impact Model Intercomparison Project (ISI-MIP) (Hempel et al., 2013). ISI-MIP data of five climate models (GFDL-ESM2M, HadGEM2, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M) and for four RCPs (RCP 2.6, 4.5, 6.0 and 8.5) - totaling 20 combinations of respectively RCPs and climate models - were used for generating climate input data in NAEZ-Afghanistan covering the period of 2011 to 2099 and were used to compile results for three future 30-year periods, the 2020s (period 2011–2040), 2050s (period 2041–2070) and the 2080s (period 2070–2099).

[1] WATCH was a large Integrated Project funded by the European Commission under the Sixth Framework Programme, Global Change and Ecosystems Thematic Priority Area (contract number: 036946). The WATCH project started in 2007 and continued to 2011.

1.3 Land Cover data

NAEZ Afghanistan includes a land cover dataset at 7.5 arc-seconds resolution, which was derived from the updated LCDA 2010 Land Cover Database of Afghanistan (FAO, 2016). The main data sources include medium resolution satellite imagery from SPOT-4 and Global Land Survey (GLS) Landsat Thematic Mapper, high resolution satellite imagery and air photographs and ancillary data. The complete coverage is made by 280 scenes, most of which are around year 2010, while others were selected from the existing archives or newly acquired to fill gaps or replace unacceptable images due to high snow or cloud coverage.

The Afghanistan 2010 land cover legend, was prepared using the Land Cover Classification System (LCCS), which is a comprehensive, standardized a priori classification system that enables comparison and correlation of land cover classes regardless of mapping scale, land cover type, data collection method or geographical location. The LCCS legend was compiled for the creation of the 2010 national land cover database. It comprises of 25 classes, which include two classes of rain-fed cropland and six classes detailing irrigated land. Based on the full LCDA database rasterized at 1.5 arc-seconds (about 35 m at latitude of Afghanistan), a share representation at 7.5 arc-seconds is used in NAEZ-Afghanistan. For illustration, Figure 1.1 shows dominant land cover by 11 major categories.

Major Land Cover categories

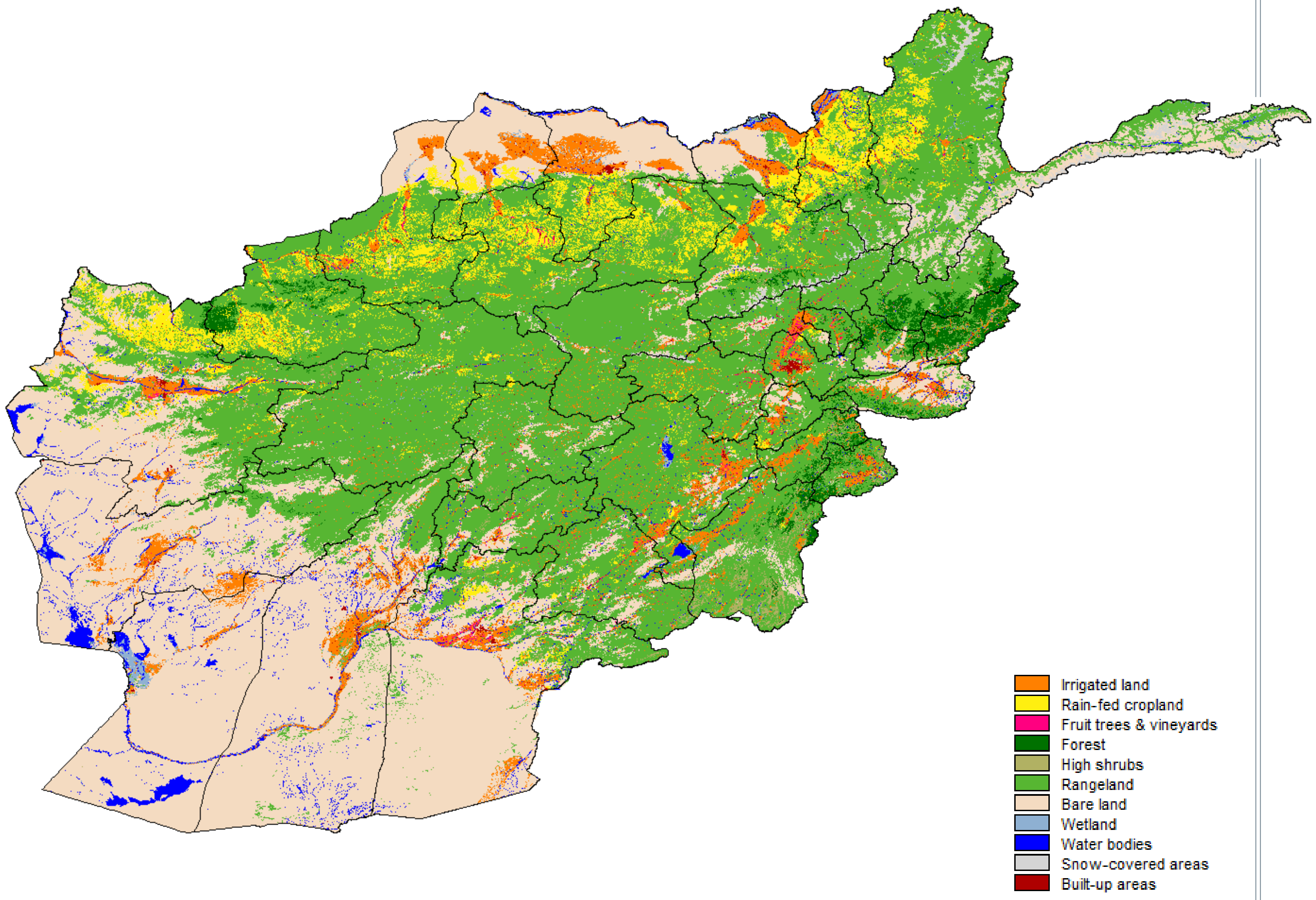


Figure 1.1

Distribution of rain-fed cropland and main categories of irrigated land

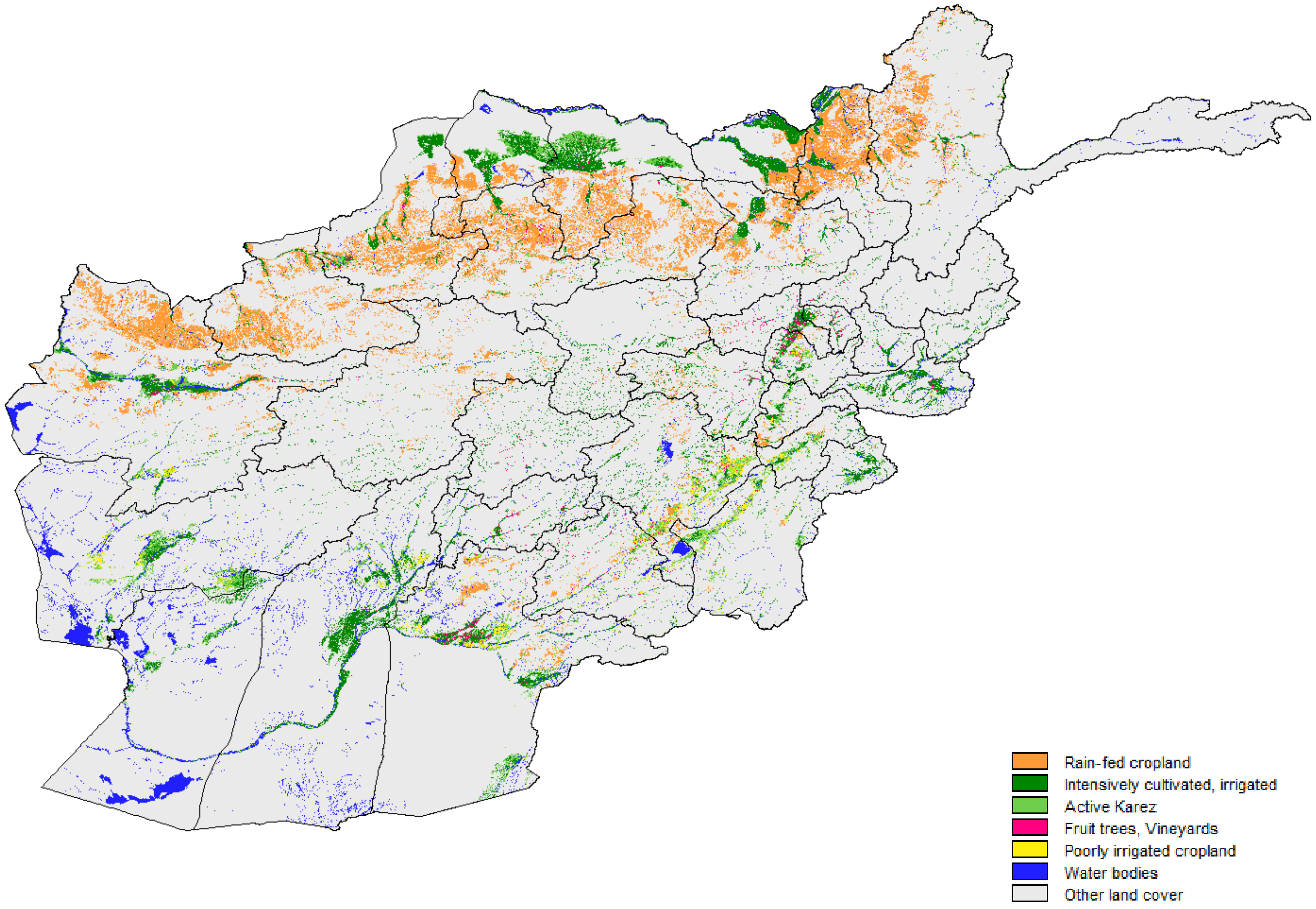


Figure 1.2

Of particular interest for NAEZ analysis is the current distribution and kind of rain-fed cropland and irrigated land. Main classes distinguished in NAEZ are shown in Figure 1.2. Irrigated land for fruit trees and vineyards has been assessed but is assumed to be unavailable for annual crops. Note must also be taken of 'Poorly irrigated' land, which accounts for 30% of irrigated land but where lack of water or other imperfections may limit crop production. However, upon advice of experts consulted by FAO-Afghanistan it has been assumed also for these areas that adequate irrigation is available to fully meet crop water requirements.

1.4 Soil and terrain data

For NAEZ Afghanistan a soil database was compiled to serve as source of soil resources data for spatially detailed evaluation of soil qualities and edaphic soil suitability. This national harmonized soil database (AFGHSD v1) contains general soil information such as soil depth, soil drainage and occurrence of soil phases relevant for agricultural land use plus 17 AEZ soil profile attributes, each for 0-30 cm and 30-100 cm soil depth.

Various soil resources maps and data sets, varying in detail and quality, are used. This includes different soil resources maps or spatial databases: (i) the USDA Soil Map of Afghanistan; (ii) the USGS Soil Map of Afghanistan; and (iii) the SoilGrid250m database. Median altitude and terrain slope data were derived from SRTM digital elevation data. Land use/land cover data were obtained from the Land Cover Atlas of Afghanistan. These different sources were integrated to define national soil association mapping units of the national harmonized soil database. Where possible, soil attributes in AFGHSDv1 were compiled from interpolated soil profile data of the Afghan soil profile database and were then complemented with soil attributes of the World Inventory of Soil Emissions Database (AEZ–WISE II).

AFGHSDv1 covers the entire territory of Afghanistan with 2398 soil association map units with soils classified according to the revised soil legend (FAO'90) of the FAO/Unesco Soil Map of the World (FAO, Unesco & ISRIC, 1990).

Data integration for the National Afghanistan Harmonized Soil Database (AFGHSDv1)

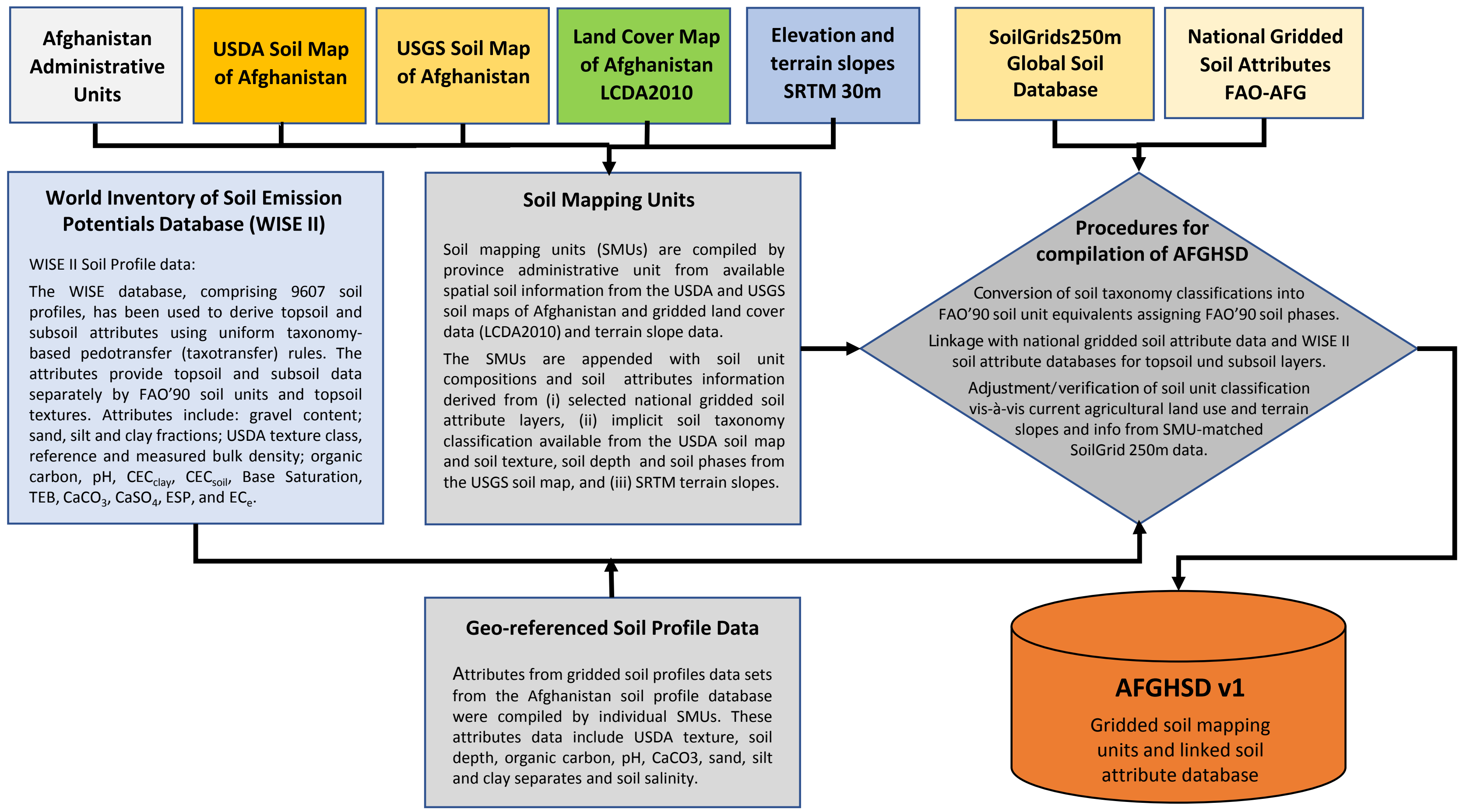


Figure 1.3

Generalized map of dominantly occurring soil units or miscellaneous units

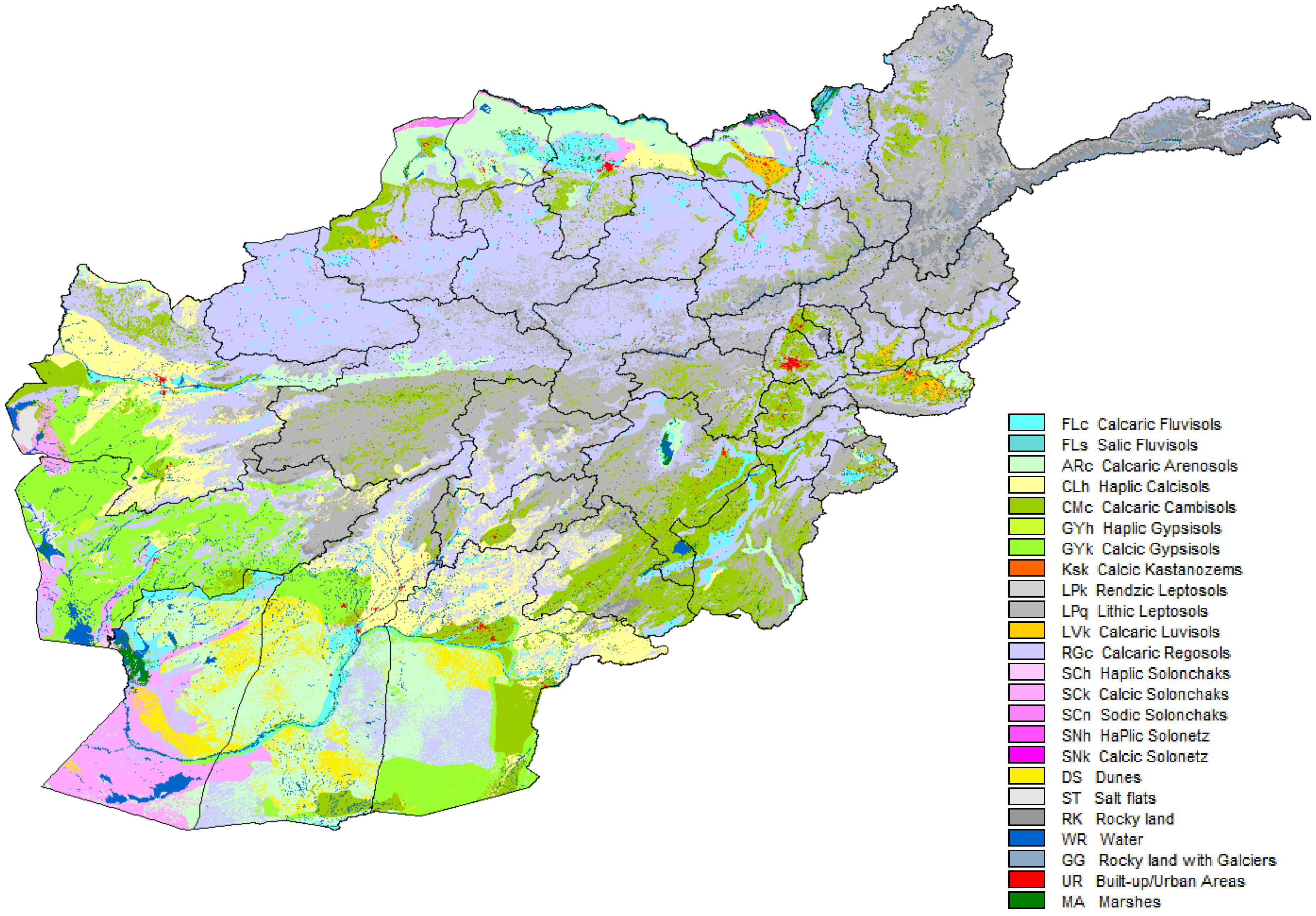


Figure 1.4

Terrain data was derived from 1 arc-second (about 30m at equator) SRTM data (Farr et al., 2007), provided by FAO-Afghanistan, and classified in terms of elevation and terrain slope classes for use in NAEZ as follows:

1. Median elevation (m) of 1arc-second grid-cells

2. Distributions (%) of calculated 1 arc-second terrain slopes in terms of eight slope gradient classes:0–0.5%, 0.5–2%, 2–5%, 5–8%, 8–16%, 16–30%, 30–45%, and > 45%.

Figure 1.3 provides an overview of data integration creating the national Afghanistan Harmonized Soil Database (AFGHSDv1). Figure 1.4 presents a general soil map comprising of 24 FAO soil units compiled from 2398 map units contained in AFGHSDv1. For illustration, the general soil map units are represented here by dominantly occurring soil units (classified according to the FAO'90 revised legend) or miscellaneous units (i.e., dunes, salt flats, rocky land, rocky land with glaciers, marches, water bodies and built-up/urban areas).

1.5 Geographical regions

Figure 1.5 shows the delineation of eight regions used for presenting regional results of agro-ecological zones and crop suitability under current and future climate. Regions comprise of three to six provinces, as follows:

Northeastern (NE):	Badakhshan, Baghlan, Kunduz, Takhar
Northwestern (NW):	Balkh, Faryab, Jawzjan, Samangan, Sar-e-pul
Eastern (EA):	Kunarha, Laghman, Nangarhar, Nooristan
Central (CE):	Kabul, Kapisa, Logar, Panjsher, Parwan, Wardak
West-Central (WC):	Bamyan, Daykundi, Ghazni
Western (WE):	Badghis, Farah, Ghor, Herat
Southeastern (SE):	Khost, Paktika, Paktya
Southwestern (SW):	Helmand, Kandahar, Nimroz, Urozgan, Zabul

Major regions used for reporting the results of agro-ecological analysis

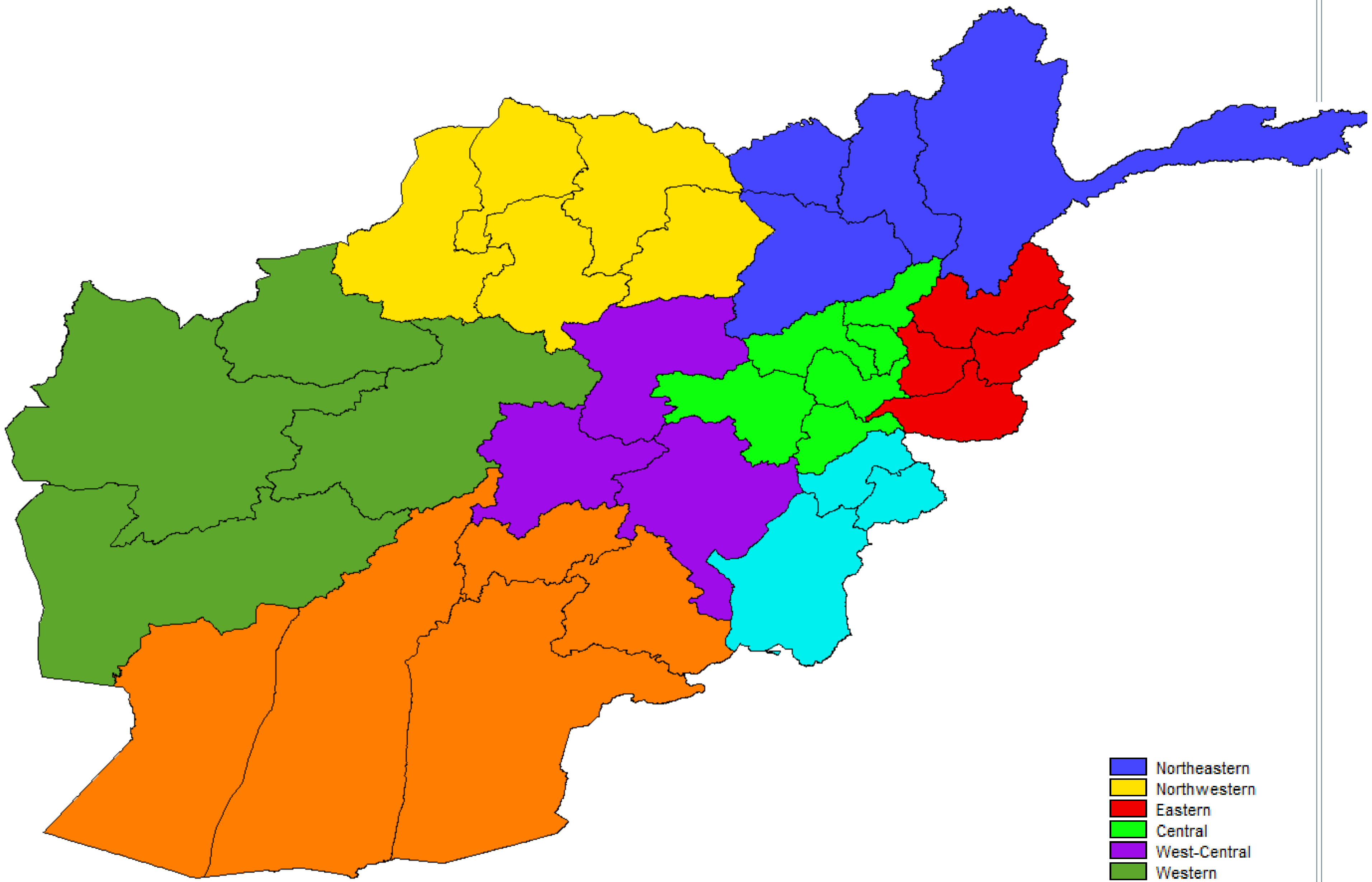


Figure 1.5

Table 1.1 lists selected indicators for each region. In terms of total land, the largest extents are contributed by the Southwestern and Western regions, together accounting for more than half the territory of Afghanistan. The highest population density occurs in the Central region, followed by the Eastern region. The highest cropland share of 27.6% is found in the Northwestern region. However, in this region as well as in Northeastern region the share of irrigated land in total cropland is lowest, only about 30%, compared to Central, Eastern, Southeastern and Southwestern region where irrigation can be applied in 85% to 100% of the cropland. Table 1.1 shows for cropland in all regions also the mean altitude, mean annual temperature and annual precipitation during 1981–2010.

Note, mean altitude of current cropland is more than 2000 m in Central, West-Central and Southeastern region and is lowest in the Eastern region (1093 m). Precipitation received on cropland in Afghanistan was on average 283 mm, with a range across regions of 200 mm (Southwestern region) to 430 mm (Eastern region).

Table 1.1 Selected indicators by region

Regions	Total Land (1000 ha)	2010 Population % of total	Cropland Characteristics				
			Cropland share (%)	Of which Irrigated (%)	Mean Altitude (m)	Mean Temp (°C)	Annual Precipitation (mm)
North Eastern	7 734	14.4	18.2	29	1 310	13.4	370
North Western	7 679	14.3	27.6	31	1 145	14.1	242
Eastern	2 490	9.6	6.9	100	1 093	16.5	430
Central	3 037	23.6	11.4	85	2 226	8.8	421
West Central	5 517	7.9	8.7	84	2 443	9.9	309
Western	16 235	13.3	10.2	38	1 258	15.4	247
South Eastern	2 863	5.9	10.2	95	2 021	13.1	369
South Western	18 342	11.1	5.8	90	1 192	18.9	200
Afghanistan	63 896	100.0	11.8	50	1 373	14.4	283

+ Total land and current cropland areas were calculated using the NAEZ-Afghanistan gridded spatial inventory of land resources. Mean altitude, mean annual temperature and annual precipitation were derived from the NAEZ Afghanistan climate inventory. Cropland includes irrigated land for fruit trees and vineyards.

2. Agro-ecological zones classification

2.1 Introduction

The agro-ecological zones methodology provides a framework for establishing a spatial inventory of land resources compiled from available environmental data sets and assembled to quantify multiple spatial characteristics required for the assessments of land productivity under location-specific agro-ecological conditions. The AEZ class layer for Afghanistan provides a uniform classification of bio-physical resources relevant to agricultural production systems.The inventory combines spatial layers of thermal and moisture regimes with broad categories of soil/terrain qualities. It also indicates locations of areas with dominantly irrigated soils and shows land with severely limiting bio-physical constraints including very cold and very dry areas as well as areas with very steep terrain or very poor soil/terrain conditions.

2.2 Temperature regime classes

The delineation of four temperature regime classes (TR), which are used to define AEZs, has been applied to subdivide the country in areas which are generally too cold for cropping (TR1), areas where heat provision can support only one crop per year (TR2), areas where the temperature regime allows potential double cropping (TR3), and areas with ample heat supply for potential year-round cropping (TR4). Conditions in different TR classes relate to the thermal requirements of different crops and the possibility to grow one, two or even three sequential crops. Since water supply from rainfall is very limited in most of Afghanistan, double and year-round cropping can be practiced generally only when irrigation is available.

Temperature regime classes were defined as follows:

TR1: Cold conditions / No or marginal cropping: Class TR1 is assigned when the length of the temperature growing period ($LGP_{t=5}$) is less than 120 days or annual accumulated temperature sum ($TS_{t=5}$) is less than 1400 degree-days (dd).

TR2: Cool conditions / Single cropping: Class TR2 is used in areas where at least one of the following three conditions applies. (i) The temperature growing period ($LGP_{t=5}$) exceeds 120 days but is less than 240 days; (ii) Annual accumulated temperature sum $TS_{t=5}$ exceeds 1400 dd but is less than 4000 dd; or (iii) Annual accumulated temperature sum $TS_{t=10}$ is less than 3200 dd.

TR3: Moderately warm conditions / Potential double cropping: Three conditions are tested for the occurrence of class TR3. (i) Temperature growing period ($LGP_{t=5}$) exceeds 240 days but is less than 345 days; (ii) Annual accumulated temperature sum $TS_{t=5}$ exceeds 4000°days but is less than 6000°days; or (iii) Annual accumulated temperature sum $TS_{t=10}$ exceeds 3200°days but is less than 5500°days.

TR4: Warm conditions / Potential year-round cropping: The class of year-round cropping is defined as areas where the temperature growing period ($LGP_{t=5}$) exceeds 345 days, annual accumulated temperature sum $TS_{t=5}$ exceeds 6000°days, and annual accumulated temperature sum $TS_{t=10}$ exceeds 5500°days.

The spatial distribution of temperature regime classes TR1 to TR4, using average annual climate indicators calculated for the period 1981–2010, is shown in Figure 2.1a. Distributions of thermal regime classes will shift with climate change, from south to north and from lower to higher altitudes. Figure 2.1b provides ensemble mean results for projected climate of the period 2041–2070 under RCP 4.5. Figure 1.2c shows the results under rapid climate change as projected for the period 2071–2099s under RCP8.5.

The cold thermal regime class TR1 is considered not suitable for crop production. Average daily temperature is below 5°C for more than 8 months, which renders cropping impossible or very marginal. Agricultural use of TR1 outside permafrost zones is limited to pastures and occasionally cryophilic crops with very short duration cultivars adapted to germinate and grow at marginal soil temperatures, e.g., specific spring wheat and barley varieties and early white potato.

The cool thermal regime class TR2 occurs at higher altitudes. Zone TR2 cannot accommodate crops adapted to warm temperatures. Cultivation is mostly practiced with cryophilic crops, including wheat, barley, potatoes or rapeseed. TR2 imposes frost risks and therefore frost sensitive perennials, like citrus or olive, cannot be grown.

Thermal regime class TR3 occurs mainly in areas at altitudes below 1500m, but excluding the warm Southeastern and Southwestern regions of the country. Heat provision in TR3 is less than in TR4 and mean monthly temperature can be less than 5°C for up to 4 months. TR3 allows some crops adapted warmer temperatures to be grown, e.g., tobacco, sunflower, soybean and various vegetables. In the subtropical thermal climate some temperature seasonality occurs and where water is available thermal regime class TR3 can support sequential cropping of a winter/spring crop and a summer/autumn crop.

Thermal regime class TR4 occurs mainly in the Southeastern and Southwestern regions at altitudes generally below 1000m. There is no or only little frost risk for perennial crops, no hibernation for annual crops. Where irrigation and a reliable water supply are available, year-round cropping can be practiced and, depending on season, a wide range of crops can be grown in TR4 including thermophilic annual crops like cotton, tobacco, rice, soybean or groundnut (crop adaptability group C3-II); maize, sorghum, foxtail millet (crop adaptability group C4-II); and during the cooler season wheat, barley, white potato, bean, rapeseed and sunflower (crop adaptability group C3-I).

Temperature regime classes for current and future climate, Reference climate 1981–2010

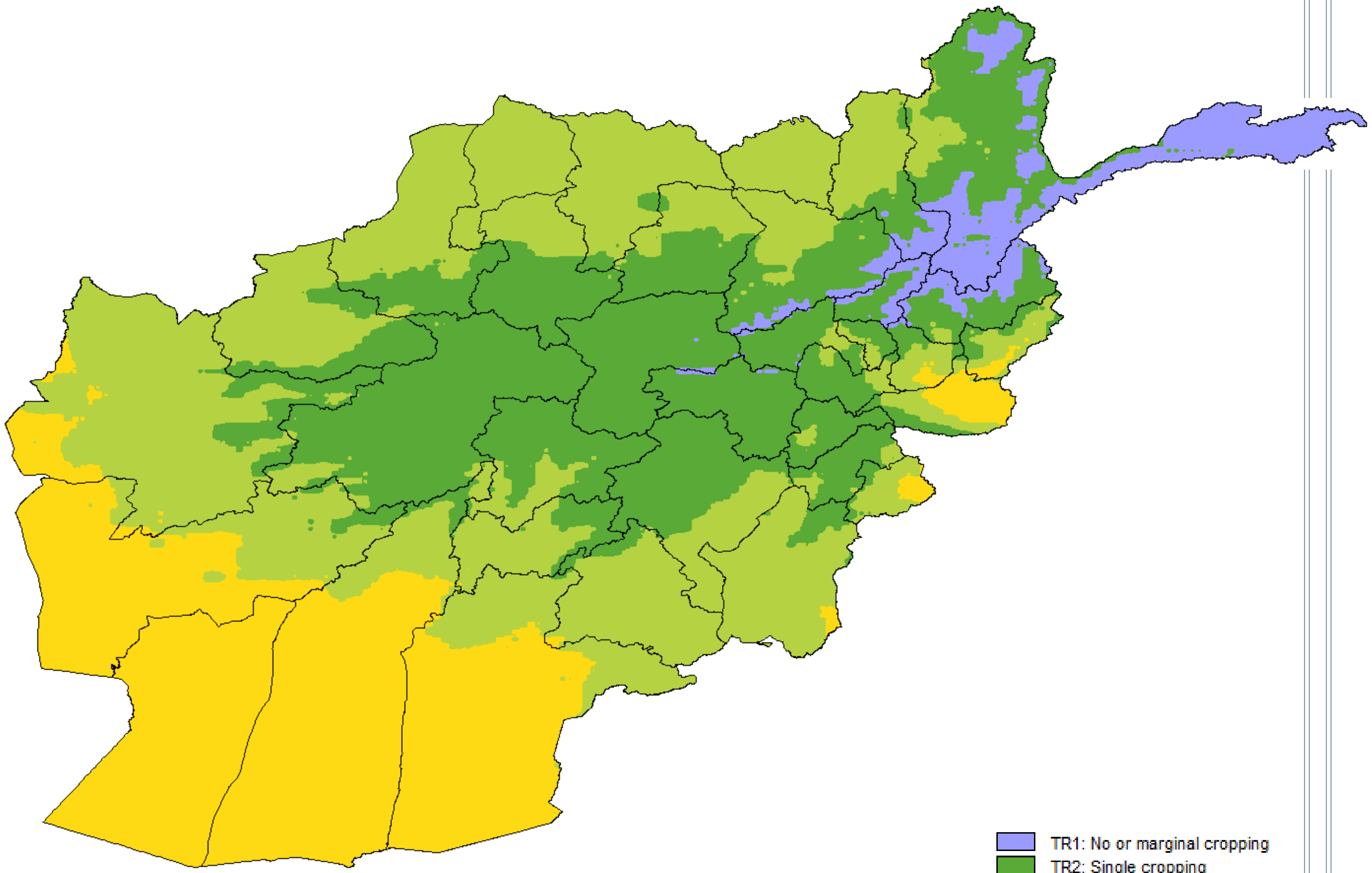


Figure 2.1a

Ensemble mean, RCP8.5, 2041–2070–2099

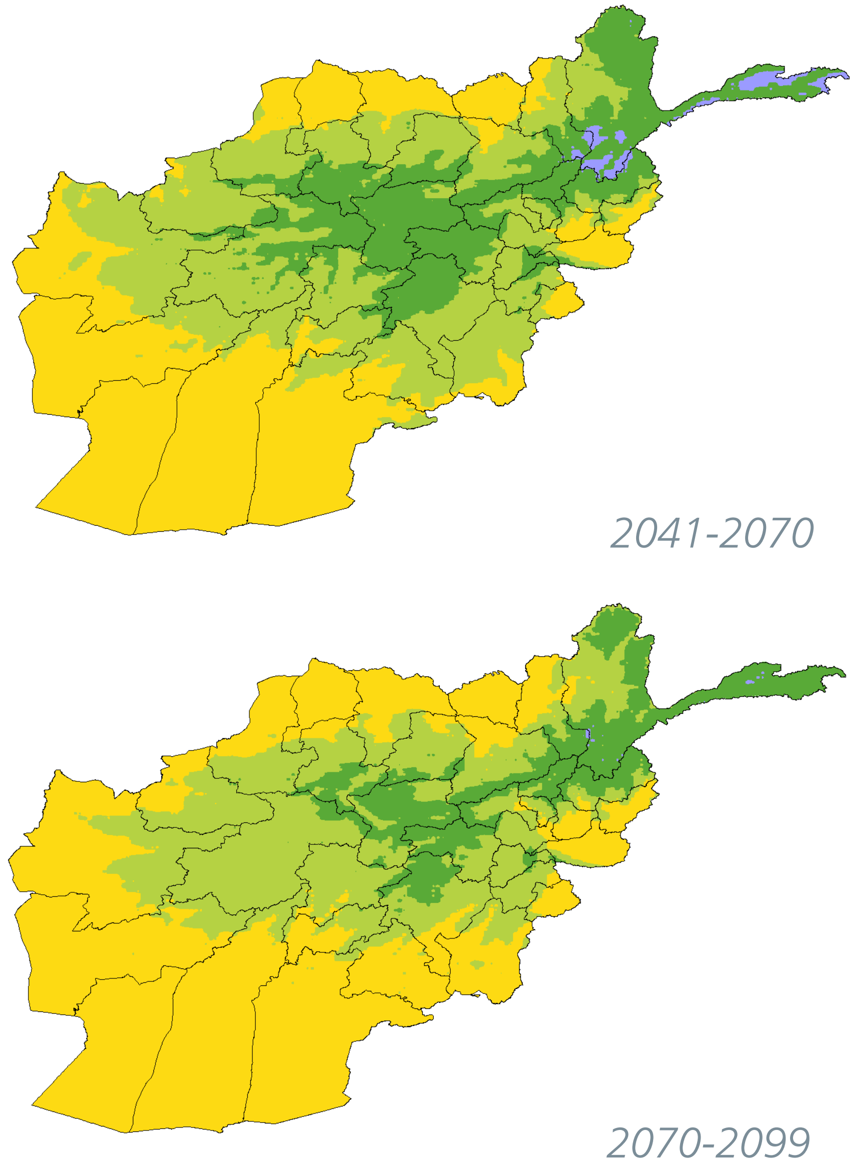


Figure 2.1b, 2.1c

Besides the prevailing temperature regime, annual precipitation – both its total amount and distribution within the year – is of critical importance for plant growth in general and in particular for the cultivation of rain-fed crops. The climate of Afghanistan is characterized by a pronounced seasonality of precipitation (FAO & IIASA, 2019).

A major share of annual precipitation in Afghanistan falls in winter and early spring, whereas the summer and early autumn are dry and hot, notably in the north-western, western and south-western regions. By implication, where rain-fed crop cultivation is possible at the generally low precipitation, cropping needs to occur in winter and spring, e.g., cultivating a suitable winter or spring type such as wheat and barley or other cryophilic crops. Cropping in summer or cultivation of perennial crops largely depend on the availability of water for irrigation.

2.3 Moisture regime classes

The delineation of five moisture regime classes makes use of the NAEZ agro-climatic inventory and applies results of the NAEZ daily reference water balance to define broad moisture regime classes as follows:

M1: delineates desert/arid areas where 0 ≤ LGP* < 50 days

M2: is used for dry semi-arid areas with 50 ≤ LGP* < 70 days

M3: represents semi-arid areas with 70 ≤ LGP* < 90 days

M4: denotes semi-arid areas where 90 ≤ LGP* < 120 days, and

M5: indicates moist semi-arid or sub-humid areas with LGP* > 120 days.

Moisture regime classes M1 to M5 are based on the growing period indicator LGP* using agro-climatic indicators presented in Part 1 of this Atlas (FAO & IIASA, 2019). For areas with temperature growing period $LGP_{t=5}$ > 300 days the indicator LGP* is set to the total number of annual growing period days (LGP). When $LGP_{t=5}$ < 300 days, i.e., areas with seasonal temperature limitations, the LGP* indicator is set as the maximum of LGP days and a function of the annual precipitation over potential evapotranspiration (P/ET0) ratio. This function results in 60 days for a ratio P/ET0 ~ 0.15, in 90 days for P/ET0 ~ 0.275, 120 days for P/ET0 ~ 0.40 and 180 days for P/ET0 ~ 0.65.

Moisture regime classes for current and future climate are presented in Figure 2.2.

Figure 2.1 and Figure 2.2 illustrate the projected impacts of climate change on respectively temperature regime and moisture regime classes. For temperature regime classes the implication is that the cold and cool classes TR1 and TR2 will shrink substantially with climate change and will be found in the future only at high and very high altitudes. Class TR4, with temperature conditions allowing year-round cropping, will expand from current areas, mainly in the Southwestern region, into large parts of Western and Northwestern region.

The impact of warming, combined with relatively little changes in annual precipitation, will result in the expansion of the arid and dry semi-arid moisture regime classes M1 and M2, and will cause a reduction of extents in class M3. Overall this signals a gradual worsening of the annual soil water balance with the implication that in large parts of Afghanistan irrigation will become increasingly important for successful cropping.

Moisture regime classes for current and future climate Reference climate 1981–2010

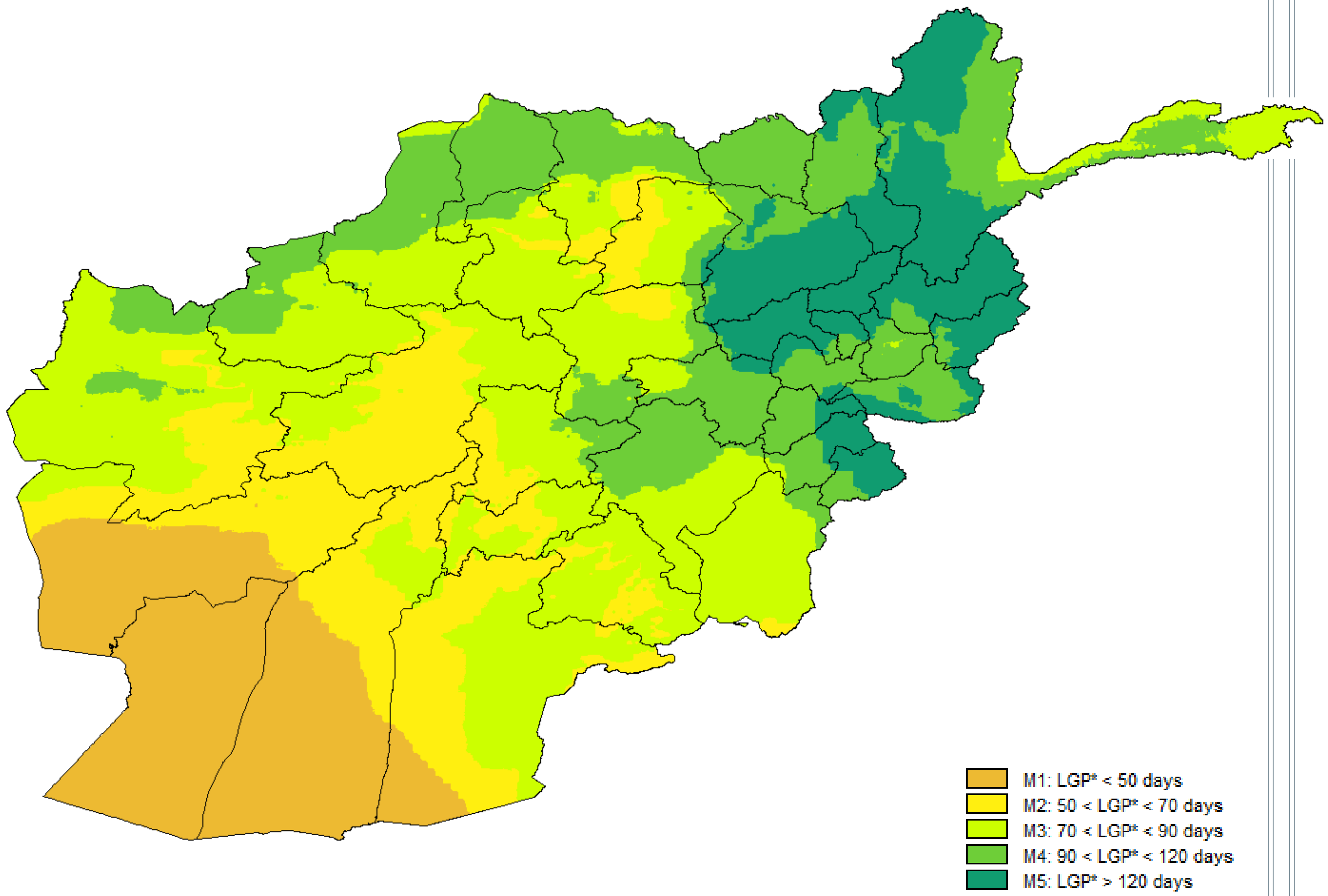


Figure 2.2a

Ensemble mean, RCP8.5, 2041–2070–2099

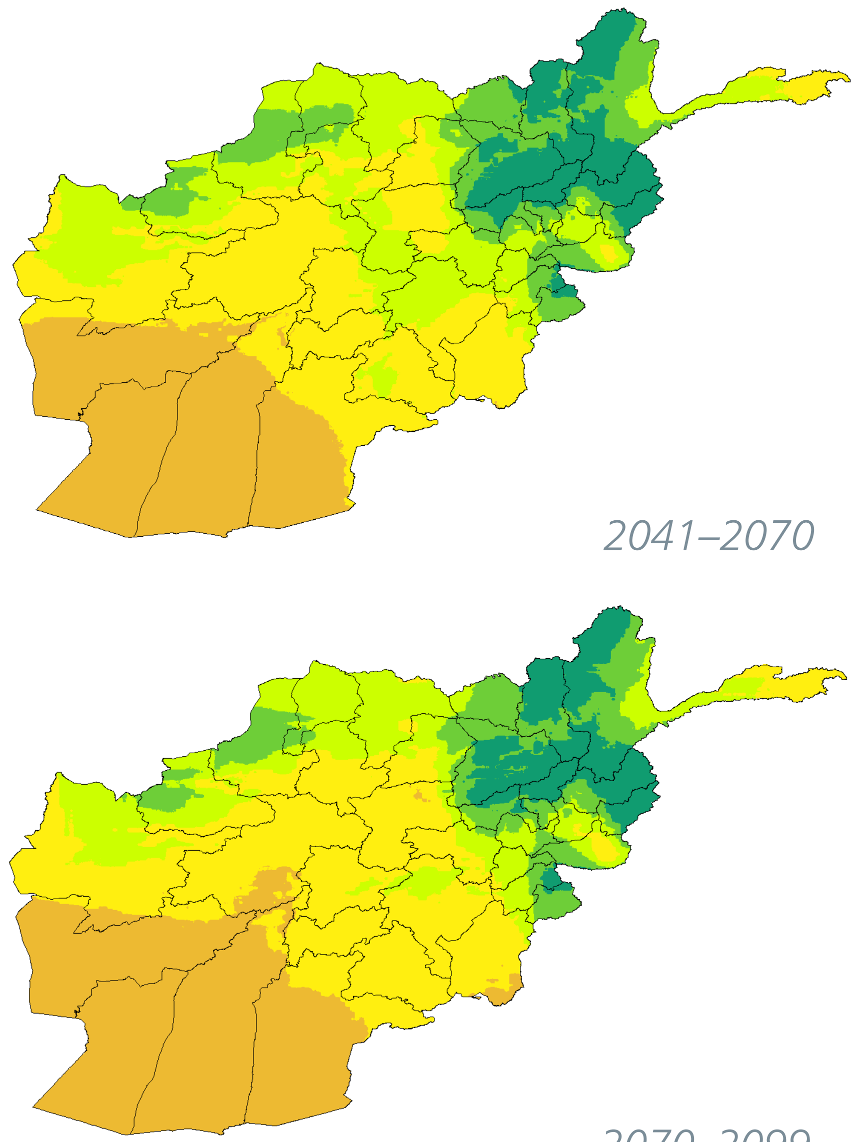


Figure 2.2b. 2.2c

2.4 AEZ classes related to soil/ terrain and special purpose land cover

The delineation of agro-ecological zones in NAEZ-Afghanistan distinguishes four classes related to soil quality and terrain conditions. The mapping of classes uses the soil/terrain inventory, i.e., the soil attribute data from the soil database AFGHSD v1 and a terrain slope distribution inventory by 1 arc-second grid cells, which was derived from original 1 arc-second SRTM data (i.e., about 30 m). The following soil/terrain related classes are distinguished:

ST1: represents very steep terrain where the sum of percentages of slope classes SLP7 (30-45%) and SLP8 (slope > 45%) exceeds in a grid cell a given target threshold (e.g., 95%),

ST2: comprises grid cells with no or slight soil/terrain limitations,

ST3: indicates areas with moderate soil/terrain constraints, and

ST4: denotes areas with severe and very severe soil/terrain limitations. It also includes non-soil miscellaneous units of the soil database (e.g., rock outcrops, sand dunes, glaciers, etc.).

Soil/terrain limitations and special purpose land cover classes used for AEZ delineation

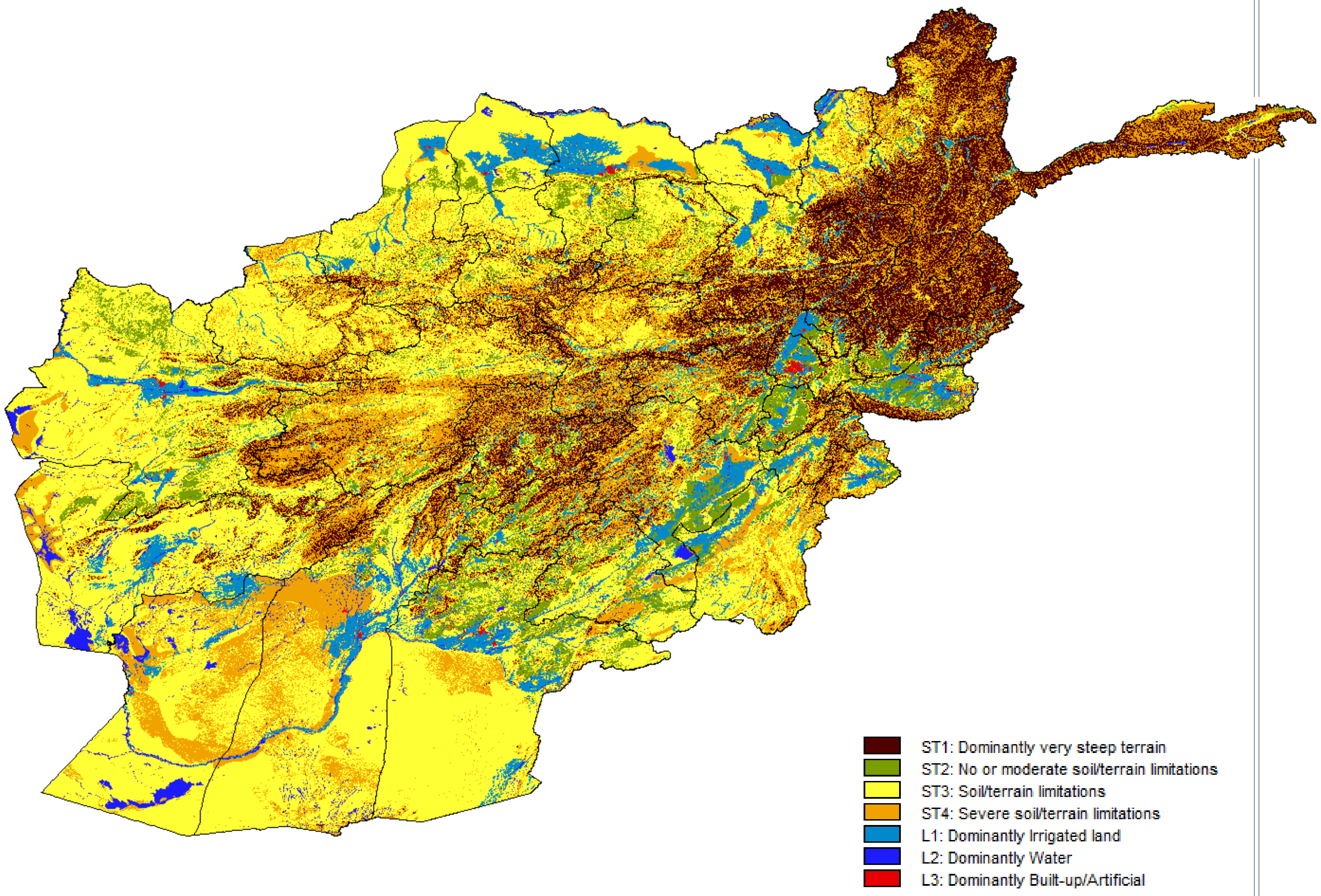


Figure 2.3

Further, NAEZ-Afghanistan distinguishes three land cover classes, L1–L3 listed below, related to selected (special purpose) elements of the LCDA 2010 land cover database (FAO, 2016):

L1: denotes dominantly irrigated areas where the share of irrigated cropland in a grid cell exceeds a specified minimum threshold (e.g., 25% of a 7.5 arc-second grid cell),

L2: relates to the dominance of inland water bodies in a grid cell, i.e., where the respective land cover share for water bodies exceeds a specified threshold (e.g., 50% of a 7.5 arc-second grid cell), and

L3: relates to areas where built-up/artificial surfaces dominate.

For constructing AEZs, the three special purpose land cover classes L1 to L3 were combined with soil/terrain related classes ST1 to ST4 as shown in Figure 2.3:

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Table 2.1 AEZ classes in NAEZ-Afghanistan

AEZ	Acronym	Description
01	TR1	Combinations of TR1 (cold/no or marginal cropping) with M1-M5 and ST2-ST4
02	TR2-IR	Combinations of TR2 (single cropping) with L1 and any of M1-M5 and ST1-ST4
03	TR2-MST2	Combinations of TR2 (single cropping) with M3 and ST2-ST3
04	TR2-MST3	Combinations of TR2 (single cropping) with M4-M5 and ST2-ST3
05	TR2-MST4	Combinations of TR2 (single cropping) with M4-M5 and ST2-ST3
06	TR3-IR	Combinations of TR3 (double cropping) with L1 and any of M1-M5 and ST1-ST4
07	TR3-MST2	Combinations of TR3 (double cropping) with M2 and ST2-ST3
08	TR3-MST3	Combinations of TR3 (double cropping) with M3 and ST2-ST3
09	TR3-MST4	Combinations of TR3 (double cropping) with M4-M5 and ST2-ST3
10	TR4-IR	Combinations of TR4 (year-round cropping) with L1, any of M1-M5 and ST1-ST4
11	TR4-MST2	Combinations of TR4 (year-round cropping) with M2 and ST2-ST3
12	TR4-MST3	Combinations of TR4 (year-round cropping) with M3 and ST2-ST3
13	TR4-MST4	Combinations of TR4 (year-round cropping) with M4-M5 and ST2-ST3
14	MST1	Desert/Arid climate class; areas with moisture regime class M1, except for special purpose land cover classes L1, L2, L3, and soil/terrain classes ST1 and ST4
15	STEEP	Dominantly very steep terrain; grid-cells where soil/terrain related class ST1 occurs
16	POOR SOIL	Land with dominantly severe soil/terrain limitations; all areas of soil/terrain class ST4 except where set to classes 01, 02, 06, 10, 15, 17 or 18
17	WATER	Dominantly inland water; is set in grid cells where L2 occurs
18	URBAN	Dominantly built-up/artificial surface; is set in grid cells where L3 occurs

2.5 Agro-ecological zones classes in NAEZ Afghanistan

The temperature regime classes TR1-TR4, moisture regime classes M1-M5, soil/terrain related classes ST1-ST4, and special purpose land cover classes L1-L3, represent the different dimensions used for AEZ classification in NAEZ-Afghanistan. These were combined step by step, following a priority scheme, to form 18 unique AEZ classes, listed in Table 2.1.

Of the 18 AEZ classes, class AEZ-01 and AEZ-14 are climatically not or only very marginally suitable for cropping. Classes AEZ-15 to AEZ-18 are severely limited for agricultural use due to soil/terrain constraints or because of water bodies and urban land use.

AEZs compiled for baseline climate conditions during 1981–2010 (see Table 2.2) show the largest extents for the classes 'Dominantly severe soil/terrain limitation' (22.5%, AEZ-16) and 'Dominantly very steep terrain' (15%, AEZ-15).

In total, land with severe constraints (i.e., the classes with very steep terrain (AEZ-15), poor soils (AEZ-16), very cold climate (AEZ-01), or desert/arid conditions (AEZ-14)) accounts for slightly more than 50% of the territory of Afghanistan. The share of severely limited land is largest in the Northeastern and Eastern regions (more than 70%) and with about 24% is lowest in the Northwestern region.

Land with thermal conditions for year-round cropping (TR4) and without severe moisture/soil/terrain constraints (AEZ-10 to AEZ-13) account for 9% of the territory. These areas are mainly located in the Southwestern, Western and Eastern region.

Table 2.2 Distribution of total land by AEZ classes

Agro-ecological zones class	DISTRIBUTION OF TOTAL LAND BY AEZ CLASS (%) AND REGION*								
	AFG	NE	NW	EA	CE	WC	WE	SE	SW
01 Cold / No or marginal cropping	2.2	14.6	0.0	5.7	3.5	0.2	0.0	0.0	0.0
02 Single cropping / Dominantly irrigated	1.3	1.1	0.7	0.4	8.4	4.2	0.7	2.3	0.2
03 Single cropping / Dry semi-arid	2.0	0.0	2.1	0.0	0.0	2.1	5.9	0.0	0.3
04 Single cropping / Semi-arid	4.2	0.1	11.4	0.0	1.5	10.7	6.5	2.0	0.4
05 Single cropping / Moist semi-arid	2.9	5.1	1.3	1.2	23.6	7.0	0.0	7.3	0.0
06 Double cropping / Dominantly irrigated	3.7	4.3	8.8	3.0	3.1	4.5	2.1	8.8	1.7
07 Double cropping / Dry semi-arid	4.6	0.0	4.6	0.0	0.0	1.8	8.2	0.7	6.5
08 Double cropping / Semi-arid	11.2	0.0	17.3	0.0	0.0	8.4	17.3	33.9	9.1
09 Double cropping / Moist semi-arid	8.0	17.1	29.6	9.6	4.1	0.0	6.1	3.8	0.0
10 Year-round cropping / Dominantly irrigated	2.0	0.0	0.0	4.5	0.0	0.0	1.9	1.0	4.5
11 Year-round cropping / Dry semi-arid	3.4	0.0	0.0	0.0	0.0	0.0	2.5	0.0	9.5
12 Year-round cropping / Semi-arid	3.2	0.0	0.0	0.0	0.0	0.0	3.4	0.9	7.9
13 Year-round cropping / Moist semi-arid	0.5	0.0	0.0	9.7	0.0	0.0	0.0	1.8	0.0
14 Desert / Arid climate	11.9	0.0	0.0	0.0	0.0	0.0	11.9	0.0	31.2
15 Dominantly very steep terrain	15.0	40.2	7.5	47.8	30.9	24.4	8.9	7.4	3.7
16 Dominantly severe soil/terrain limitations	22.5	16.9	15.9	17.3	24.1	36.0	22.7	29.7	22.7
17 Dominantly water	1.3	0.5	0.5	0.5	0.1	0.8	1.8	0.4	2.1
18 Dominantly urban/built-up land	0.2	0.1	0.3	0.2	0.7	0.1	0.1	0.1	0.1
Total land area (1000 ha)+	64 159	8 053	7 715	2 501	3 017	5 572	16 048	2 842	18 321
Total land (% of total)	100	12.6	12.0	3.9	4.8	8.7	25.0	4.4	28.6

* NE: Northeastern; NW=Northwestern; E=Eastern; C=Central; WC=West Central; W=Western; SE=Southeastern; SW=Southwestern

+ Land extents were calculated using the NAEZ-Afghanistan gridded spatial inventory of land resources.

2.6 Changes of agro-ecological zones due to climate change

The spatial distribution of AEZ classes, using climate conditions of the historical reference period 1981–2010 and for future climate (ensemble mean of RCP 8.5 in 2050s and 2080s) is presented in Figure 2.4. Cold and cool zones are shown in blue colors, areas with severe soil/terrain limitations or dominantly steep slopes are mapped in grey colors, classes of dominantly irrigated land use purple colors, and arid areas are shown in a light-yellow color.

With climate change, the occurrence of AEZ classes will shift due to increasing heat provision, alterations in precipitation patterns, higher crop water requirements, and resulting changes in soil moisture conditions. Note, all classification factors related to soil/terrain limitations and special purpose land cover classes were kept fixed at base period levels.

Agro-ecological zones classes for current and future climate Reference climate 1981–2010

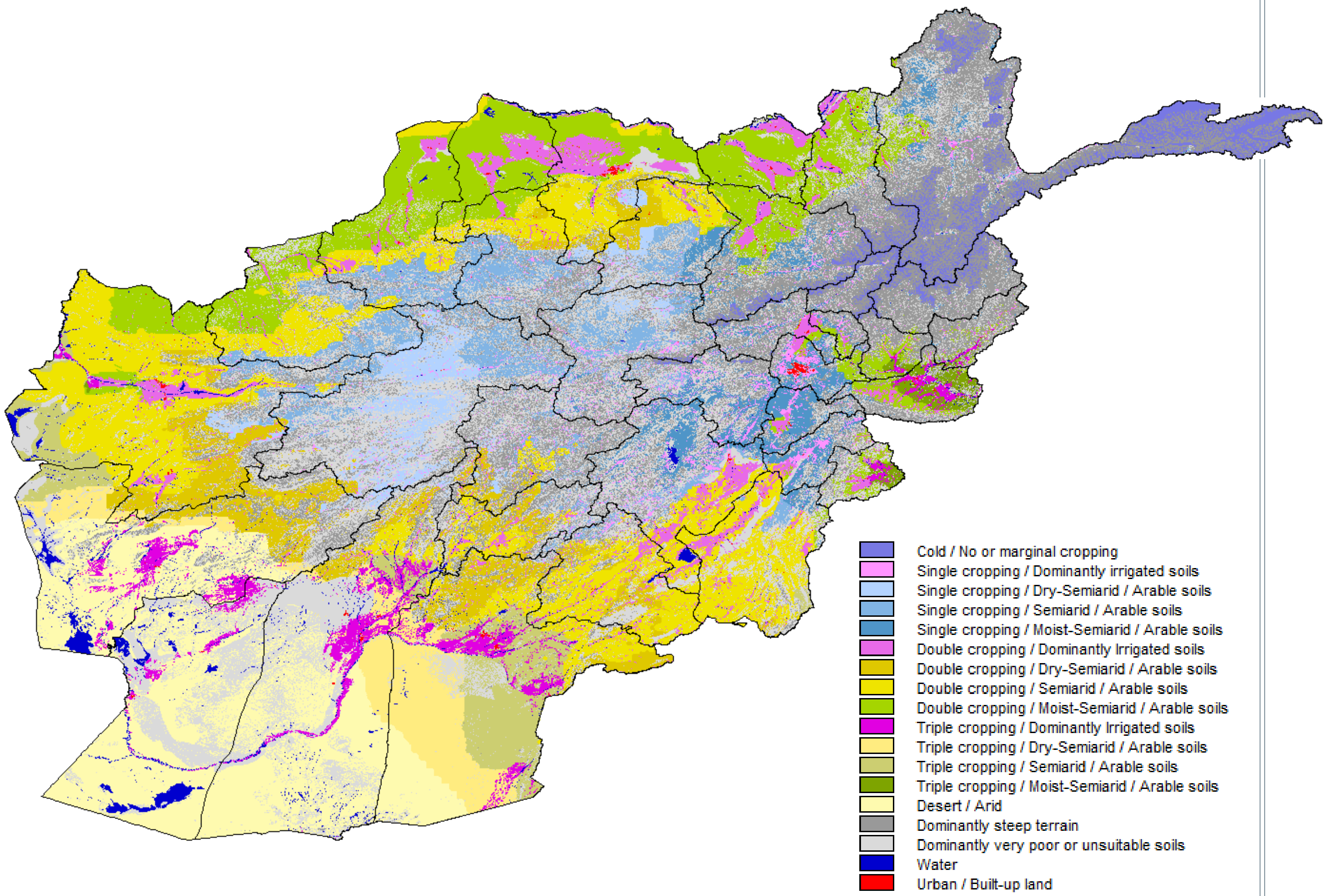
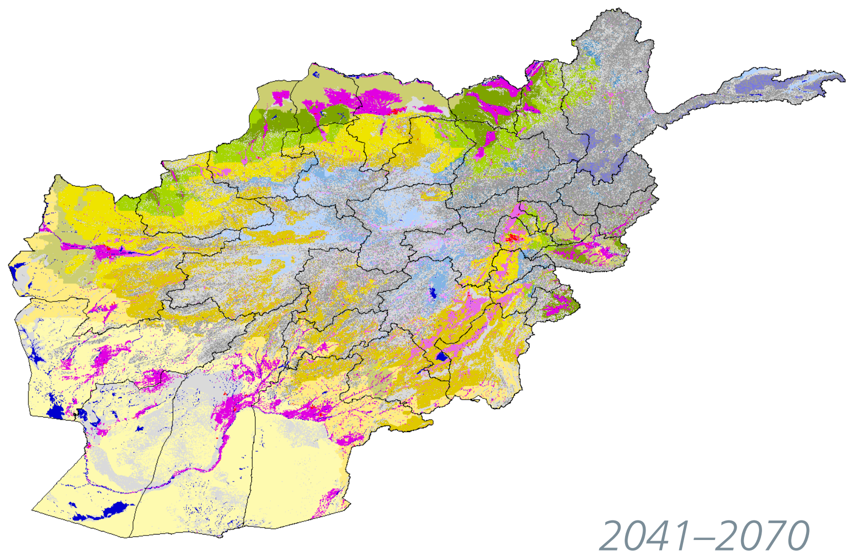
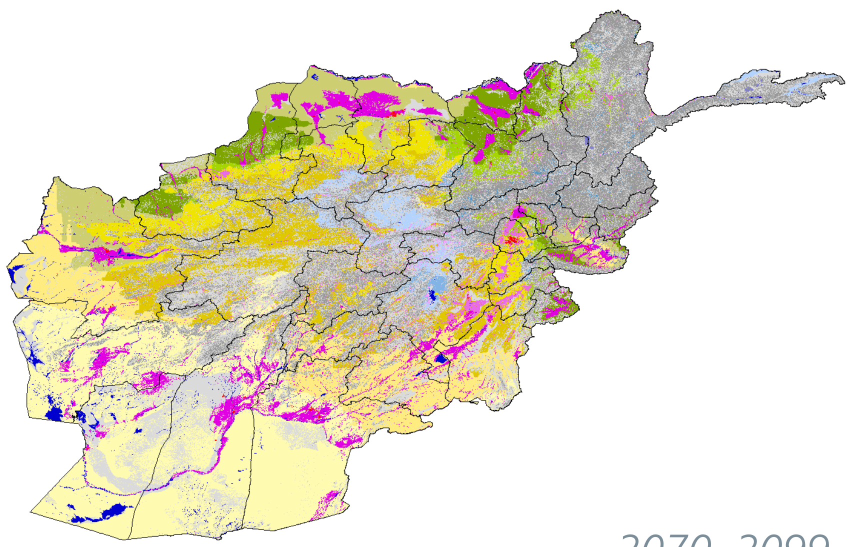


Figure 2.4a

Ensemble mean, RCP8.5, 2041–2070–2099



2041–2070



2070–2099

Figure 2.4b, 2.4c

Climate change results in higher seasonal and annual temperatures everywhere in Afghanistan. Precipitation changes are somewhat less uniform. They tend to result in decreasing annual levels or at best remaining at historical levels. The impact of these changes on a farmer's field can range from very negative to positive depending on the climate point of departure, i.e., altitude, prevailing temperature and rainfall in the historical period, the availability or possible development of reliable irrigation, as well as soil and terrain conditions.

The transition dynamics among AEZ classes suggest that potential multi-cropping opportunities in irrigated areas will be enhanced provided irrigation water is available in sufficient volumes at the times when needed. For instance, the share of potential year-round cropping on irrigated land will increase from an estimated 14% of current irrigated land to more than 20% by 2041–2070 and under rapid climate change up to 35% by 2071–2099

Warming is seen as an opportunity especially in the Northeastern, Central and West-Central regions where cold and cool temperatures have been limiting the number of days in a year suitable for cropping. In contrast, in low-lying southern parts of the country high growing period temperatures in the future may negatively affect the crop production potential, even under irrigation conditions.

Soil moisture conditions throughout the year, the second pillar of crop cultivation, will be negatively affected by climate change in most regions, including the large Northwestern and Western regions where 60-70% of the cropland is cultivated with rain-fed practices. Rising temperatures and stable or declining precipitation will cause a growing water deficit of 'green' water in the annual soil water balance. It also implies reduced runoff and negative impacts on water resources. However, note that water resources have not been analyzed with the current NAEZ-Afghanistan system and databases.

Warming will shorten or eliminate the dormancy period in winter (taken to be the period when average daily temperature is below 5°C). This will alter the crop calendar of winter and spring crops and can reduce irrigation requirements by shifting the crop growth cycle to the part of the year when better soil moisture conditions prevail, as is typically the case in winter rainfall areas. In contrast, the irrigation demand of summer crops and perennial crops is likely to increase.

The analysis of AEZ classes gives a robust understanding of key agronomic trends evolving with climate change. Nevertheless, impacts of climate change on individual crops can vary widely depending on their specific temperature requirements and tolerances, the flexibility of adjusting crop calendars, the length of crop growth cycles, and the crop water source, i.e., rain-fed or irrigated cultivation.

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3. Impacts of climate change on the suitability of crops

3.1 Introduction

The quality and availability of land and water resources, together with socio-economic conditions and institutional factors, are essential to assure sustainable food security. In order to optimize the wise use of the land and water resources it is important to determine their agronomic potential. The crop cultivation potential describes the agronomically possible upper limit to produce different crops under given agro-climatic, soil and terrain conditions for specific levels of agricultural inputs and management conditions.

The suitability of land for the cultivation of a given crop/LUT depends on specific crop requirements as compared to the prevailing agro-climatic and agro-edaphic conditions at a location. AEZ combines these two components systematically by successively modifying grid-cell specific agro-climatic potential yields according to assessed soil limitations and terrain constraints.

Calculation procedures for establishing crop suitability estimates include five main steps of data processing, namely:

(i) Climate data analysis and compilation of general agro-climatic indicators for historical, baseline and future climates;

(ii) Crop-specific agro-climatic assessment and water-limited biomass/yield calculation;

(iii) Yield-reductions due to the impacts of agro-climatic risks and constraints of workability, pests and diseases;

(iv) Crop specific edaphic assessment and yield reductions due to soil and terrain limitations, and

(v) Integration of results from steps (i) to (iv) into crop-specific grid-cell databases. These are used to map by time period the agro-ecological suitability, attainable yields and potential production, and to compile detailed crop summary tables by districts, provinces and major regions.

Table 3.1 Selected cropland indicators from GIS and statistical sources

Cropland Indicator (1000 ha)	LCDA 2010	FAOSTAT 2009-11	FAOSTAT 2014-16
Cropland, of which:	7 535	7 910	7 910
Rain-fed cropland	3 734		
Irrigated land, of which:	3 800	3 208	3 208
Intensive cultivation	2 237		
Active Karez system	254		
Orchards & Vineyards	200		
Poorly irrigated	1 110		
Irrigated land (excl. Poorly irrigated class)	2 691		
Cultivated rain-fed land		1 536	1 309
Area actually irrigated		1 925	2 266
Land under crops, of which		3 462	3 575
Land under temporary crops		3 344	3 420
Land under permanent crops		118	155
Land with temporary fallow		4 449	4 335
Total harvested area		3 458	3 557

Source: LCDA 2010; FAOSTAT (download on 5 May 2021 from http://www.fao.org/faostat/en/#data/RL)

For the current study of Afghanistan, agro-ecological suitability and production potential has been assessed for 9 cereals (barley, buckwheat, maize, millet, oat, paddy rice, rye, sorghum and wheat), 2 tuber crops (potato and sweet potato), 2 sugar crops (sugarcane and sugar beet), 2 pulses (chickpea and gram), 5 oilseeds (groundnut, mustard, rapeseed, sesame, soybean and sunflower), 1 spice crop (cumin), 2 industrial crops (cotton and flax), 3 vegetables (cabbage, onion and tomato), 2 fodder crops (alfalfa and silage maize), and 2 perennial crops (citrus and olive).

Crops were assessed for intermediate inputs/management assumptions, for rain-fed and irrigated production on current cropland. The land was evaluated in terms of area extents of prime, good, moderate and marginal quality for baseline climate (1981–2010) and climate scenario ensemble means compiled from simulations using outputs of five Earth system models and pertaining to different representative concentration pathways.

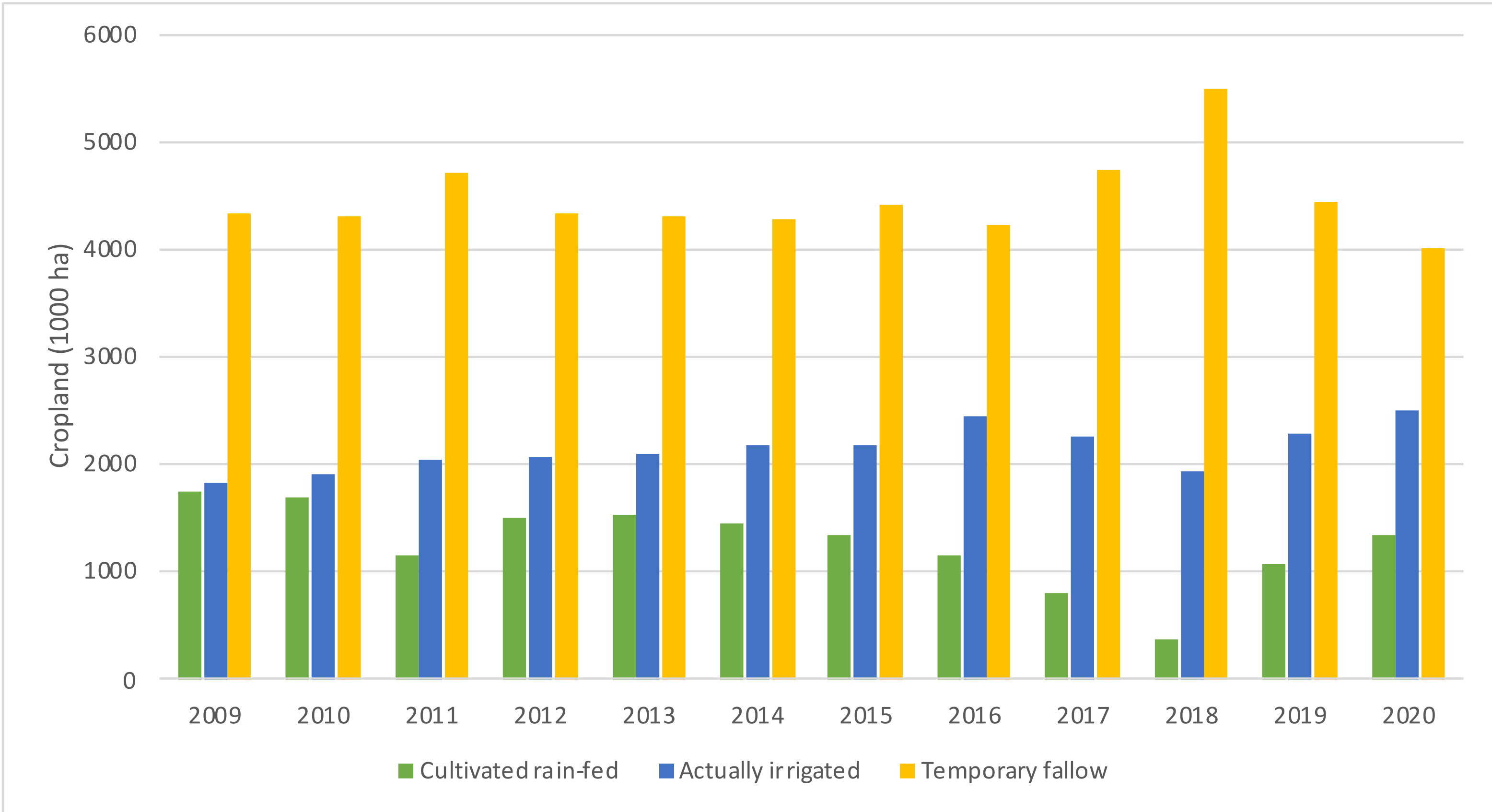
Impacts of climate change on crop suitability and yields vary between C3 and C4 crops[1] , between annual crops and perennials, and between individual crop-specific tolerances for high temperatures and moisture stress as well as climate related agro-climatic constraints. C3 crops are generally less heat tolerant than C4 crops but can benefit substantially more from CO_2 fertilization. Perennial crops (and grasses) are dependent on favorable temperature and rainfall distributions (or irrigation) throughout the year. This is in contrast to annual crops, which may allow crop calendar shifts and cultivar changes to optimize growth cycle temperature and soil moisture conditions.

Before presenting current and future crop specific results obtained in simulations with the NAEZ-Afghanistan system, it is important to summarize some aspects of current agricultural land use in Afghanistan. Table 3.1 lists selected cropland indicators compiled from the Land Cover Atlas of the Islamic Republic of Afghanistan (LCDA 2010), the GIS land cover data source used in the NAEZ assessment, and data extracted from the UN FAO statistical database FAOSTAT.

Total cropland use derived from LCDA 2010, including perennial fruit trees and vineyards, obtained by summing up the cropland shares of individual grid cells in the raster database, amounts to 7.5 million hectares. The extent of cropland reported in FAOSTAT is 7.9 million hectares (Official data reported on FAO Questionnaires from countries). This is more than twice the total harvested area of 3.6 million hectares reported for 2014–16 in FAOSTAT and in the national statistical sources. The Afghanistan Statistical Yearbook and FAOSTAT list for this period 'land with temporary fallow' amounting to

[1] The difference between C3 and C4 plants relates to the process that plants use to turn light, carbon dioxide, and water into sugars that fuel plant growth, using the primary photosynthetic enzyme Rubisco. In C3 plants the first carbon compound produced in photosynthesis contains three carbon atoms; in C4 plants the CO2 is first fixed into a compound containing four carbon atoms. C4 plants have substantially higher rates of CO2 exchange, which is reflected in higher biomass and yield production capacities as compared to C3 plants

Cropland use in 2009–2018



Source: Afghanistan Statistical Yearbook, various years.

Figure 3.1

4.3 million hectares, i.e., in any particular year a very substantial fraction of the cropland base is not used for cropping. Actually cultivated rain-fed cropland is reported to be on average 1.3 million hectares in 2014–2016 compared to 3.7 million hectares classified as rain-fed cropland in LCDA 2010.

Figure 3.1 shows very substantial fluctuations of land under rain-fed cultivation, mainly caused by recurrent drought conditions, e.g., such as in 2017 and 2018. The reported rain-fed cropland use varied during 2009-2020 between as little as 0.4 million hectares (in 2018) and as much as 1.7 million hectares (in 2009 and 2010). This is mirrored by temporary fallow cropland ranging during the last decade between 5.5 million hectares (in 2018) and 4.0 million hectares (in 2020).

LCDA 2010 records land classified as irrigated cropland, orchards and vineyards of 3.8 million hectares of which 1.1 million is termed 'Poorly irrigated/Inactive Karez system'. FAOSTAT puts total land equipped for irrigation at 3.2 million hectares. However, the area actually irrigated in 2014–16 is reported in FAOSTAT as 2.3 million hectares.

In the last decades, cereal crops have been accounting for about 85% of all reported harvested area in Afghanistan (see Table 3.2). By far the most important staple crop has been wheat, contributing two-thirds of annual harvested areas. Other significant cereals include barley, rice and maize.

While cereal cultivation is important in all regions, contributing about 70-90% of a region's harvested areas, there are some variations of cereal crop shares across regions (see Table 3.3). Cereal harvested area accounts for 90% of reported total harvested area in two regions (Northeastern and Southeastern region). The lowest shares, below 80% of total harvested area, are found in Central and Southwestern regions where fruits and nuts are widely cultivated, contributing respectively 14% and 13% of cropped area.

In the following sections the results of simulations with projected future climate are summarized for selected major crops, which were chosen in view of their importance according to the statistical data, the projected climatic trends, and emerging adaptation needs and opportunities. Differences in crop requirements and suitability, and the large heterogeneity of land resources, from Northeastern to Southwestern region, create differences in climate change impacts, which will depend on location (latitude and altitude), crop type and crop calendar (winter crops, summer crops, perennial crops), and critically on water source for cropping (rain-fed or irrigated). Suitability and productivity results are presented for selected crops currently grown, namely Wheat, Barley, Maize, Paddy Rice, Cotton, White Potato, and Citrus. The chapter closes with an assessment of climate change impacts on rangeland production.

Table 3.2 Cultivated area, production and yield of major crops in Afghanistan

Crop Indicator	1999-2001			2009-2011			2014-2016		
	1000 ha	1000 tons	kg/ha	1000 ha	1000 tons	kg/ha	1000 ha	1000 tons	kg/ha
Wheat	1 945	1 855	954	2 387	4 328	1 813	2 361	4 866	2 061
Barley	130	126	964	223	410	1 837	281	409	1 453
Rice, paddy	130	261	2 000	206	663	3 218	168	435	2 592
Maize	112	172	1 533	169	300	1 781	142	315	2 214
Pulses	46	47	1 019	69	57	828	112	83	745
Oilseeds	116	108	933	63	58	921	95	82	865
Vegetables	70	538	7 707	86	609	7 087	107	964	9 016
Melons	15	166	10 790	56	577	10 270	90	858	9 515
Fruits & Nuts	111	729	6 571	134	865	6 919	158	1 236	7 814
Other crops	34	-	-	29	-	-	34	-	-
Total cultivated	2 710	4 065	1 500	3 412	8 011	2 348	3 548	9 325	2 628

Source: Afghanistan Statistical Yearbook, various years; FAOSTAT (at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021.

Table 3.3 Harvested area share of major crops in 2014-16, by region

Crops	CULTIVATED AREA BY REGION (% of total harvested area in region)*								
	AFG	NE	NW	EA	CE	WC	WE	SE	SW
Wheat	66.5	68.7	70.3	47.9	54.8	69.9	73.1	71.4	60.8
Barley	7.9	6.9	10.7	2.5	3.3	5.2	7.5	13.5	10.4
Rice, paddy	4.7	13.2	0.5	13.6	0.1	0.4	1.9	2.6	0.0
Maize	4.0	0.8	1.6	22.8	10.3	3.3	1.2	3.3	5.3
Pulses	3.1	1.8	3.7	0.2	4.1	7.6	4.3	2.6	2.2
Oilseeds	2.8	3.2	5.5	2.8	0.4	0.2	0.4	0.2	2.6
Vegetables	3.0	1.8	1.7	4.9	10.4	6.4	2.5	2.8	1.4
Melons	2.5	2.4	2.8	0.5	0.0	0.0	5.5	0.2	3.8
Fruits & Nuts	4.5	0.8	2.8	2.4	14.1	6.0	2.7	2.1	12.6
Other crops	0.9	0.5	0.4	2.4	2.7	0.9	0.9	1.4	0.7
TOTAL crops (1000 ha)	3 548	888	895	235	260	252	462	134	422

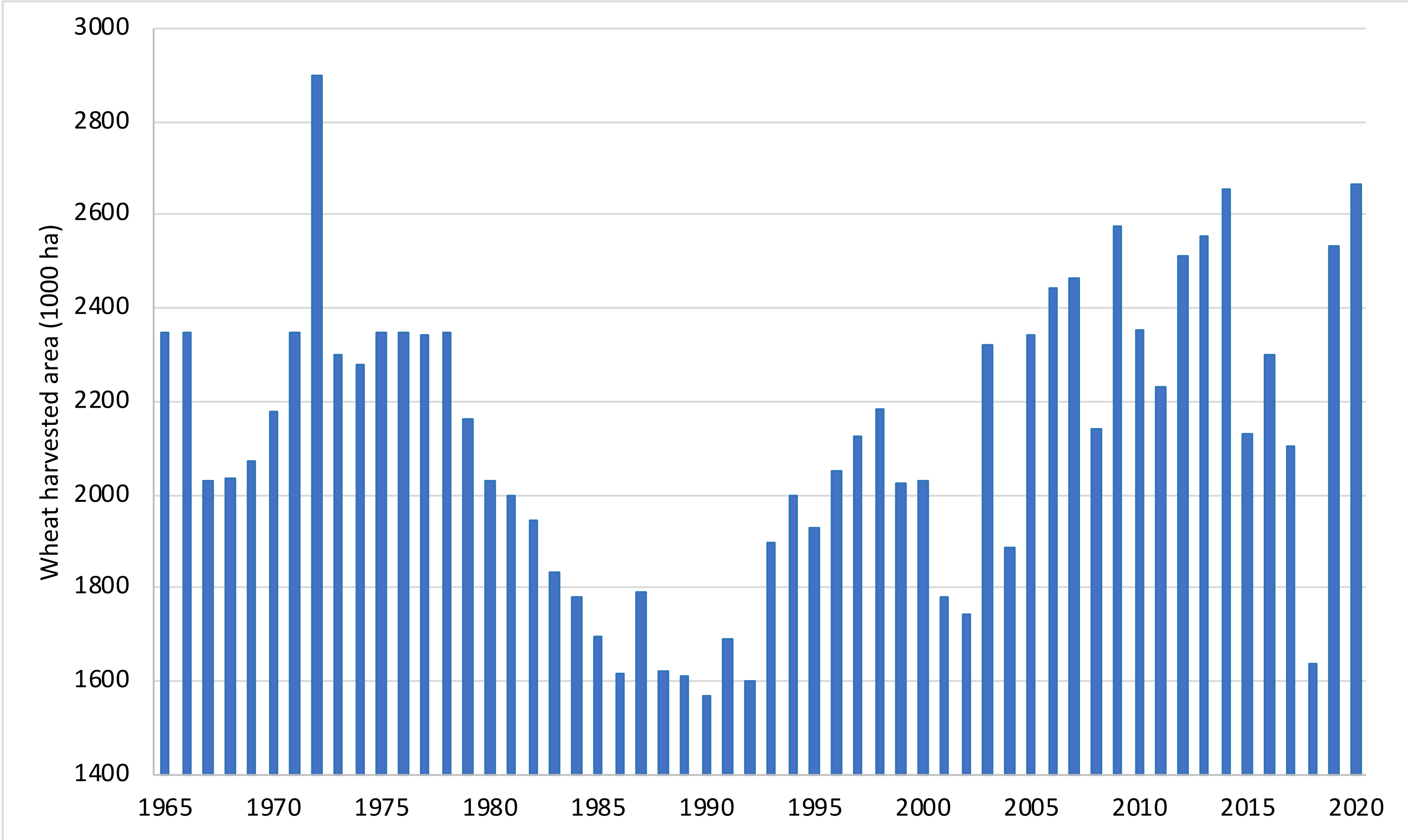
* NE: Northeastern; NW=Northwestern; E=Eastern; C=Central; WC=West Central; W=Western; SE=Southeastern; SW=Southwestern
Source: Afghanistan Statistical Yearbook 2016-17 (MAIL data by province for 2007 to 2017 provided by FAO-Afghanistan); FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021.

3.2 Climate change impacts on wheat suitability and production

Wheat is the most important annual crop in Afghanistan. According to the data reported in FAOSTAT, wheat harvested area reached a peak in 1972 at 2.9 million hectares. The 1980s, marked by the Russian intervention in Afghanistan, saw a steady decline of reported harvested areas to about 1.6 million hectares. Since then, wheat areas have again been increasing somewhat, to an average of 2.4 million hectares both in 2009–11 and in 2014–16. However, wheat area and production have been varying widely over the years. Wheat production during the last decades reached a highest level of nearly 5.4 million tons in 2014 as well as a lowest level of only 1.5 million tons in 2000. The recent drought in 2018 resulted in a wheat harvest of 3.6 million tons. The 3-year average for 2009–11 was 4.3 million tons and in 2014–16 amounted to 4.9 million tons. It is worth noting that wheat occupies about ten times more cropland in Afghanistan than any other crop.

Table 3.4 presents suitability and potential production of Afghanistan's cropland (spatial distribution of cropland has been derived from LCDA 2010 land cover and amounting to about 7.5 million ha) when assessed for producing wheat. Comparing the simulated land suitability and potential production of the period 1961–1990 and the period 1981–2010, the results suggest a very modest improvement both on rain-fed land (plus 8%) and irrigated land (plus 2%). Differences are most pronounced in Northwestern and Western regions, where the assessed wheat production capacity was higher by 7.5% in 1981–2010 compared to results obtained for period 1961–1990.

Wheat harvested area, Period 1965–2020



Source: FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021; Afghanistan Statistical Yearbook 2020 (NSIA, 2021).

Figure 3.2

Wheat (Triticum ssp)

Spring wheat (with growth cycles between 90 to 150 days) and winter wheat (with pre- and post-dormancy growth cycles of 35+105 to 50+150 days) are assessed in cool environments, while subtropical cultivars (with growth cycles of 100 to 150 days), grown in winter without hibernation, are assessed in the warmer subtropical environments of Afghanistan with year-round temperature growing periods. Wheat is a cool-loving (cryophilic) crop. Warm temperatures may cause yield losses due to increased respiration because of higher night-time temperatures. Wheat requires rainfall between 350 mm and 1250 mm. High humidity combined with warm temperatures during growth may cause disease problems (e.g., rust). During ripening and harvest dry conditions are required.

Wheat belongs to the C3 crop group (C3 I) which is characterized with optimum photosynthesis and growth at temperatures between 15°C and 20°C. Temperatures above 20°C lead to lower photosynthesis, and temperatures above 30°C cause growth cycle curtailment and severe heat stress, both leading to lower yields. Wheat is well suited for cultivation in subtropical winter rainfall areas, such as in Afghanistan, and is the dominant food staple of the country.

Table 3.4 Suitability of wheat on rain-fed and irrigated cropland in 1981-2010, by region

Regions	Rain-fed Cropland	Suitable area and potential production			Irrigated Cropland	Suitable area and potential production		
		Area	Production	Yield		Area	Production	Yield
	1000 ha	1000 ha	1000 tons	tons/ha	1000 ha	1000 ha	1000 tons	tons/ha
Northeastern	1 001.4	546.2	511.9	1.04	386.9	302.5	1 111.0	4.08
Northwestern	1 457.3	427.0	280.5	0.73	636.4	459.4	1 384.8	3.35
Eastern	0.5	0.0	0.0	1.08	165.9	127.2	495.8	4.33
Central	51.2	15.9	16.9	1.18	250.5	183.7	918.8	5.56
West-central	76.7	10.7	7.8	0.82	375.7	268.0	1 204.7	4.99
Western	1 026.3	398.7	247.1	0.69	610.3	506.5	1 510.8	3.31
Southeastern	14.7	4.0	4.2	1.16	273.8	249.2	1 173.9	5.23
Southwestern	106.5	19.8	12.6	0.71	900.7	751.3	2 205.0	3.26
TOTAL	3 734.5	1 422.2	1 081.1	0.85	3 600.2	2 847.9	10 004.9	3.90

Source: Afghanistan Statistical Yearbook, various years; FAOSTAT (at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021.

Note: The values shown are suitable extents and potential production on all current rain-fed and irrigated cropland, based on LCDA 2010 land cover. For irrigation conditions the prime (VS), good (S) and moderately (MS) suitable land are included; for rain-fed conditions marginally suitable areas (mS) are included as well. The assessment assumes an intermediate level of inputs and management. Also, it is assumed that in the areas classified as equipped for irrigation the available irrigation water can fully meet crop water requirements.

Table 3.5 Suitability of wheat on different classes of irrigated land in 1981-2010, by region

Regions	LCDA Irrigated Areas (1000 ha)				Suitable land for irrigated Wheat (1000 ha)			
	Intensively Irrigated	Active Karez	Orchard & Vineyard	Poorly Irrigated	Intensively Irrigated	Active Karez	Orchard & Vineyard	Poorly Irrigated
Northeastern	356.3	1.5	18.3	29.1	284.5	1.0	9.8	17.1
Northwestern	444.6	0.0	25.6	191.7	311.4	0.0	19.5	148.0
Eastern	146.4	1.2	6.0	18.3	110.0	1.1	4.7	16.1
Central	170.0	11.7	45.4	68.9	113.3	10.9	35.1	59.5
West-central	180.0	69.7	26.6	126.1	90.8	64.4	19.5	112.8
Western	317.2	44.0	13.0	249.0	246.0	40.6	10.2	219.9
Southeastern	97.6	38.8	4.0	137.4	81.7	36.4	3.5	131.1
Southwestern	525.0	87.0	61.2	288.6	427.8	77.3	50.9	246.2
TOTAL	2 236.7	253.5	200.1	1 109.7	1 665.5	231.7	153.1	950.6

Note: The values listed are suitable extents on irrigated land, as delineated based on LCDA 2010 land cover and are shown by region as defined in the previous chapter. For irrigation conditions the prime (VS), good (S) and moderately (MS) suitable land was included; not suitable and marginally suitable irrigated land was excluded. Irrigated land for fruit trees and vineyards is assumed to be not available for wheat or other annual staples. The assessment considers an intermediate level of inputs and management.

Results of irrigated wheat potential on all current arable land equipped with irrigation (3.6 million ha, as derived from LCDA 2010 land cover) indicate a maximum suitable area for wheat of nearly 2.85 million hectares and a potential production of 10.0 million tons. For rain-fed land (3.7 million ha according to LCDA) the suitable area, including marginally suitable extents, amounts to 1.42 million ha and a potential production of 1.1 million tons. However, note that in reality not all areas classified as irrigated land will be available for wheat cultivation due to likely water deficits in the 'Poorly irrigated' land class (1.1 million ha). At national level nearly one-third of irrigated cropland is classified as 'Poorly irrigated'. For the regions this class accounts for 7.4% (in NE region) to more than 50% (in SE region). When excluding 'Poorly irrigated' land, the area suitable for irrigated wheat reduces to 1.9 million hectares (on a remaining irrigated cropland of 2.5 million ha) and the potential production amounts to 6.6 million tons.

Table 3.5 lists the areas suitable for irrigated wheat cultivation for various LCDA 2010 irrigated land classes differentiated in the resource inventory. Note, upon the advice of experts available at FAO-Afghanistan, 'Poorly irrigated' areas listed in Table 3.5 have been included when estimating suitability and production potentials.

Table 3.6 presents for different periods and RCPs an overview of climate change impacts on the extents of cropland suitable for wheat on current rain-fed and irrigated cropland relative to reference period 1981–2010. Results have been summarized for eight major regions of Afghanistan and refer to the ensemble means of crop simulation outcomes using climate projections of five climate models and for the four RCPs.

Table 3.6 Climate change impacts on suitable cropland for wheat

Regions	% Change of suitable area relative to historical suitable area of period 1981-2010											
	RCP2.6 vs Historical			RCP4.5 vs Historical			RCP6.0 vs Historical			RCP8.5 vs Historical		
	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
Northeastern	6.6	5.3	5.8	4.7	4.6	12.2	5.7	5.4	8.9	4.8	7.1	10.9
Northwestern	11.1	8.9	10.1	4.3	10.6	18.4	7.8	8.5	20.8	3.6	9.5	15.0
Eastern	0.5	0.5	0.5	0.4	0.3	0.5	0.5	0.4	0.1	0.4	0.1	-2.1
Central	5.8	6.3	7.4	6.5	9.0	8.3	5.0	8.0	9.5	6.0	8.4	7.6
West-central	6.3	7.4	7.2	6.7	7.7	9.2	5.1	7.4	9.1	5.9	8.8	5.6
Western	2.2	2.1	5.9	5.7	0.7	5.4	3.8	7.5	6.9	-8.4	-1.1	8.2
Southeastern	1.0	1.9	1.4	1.0	1.2	1.6	0.9	1.1	1.5	1.1	1.9	0.3
Southwestern	4.1	4.3	5.8	3.8	1.5	0.9	6.1	4.2	-0.5	3.8	0.4	-8.9
TOTAL	5.6	5.0	6.4	4.5	4.5	8.6	5.3	6.1	8.6	1.3	4.3	6.1

Note: The shown percentage changes were calculated relative to the historical average of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland.

Table 3.7 Climate change impacts on potential attainable wheat yields (% change w.r.t. 1981-2010)

Regions	Potential Yield (tons/ha)	% Change of average potential yield relative to potential yield of 1981-2010							
		RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Northeastern	2.12	6.6	-1.4	4.9	1.8	6.0	2.5	8.3	1.1
Northwestern	2.09	-7.2	-9.5	-13.6	-14.6	-7.1	-13.8	-7.2	-11.0
Eastern	4.33	-7.4	-8.5	-10.7	-14.3	-10.3	-16.3	-16.0	-25.8
Central	5.21	-1.8	-2.6	-5.5	-4.8	-4.3	-6.4	-4.8	-10.5
West-central	4.83	-3.1	-3.6	-4.7	-6.3	-3.6	-5.7	-4.9	-11.1
Western	2.16	-3.2	-7.3	-7.7	-9.9	-7.5	-11.5	-5.6	-16.4
Southeastern	5.17	-4.4	-5.1	-7.8	-9.5	-6.6	-10.5	-9.9	-18.6
Southwestern	3.20	-5.6	-8.2	-7.1	-9.5	-8.2	-10.7	-10.2	-15.6
TOTAL	2.88	-3.2	-6.3	-5.6	-9.1	-5.3	-9.7	-5.4	-13.4

Note: The shown percentage changes were calculated relative to the historical average of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland.

At national level and in most regions the extents suitable for wheat increase slightly with climate change. Exceptions are the Eastern region and the Southwestern region where rapid warming (especially under RCP8.5) causes in the long-term some previously suitable cropland to become unsuitable for wheat production. In contrast, for the ensemble mean of results, the national average potential wheat yield of suitable cropland decreases with climate change by 3% to 6% in 2050s and by 6% to 13% in 2080s, depending on climate scenario. Only in the Northeastern region are average potential wheat yields projected to increase. Yield impacts by region are summarized in Table 3.7 and the combined impact of area and yield changes on potential wheat production is listed in Table 3.8.

The results listed in Table 3.7 and Table 3.8 do not consider the likely beneficial effects of increased future atmospheric CO_2 concentrations. This allows us to focus on the possible impacts of changing climate conditions on the wheat production potential of each region. While wheat belongs to the group of C3 plants, which have responded well to CO_2 enrichment in controlled experiments, the magnitude of the actual CO_2 impact in farmer's fields will also depend on the presence of other environmental limiting factors (e.g., climate, soil, water, nutrients) and is in the scientific literature regarded as quite uncertain.

As presented in Table 3.8, the wheat production capacity in the 2050s is projected to increase with climate change foremost in the Northeastern region and less so in the Central and West-Central regions. Increasingly negative production impacts are found in the Eastern, Western, Southeastern and Southwestern regions. On balance, the national wheat production potential changes only little by the 2050s, but the aggregate impact may become significantly negative in the second half of this century with rapid warming such as under RCP8.5.

Table 3.8 Climate change impacts on wheat production potential (% change w.r.t. 1981-2010)

Regions	Potential Production (million tons)	% Change of average potential yield relative to potential yield of 1981-2010							
		RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Northeastern	1.62	12.3	4.3	9.7	14.2	11.7	11.6	16.0	12.2
Northwestern	1.67	1.1	-0.4	1.1	1.2	0.9	4.1	1.7	2.4
Eastern	0.50	-7.0	-8.0	-10.4	-13.9	-9.9	-16.3	-16.0	-27.3
Central	0.94	4.4	4.6	3.0	3.1	3.4	2.6	3.2	-3.7
West-central	1.21	4.1	3.3	2.6	2.3	3.5	2.9	3.5	-6.1
Western	1.76	-1.2	-1.9	-7.1	-5.0	-0.5	-5.4	-6.6	-9.5
Southeastern	1.18	-2.6	-3.8	-6.6	-8.1	-5.6	-9.1	-8.3	-18.3
Southwestern	2.22	-1.5	-2.9	-5.8	-8.7	-4.3	-11.1	-9.8	-23.1
TOTAL	11.09	1.7	-0.3	-1.3	-1.3	0.5	-1.9	-1.4	-8.1

Note: The shown percentage changes were calculated relative to the historical average of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland.

Figure 3.3 gives a graphical representation of results by region for respectively RCP4.5 and RCP8.5, using an index of potential wheat production in the 2050s and the 2080s and where each region's potential production during 1981–2010 is set to 100. The results clearly indicate that with more intense climate change scenarios an increasing share of the wheat production potential will be contributed by the Northeastern, Northwestern, Central and West-Central regions whereas especially the Southwestern, Southeastern and Eastern region experience losses of production capacity. This is summarized in Figure 3.4, which shows for historical climate and future climate scenarios the contribution of each region to the national wheat production potential.

Index of potential wheat production capacity (1981–2010 = 100)

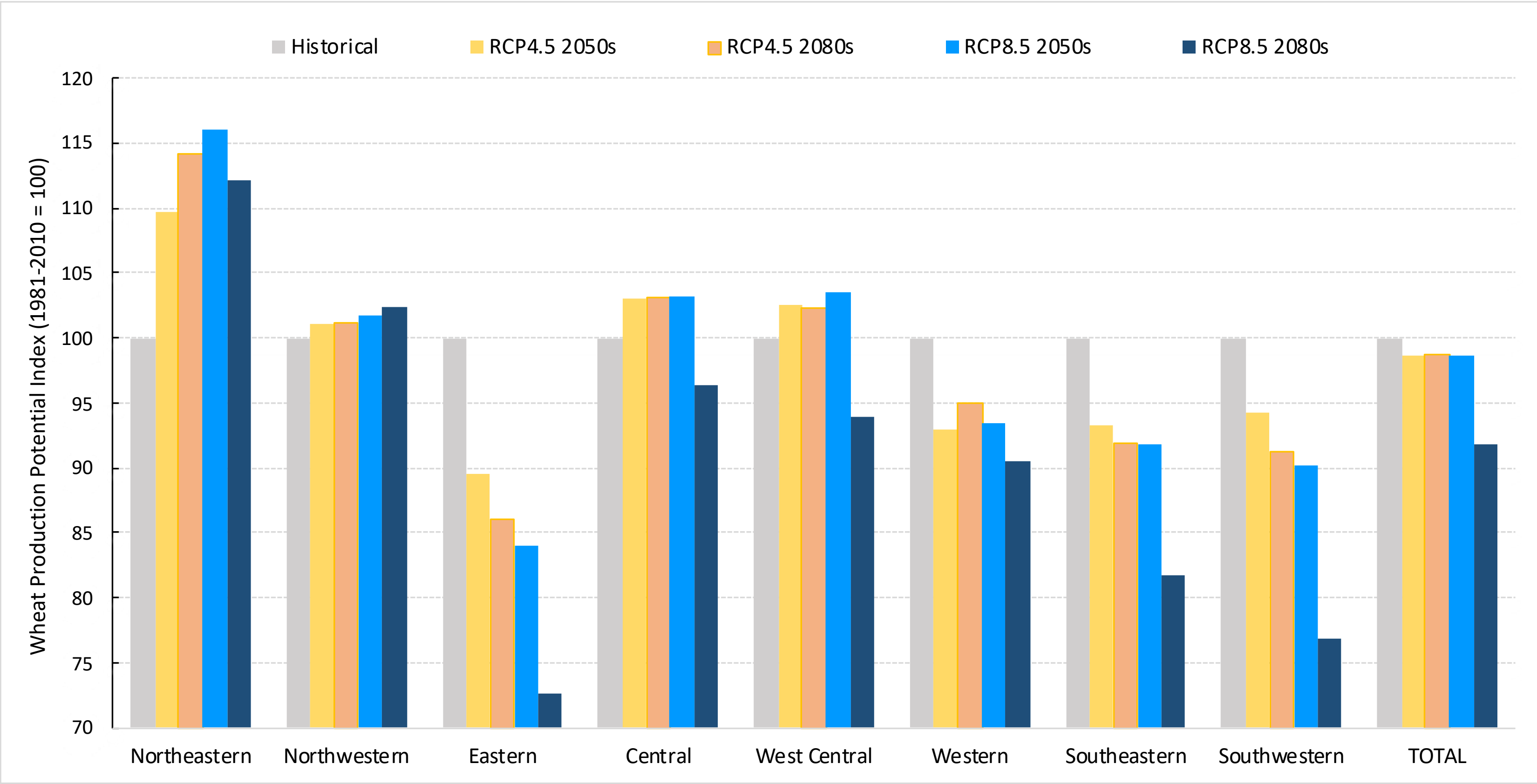


Figure 3.3

Changes of regional composition of potential wheat production capacity

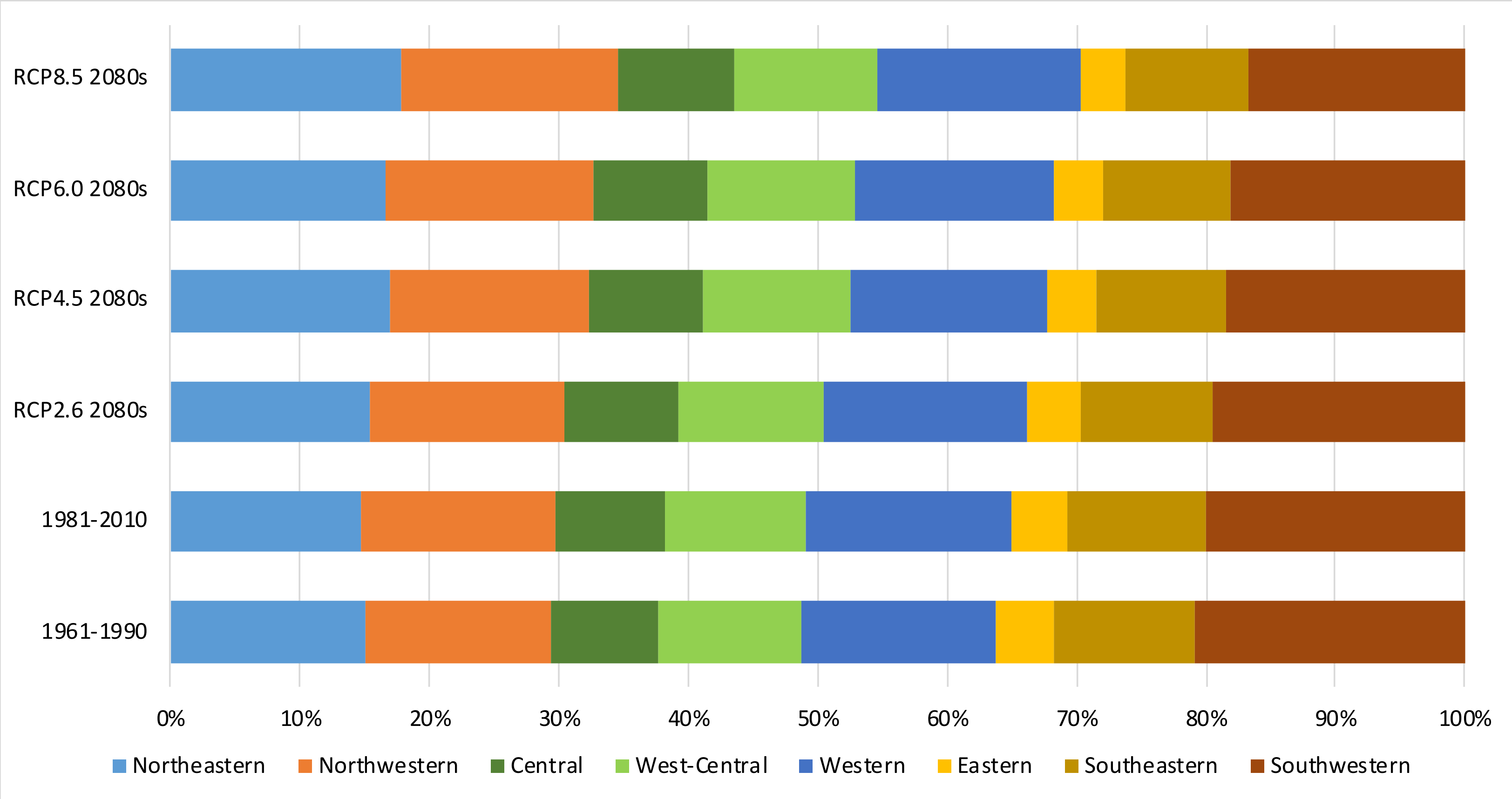


Figure 3.4

The bars in Figure 3.4 highlight the expected trend and gradual shift in the spatial distribution of Afghanistan's wheat production potential. The Northeastern, Northwestern, Central and West-Central regions combined will increase their share in total wheat production potential, from 49% under historical climate to 55% under RCP8.5 in the 2080s. While such trend is apparent for all RCPs, the magnitude of the changes will depend on the rate of warming.

The suitability of cropland can be illustrated by means of a crop-specific normalized suitability index SI, calculated for each grid cell as:

$$SI = (90 \times VS + 70 \times S + 50 \times MS + 30 \times mS + 15 \times vmS + 0 \times NS) / 0.9$$

with values ranging from 0 to 100 and where VS, S, ..., NS are the area shares of different suitability classes in a grid cell:

- **VS**: Very suitable; Prime land offering best conditions for economic crop production.
- **S**: Suitable; Good land for economic production.
- **MS**: Moderately suitable; Moderate land with substantial constraints. Economic production may require high product prices for profitability.
- **mS**: Marginally suitable; Commercial production not viable. Land could be used for subsistence production when no other land is available.
- **vmS**: Very marginally suitable; Production not feasible.
- **NS**: Not suitable; Production not possible.

The calculated SI values for each grid cell are grouped into 8 aggregate classes, termed as:

(1) Very high, when $SI > 85$;

(2) High, when $70 < SI \leq 85$;

(3) Medium, when $55 < SI \leq 70$;

(4) Moderate, when $40 < SI \leq 55$;

(5) Marginal, when $25 < SI \leq 40$;

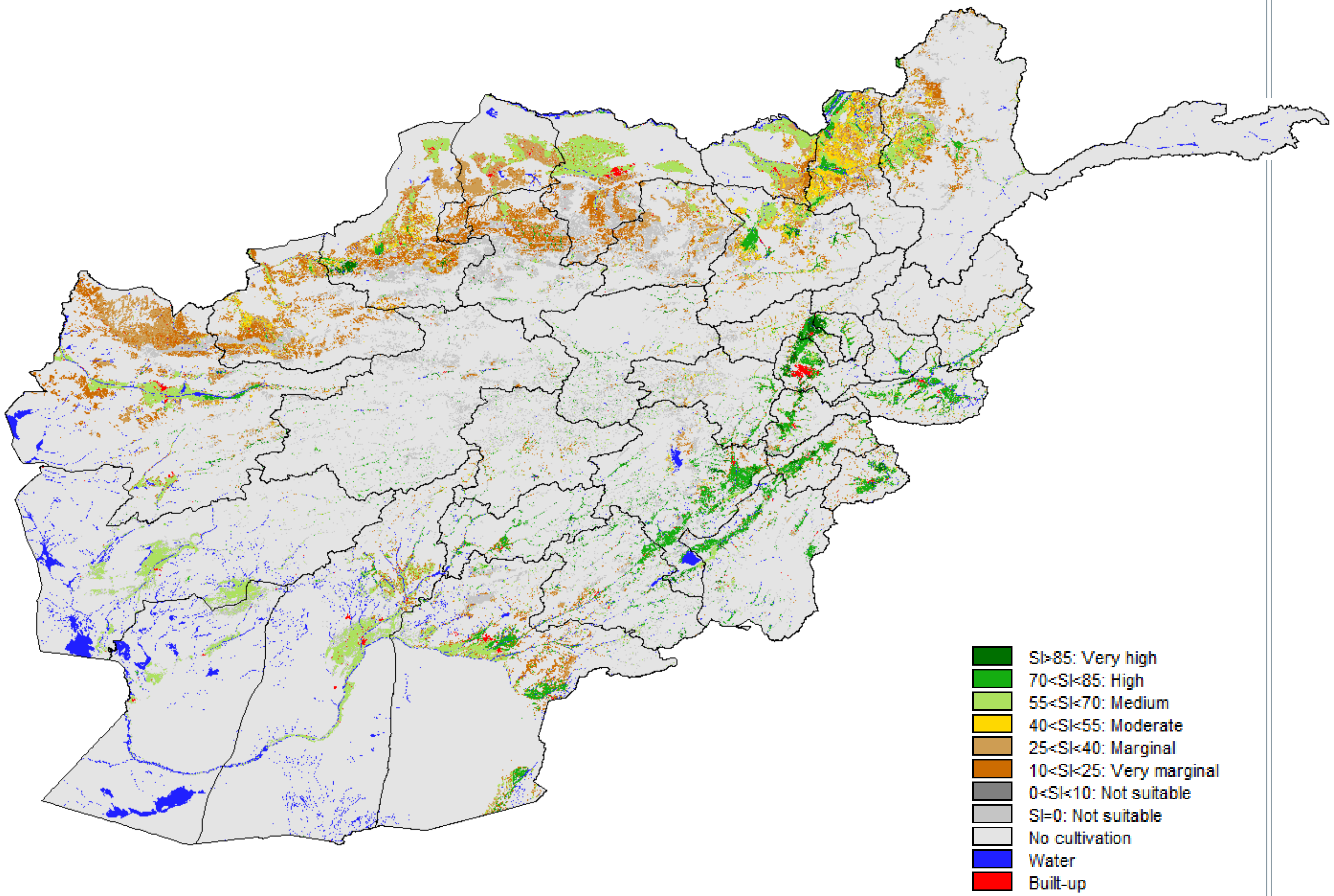
(6) Very marginal, when $10 < SI \leq 25$;

(7) Not suitable, when $0 < SI \leq 10$; and also

(8) Not suitable, when $SI = 0$

(see Figure 3.5).

Wheat suitability index class of current cropland, Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current cropland refer to average suitably class per 7.5 arc-seconds grid cell of the resource inventory.

Figure 3.5a

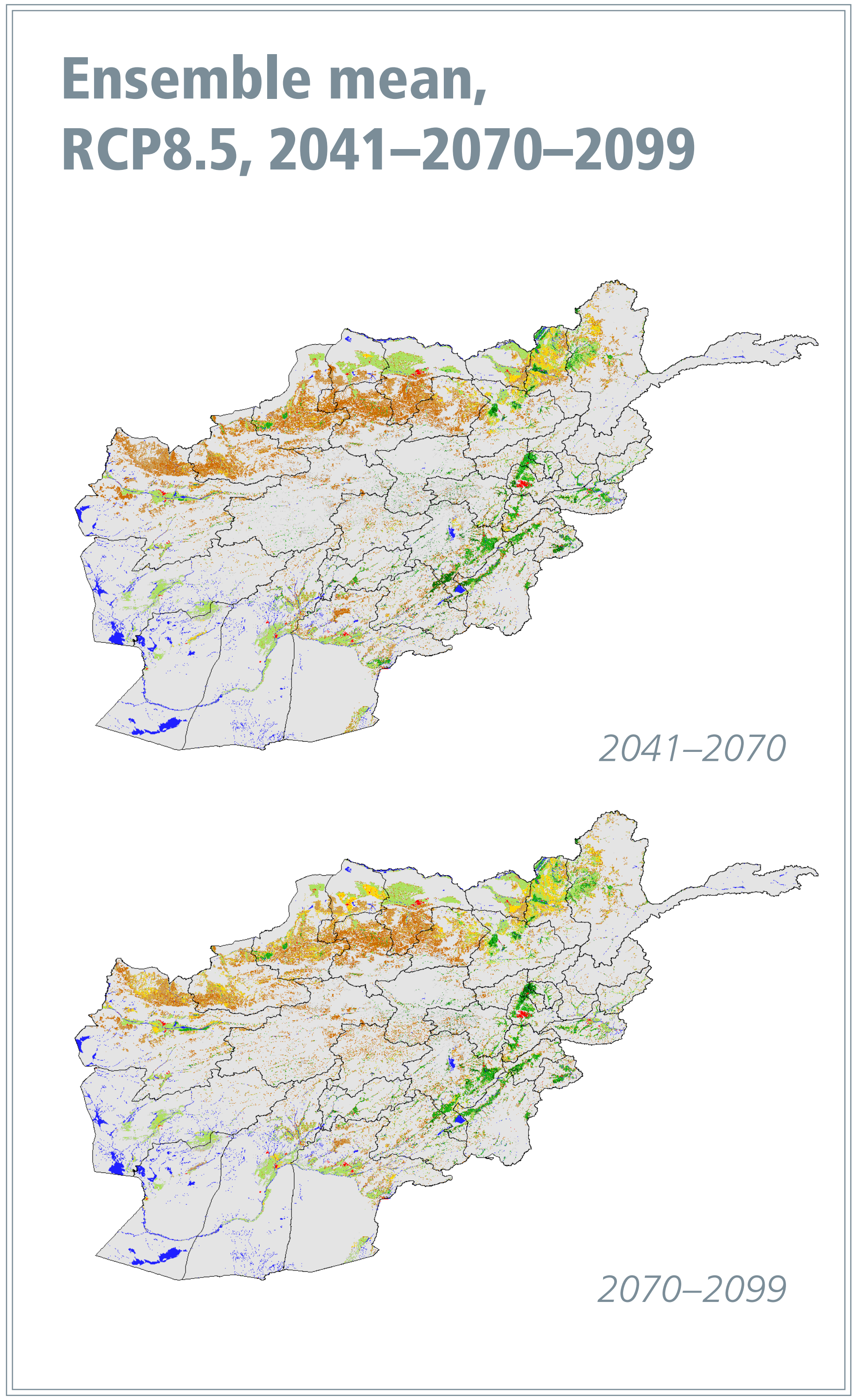
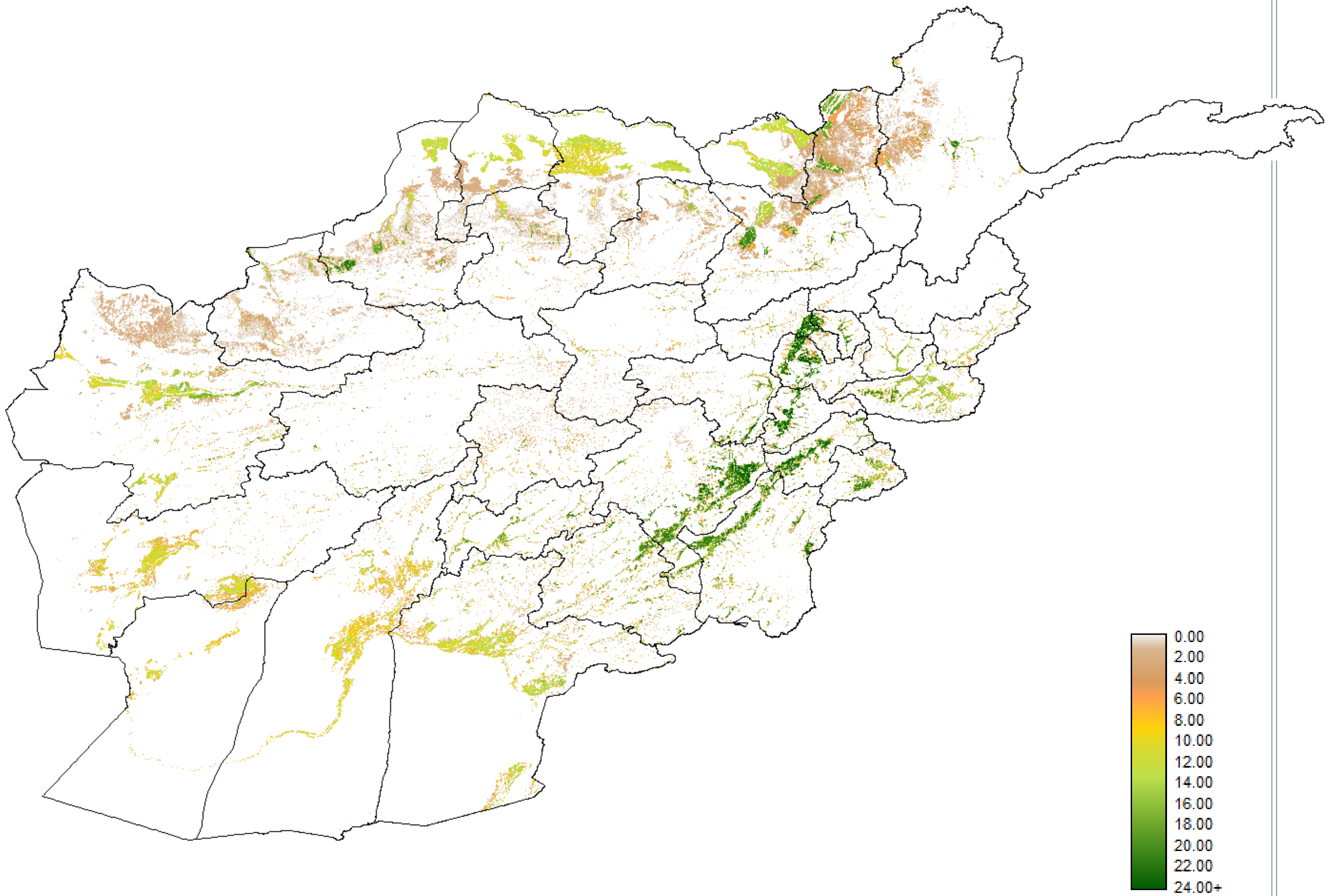


Figure 3.5b, 3.5c

Combining the map of attainable wheat yields with the occurrence of rain-fed and irrigated croplands, Figure 3.6 presents for rain-fed and irrigated wheat the production potential in pixels with cropland for the reference period 1981–2010. The map shows quantities (in tons per grid cell) that can potentially be produced if all suitable cropland is used for wheat cultivation.

The calculation of potential wheat production assumes an intermediate level of inputs/management and timely availability of irrigation to fully meet crop water demand on irrigated land.

Potential wheat production on current cropland (tons)
Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010. Values shown for current cropland refer to potential wheat production at intermediate input level per 7.5 arc-seconds grid cell, i.e. about 5 hectares.

Figure 3.6

Table 3.9 summarizes the changes in average irrigation requirements (mm) of potentially suitable irrigated wheat land. It may come as a surprise that in the NAEZ simulations average irrigation requirements for wheat decrease with climate change, which is the combined result of several factors, such as (i) changing crop calendars (shorter winters), (ii) changing wheat types selected for cultivation (spring wheat, hibernating winter wheat, subtropical wheat grown through winter), and (iii) changing suitability of wheat.

For the historical period 1981–2010 the average simulated net irrigation demand of wheat is highest for Central and Western region, and lowest for irrigated cropland in Northeastern and Northwestern region.

Increases of irrigation demand due to climate change were estimated for West-Central and Southeastern region. In all other regions the adapted crop calendars and changed wheat types resulted in lower net irrigation demand.

Table 3.9 Climate change impacts on irrigation demand of irrigated wheat

Regions	Net Irrigation Water Requirements (mm)								
	Historical	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Northeastern	243	123	124	120	106	116	114	118	105
Northwestern	215	177	179	178	166	172	161	170	154
Eastern	374	175	177	176	163	170	160	165	154
Central	478	358	354	353	346	349	333	357	306
West-central	364	431	427	433	411	421	402	416	376
Western	413	305	293	302	283	284	276	279	242
Southeastern	316	357	354	357	344	353	330	346	309
Southwestern	324	272	260	282	262	266	255	254	230
TOTAL	288	269	263	270	254	260	248	255	228

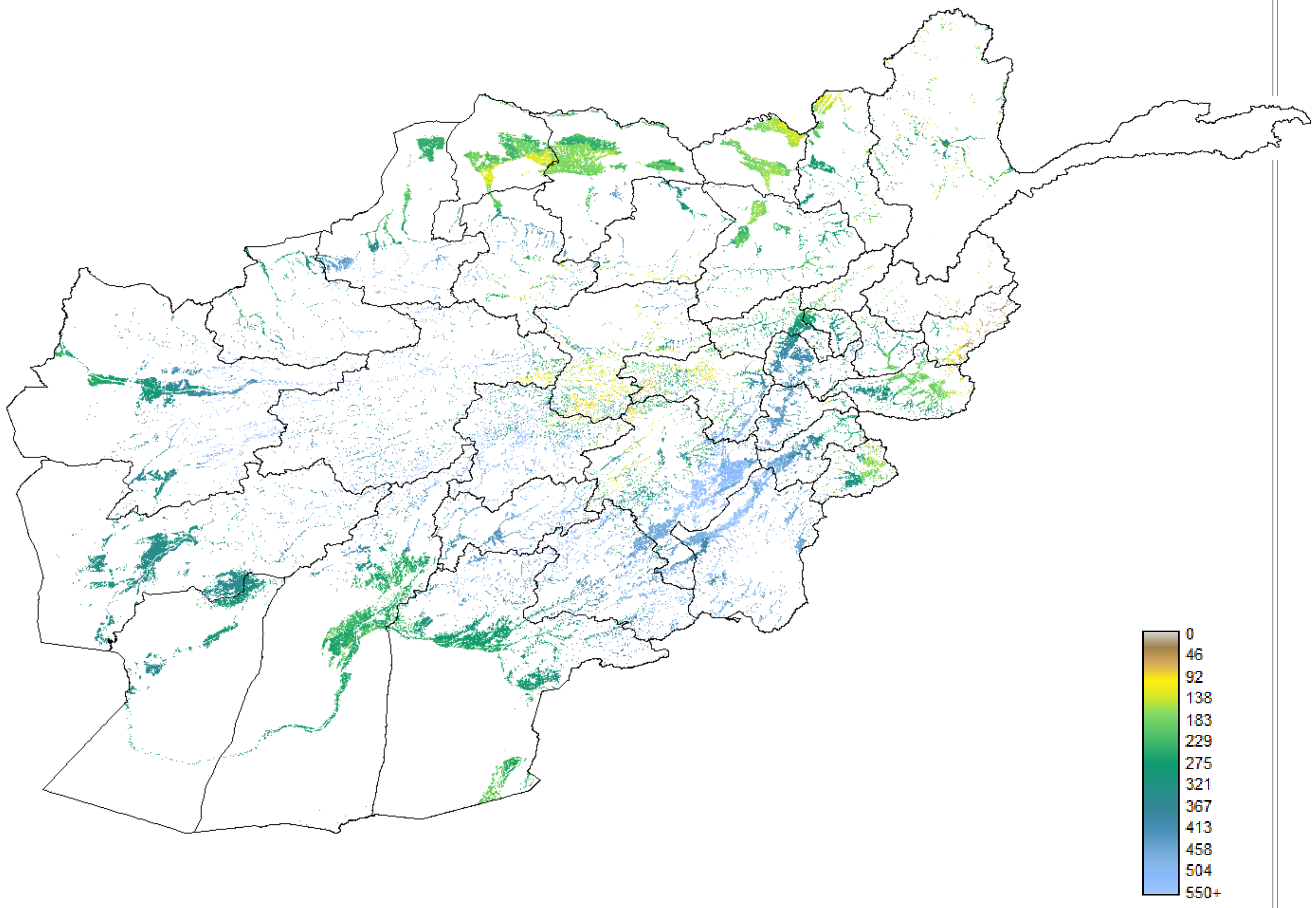
Note: Average crop water demand and soil moisture deficits were calculated for irrigated cropland that is very suitable, suitable or moderately suitable for wheat. The values shown refer to net irrigation water requirements (i.e., the amount to be taken up by the plants) assuming any crop water deficit is fully met.

Figure 3.7 shows maps of average net irrigation requirements for wheat cultivation on irrigated cropland, respectively for the historical period 1981–2010 and for an ensemble mean of simulations under RCP8.5 in the 2050s and 2080s.

With climate change crop calendars will shift and different wheat types may become possible. For example, due to future warmer winter temperatures in the higher areas with currently cold winter temperatures, winter wheat may replace spring wheat. In lowland areas, subtropical wheat may replace winter wheat and will be cultivated without a break in winter and early spring. Wheat growth cycle duration may adjust as well. These factors will lead to changes in wheat suitability, yield and irrigation demand.

A reduction of irrigation demand for wheat cultivation under climate change is visible in Figure 3.7 in almost all regions.

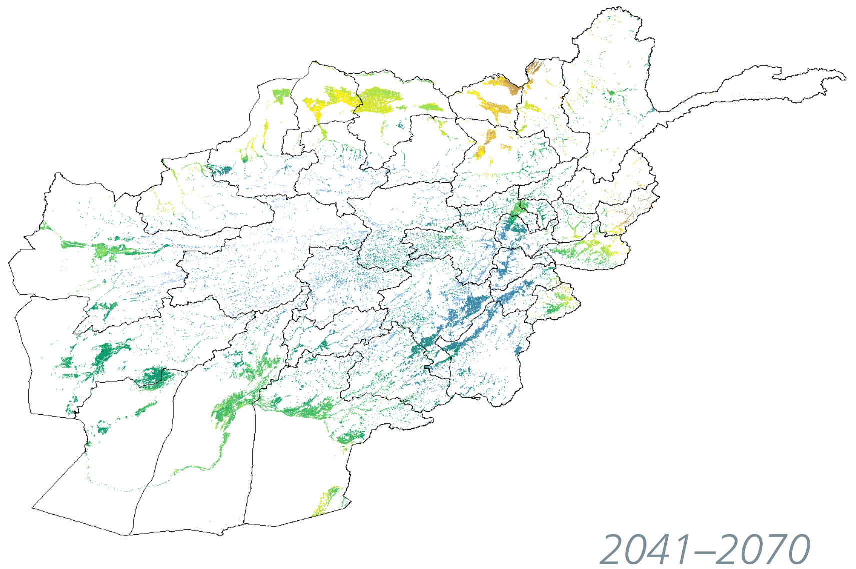
Water deficit (mm) during the wheat growth cycle Reference climate 1981–2010



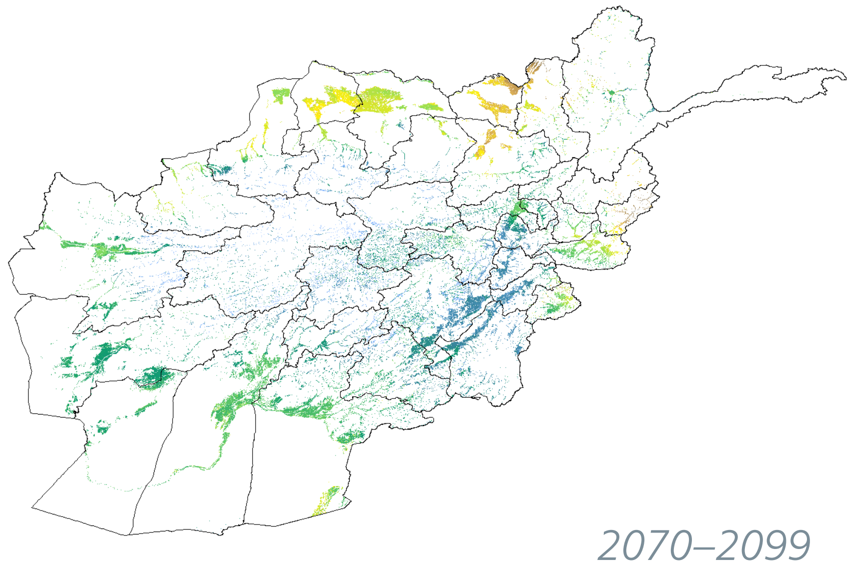
Source: Simulations using historical climate of 1981-2010. Water deficits (mm) shown indicate for 7.5 arc-second grid cells the net irrigation demand to fully meet water requirements for wheat cultivation on current irrigated cropland.

Figure 3.7a

Ensemble mean, RCP8.5, 2041–2070–2099



2041–2070



2070–2099

Figure 3.7b, 3.7c

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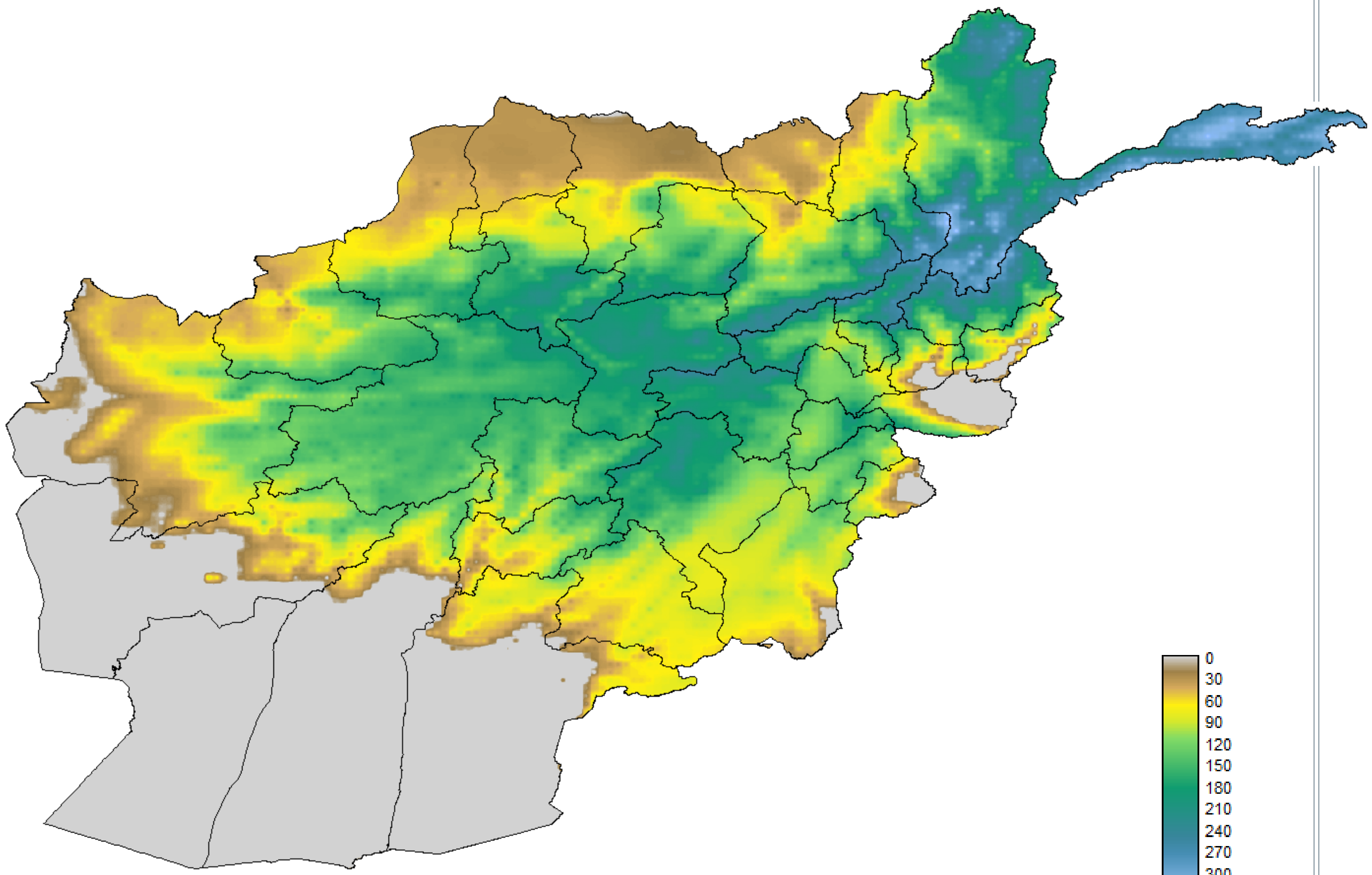
Figure 3.8 indicates the average length of the cold/dormancy period, defined as the number of days when mean daily temperature is below 5°C, for the historical climate (see Figure 3.8a) and for an ensemble mean of RCP8.5 in the 2050s and 2080s (Figure 3.8b and 3.8c).

Taking the ensemble mean for RCP8.5 in the 2080s (see Figure 3.9b), the simulated reduction of the average length of the dormancy period for cropland amounts to 46 days, with a range across regions of 21 days (Southwestern region) to 72 days (Central region). For RCP4.5 in the 2050s, the national average reduction is 20 days, with a range of 10 days to 30 days in different regions (see Figure 3.9a). In areas where a reduction of the dormancy period occurs, this means for instance that a winter wheat crop can be sown later in the year and may be harvested earlier than during 1981–2010.

The disappearance or substantial shortening of the dormancy period gives access to land on days when soil moisture conditions are still better suited for rain-fed cultivation before drying up towards summer, and irrigation gifts are therefore less required during the growth cycle.

Length of dormancy period (days)
Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010. Values shown indicate the number of days with average daily temperature Ta < 5°C.

Figure 3.8a

Ensemble mean RCP8.5, 2041–2070–2099

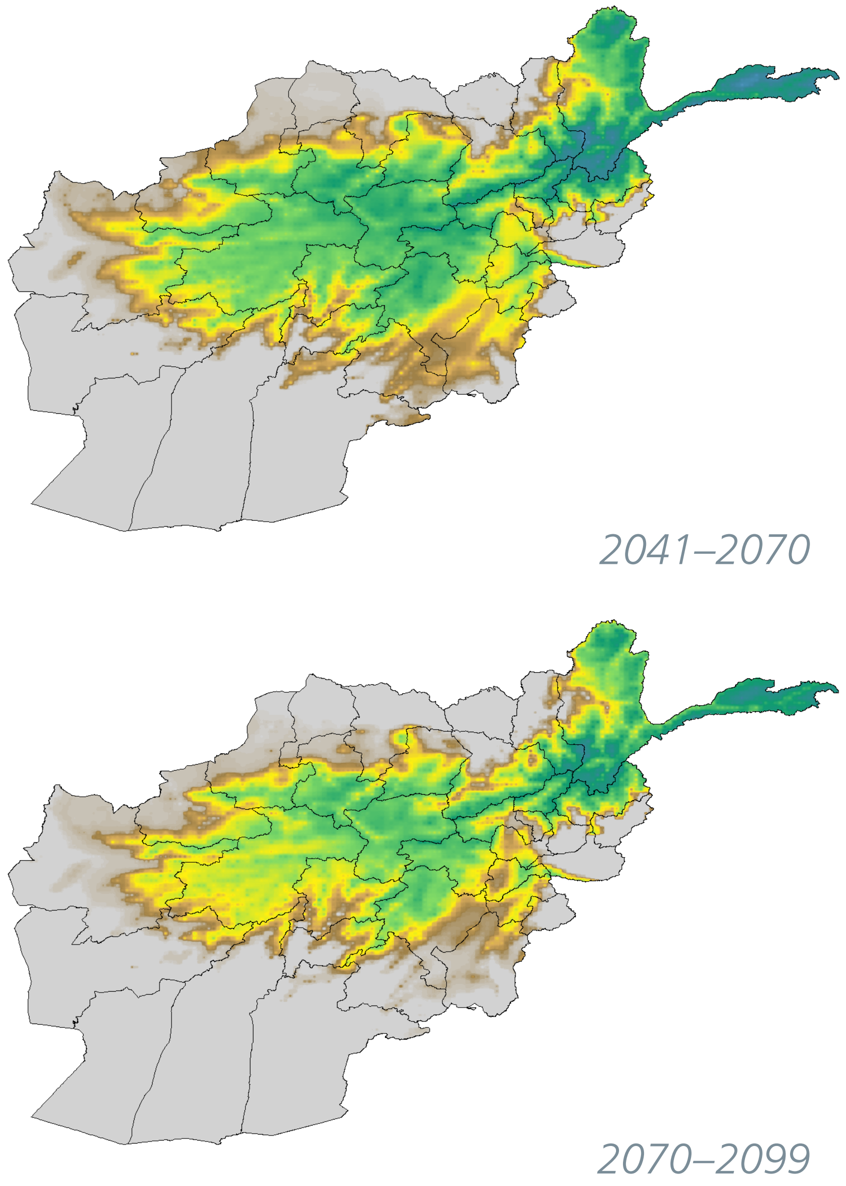
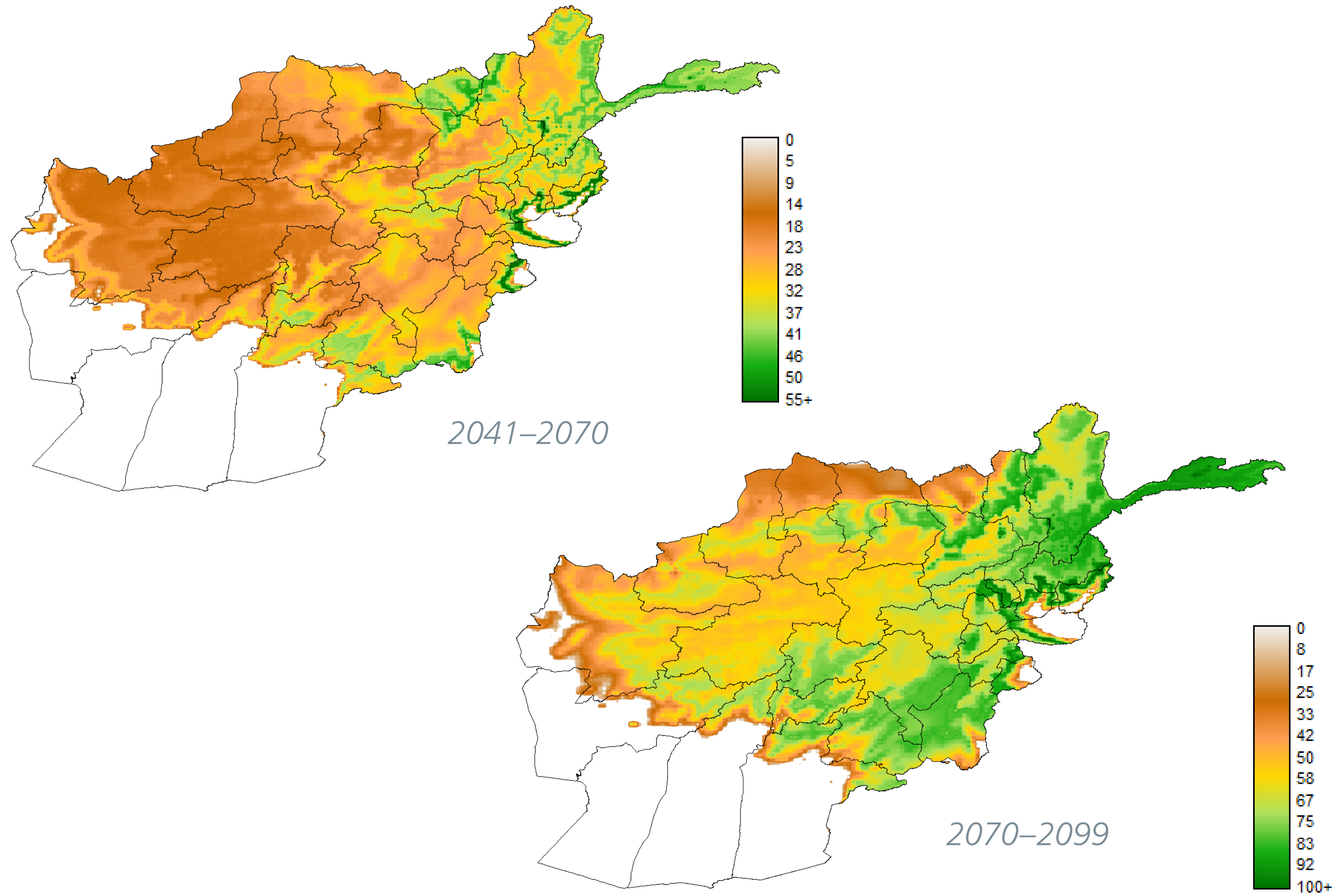


Figure 3.8b, 3.8c

Reduction in length of dormancy period compared to reference climate of 1981–2010 (days) Ensemble mean, RCP4.5, 2041–2070 / RCP8.5, 2070–2099



Source: Simulations using historical and projected future climates. Values indicate the reduction (days) in the number of days with average daily temperature Ta < 5°C for an ensemble mean of projected results relative to outcomes for period 1981-2010.

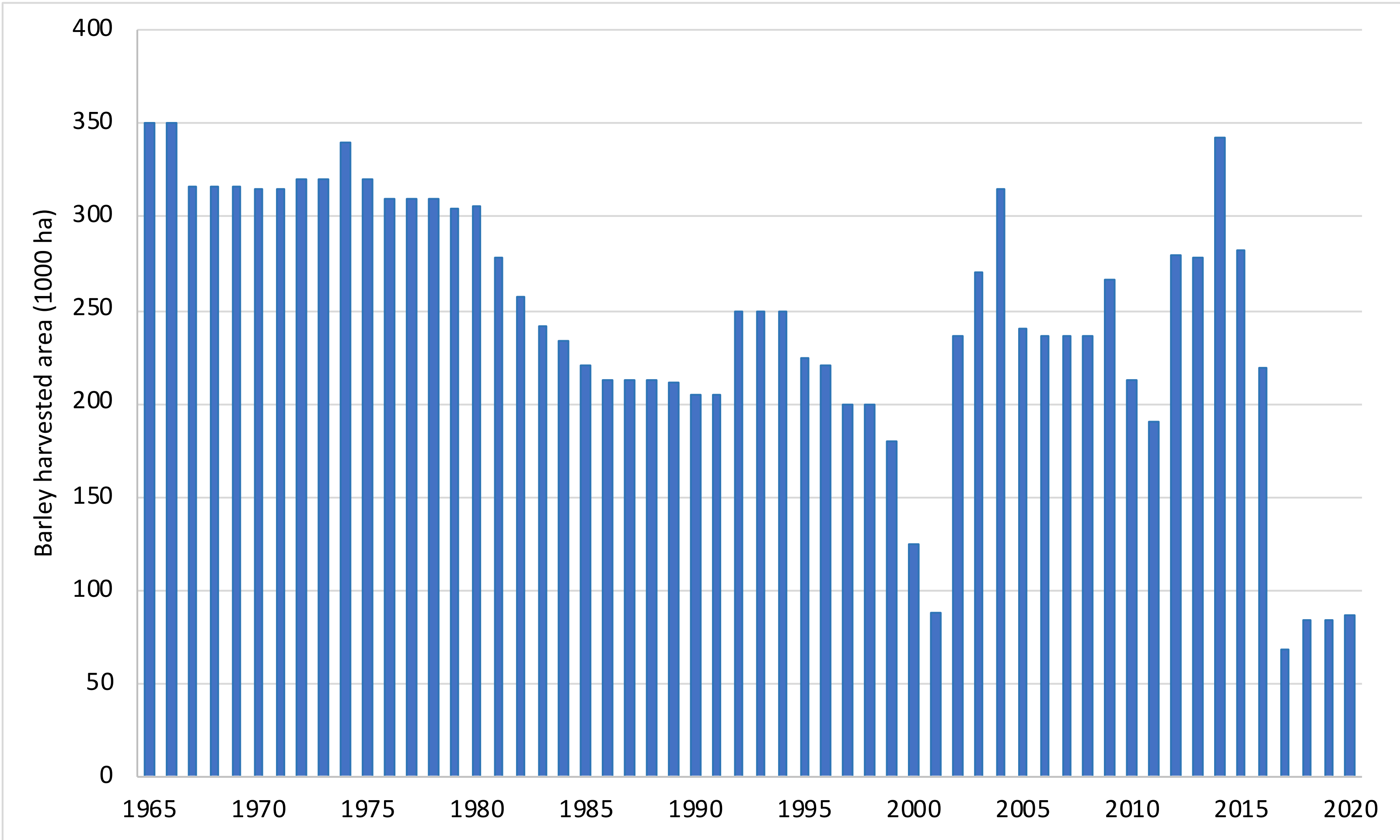
Figure 3.9a, 3.9b

3.3 Climate change impacts on barley suitability and production

According to data reported in FAOSTAT (Source: http://www.fao.org/faostat/en/#data/QC), barley cultivation in Afghanistan occupied a harvested area of more than 300 thousand hectares until the beginning of the 1980s (see Figure 3.10). Since then barley harvested area has been slowly declining, reaching a low point of less than 100 thousand hectares during the drought in 2001, but recovered to an average of about 225 thousand hectares in 2009–11, and an average 280 thousand hectares harvested area in 2014–16 with an average production of 400 thousand tons. In the recent past, most likely caused by the drought conditions around 2018, the reported harvested area of barley was well below 100 thousand hectares.

The climatic characteristics and requirements of barley are quite similar to those of wheat. Compared to wheat, barley is somewhat more robust and tolerant against soil limitations, e.g., such as salinity. Where wheat cultivation is possible, farmers will often prefer wheat to barley. However, under rain-fed conditions and on certain soil types, barley can outperform wheat. It is worth noting that of all tested cereal crops, the suitability evaluation of cropland in Afghanistan records for barley the largest potentially suitable extents. Yet, under irrigation conditions and for soils with few or no limitations the farmers will often prefer to cultivate wheat or an alternative higher value crop.

Barley harvested area, Period 1965–2020



Source: FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021; Afghanistan Statistical Yearbook 2020 (NSIA, 2021).

Figure 3.10

Table 3.10 presents suitability and potential production of Afghanistan's cropland (spatial distribution of cropland has been derived from LCDA 2010 land cover and amounts to about 7.5 million ha) when assessed for producing respectively rain-fed and irrigated barley. Comparing the simulated land suitability and potential production of the period 1961–1990 and the period 1981–2010, the results suggest a very minor improvement (plus 0.5%), with some reduction only in Southwestern region and slight increases in other regions.

Table 3.11 shows for different periods and RCPs an overview of climate change impacts on the extents of land suitable for barley on current rain-fed cropland and on land equipped for irrigation. Results refer to the ensemble means of crop simulation outcomes using climate projections of five climate models and for two RCPs, namely RCP4.5 and RCP8.5.

Barley (Hordeum vulgare)

Spring barley (with growth cycles of 90 to 135 days) and winter barley (with pre- and post-dormancy growth cycles of 35+105 to 50+150 days) were assessed in cool environments, while subtropical cultivars (with growth cycles 90 to 135 days) have been assessed in the warm subtropical environments of southern Afghanistan. Warm temperatures may cause yield losses due to increased respiration because of higher night-time temperatures. Barley requires rainfall between 300 mm and 1100 mm. High humidity combined with warm temperatures during growth may cause disease problems (e.g., rust). During ripening and harvest dry conditions are required.

Barley, like wheat, belongs to the C3 crop group (C3 I) which is characterized with optimum photosynthesis and growth at temperatures between 15°C and 20°C. Temperatures above 20°C lead to lower photosynthesis and temperatures above 30°C cause growth cycle curtailment and severe heat stress, both leading to lower yields. Similar to wheat, barley is well suited for cultivation in winter rainfall areas.

Table 3.10 Suitability of barley on rain-fed and irrigated cropland in 1981-2010, by region

Regions	Rain-fed Cropland	Suitable area and potential production			Irrigated Cropland	Suitable area and potential production		
		Area	Production	Yield		Area	Production	Yield
	1000 ha	1000 ha	1000 tons	tons/ha	1000 ha	1000 ha	1000 tons	tons/ha
Northeastern	1 001.4	632.2	879	1.54	386.9	310.5	1 300	4.65
Northwestern	1 457.3	573.0	495	0.96	636.4	580.5	2 080	3.98
Eastern	0.5	0.0	0	1.33	165.9	127.7	477	4.16
Central	51.2	18.4	22	1.35	250.5	184.3	939	5.66
West-central	76.7	10.8	8	0.80	375.7	265.3	1 263	5.29
Western	1 026.3	614.6	562	1.02	610.3	526.6	1 885	3.98
Southeastern	14.7	4.4	5	1.17	273.8	249.3	1 220	5.44
Southwestern	106.5	54.0	43	0.90	900.7	802.8	2 752	3.81
TOTAL	3 734.5	1 907.5	2 015	1.17	3 600.2	3 046.9	11 916	4.35

Note: The values shown are suitable extents and potential production on all current rain-fed and irrigated cropland, based on LCDA 2010 land cover. For irrigation conditions the prime (VS), good (S) and moderately (MS) suitable land are included; for rain-fed conditions marginally suitable areas (mS) are included as well. The assessment assumes an intermediate level of inputs and management. Simulations assume that water is available in irrigated land when needed to meet crop water demand.

Table 3.11 Climate change impacts on suitable cropland and attainable yield for barley

Regions	Suitable Area (1000 ha)	% Change relative to 1981-2010				Attainable Yield (tons/ha)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	942.7	3.8	4.9	4.5	5.2	2.57	2.5	3.8	2.9	-3.0
Northwestern	1 153.5	10.9	14.2	9.9	15.9	2.48	-12.7	-15.1	-13.1	-17.0
Eastern	127.7	0.4	0.5	0.4	-0.4	4.16	-11.2	-14.6	-16.4	-23.6
Central	202.6	8.5	8.7	8.3	8.0	5.27	-5.4	-5.2	-4.8	-13.1
West-central	276.1	10.4	12.1	10.4	8.4	5.11	-7.5	-9.5	-7.1	-16.4
Western	1 141.2	5.1	7.2	4.9	6.0	2.38	-6.0	-8.4	-8.0	-12.3
Southeastern	253.7	2.5	2.7	2.2	1.3	5.36	-9.0	-11.1	-11.1	-22.1
Southwestern	856.8	4.1	4.2	4.5	0.8	3.63	-7.1	-10.0	-10.7	-16.3
TOTAL	4 954.4	6.2	7.8	6.1	7.0	3.12	-6.8	-8.8	-8.1	-14.7

Table 3.12 Climate change impacts on barley production potential and net irrigation requirements

Regions	Potential Production (1000 tons)	% Change relative to 1981-2010				Net Irrigation (mm)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	2 179	6.4	8.8	7.5	2.1	234	-40.2	-43.2	-39.4	-44.3
Northwestern	2 575	-3.2	-3.1	-4.5	-3.8	276	-24.3	-25.7	-23.1	-32.2
Eastern	477	-10.9	-14.2	-16.0	-23.9	201	-9.9	-17.5	-14.7	-17.5
Central	961	2.6	3.1	3.1	-6.1	378	-6.4	-8.0	-4.6	-19.1
West-central	1 271	2.1	1.4	2.5	-9.4	499	-11.4	-16.5	-15.4	-27.4
Western	2 447	-1.2	-1.8	-3.5	-7.0	413	-15.6	-19.9	-19.8	-29.2
Southeastern	1 224	-6.8	-8.7	-9.1	-21.1	423	-13.9	-17.4	-16.9	-28.8
Southwestern	2 795	-3.3	-6.2	-6.7	-15.6	367	-9.2	-15.0	-16.4	-24.1
TOTAL	13 931	-1.1	-1.7	-2.5	-8.7	354	-15.4	-19.4	-18.6	-28.1

Note: The shown percentage changes were calculated relative to the historical average of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland. Average crop water demand and soil moisture deficits were calculated for irrigated cropland that is very suitable, suitable or moderately suitable for barley. The values refer to net irrigation water requirements (i.e., the amount to be taken up by the plants) assuming any water deficit is fully met.

At the national level and in all regions the extents suitable for barley increase with climate change by the 2050s. This trend continues to the 2080s in the northern regions but changes in the southern regions where some previously suitable cropland becomes unsuitable for barley production due to warming. In contrast, for the ensemble mean of results, the national average potential barley yield calculated over all suitable cropland (without accounting for possible yield impacts due to elevated atmospheric CO_2 concentrations) decreases with climate change by about 7-8% in the 2050s and by 9% to 15% in the 2080s, depending on climate scenario (Table 3.11). The combined impacts of area and yield changes on potential barley production are listed in Table 3.12.

The barley production capacity in the 2050s is projected to increase with climate change foremost in the Northeastern region and to some extent in the Central and West-Central regions. The other regions experience negative production impacts. On balance, the national barley production potential decreases only -1% to -3% by the 2050s, but may suffer significant negative impacts in the second half of this century with rapid warming such as under RCP8.5.

By the 2080s, the losses of national barley production potential depend largely on climate trajectory. In the simulations with RCP4.5 the ensemble mean falls -1.9%. Under RCP8.5, even though the Northeastern region still records a small plus, losses computed at national level amount to -9.1% due to large decreases mainly in low-lying eastern and southern regions.

As observed for wheat, the simulated results of irrigation requirements per unit area for barley decrease quite substantially with climate change due to multiple factors including (i) changing crop calendars (shorter winters), (ii) changing barley types selected for cultivation (e.g., shift from spring barley to winter barley; shift from hibernating winter barley to subtropical non-hybernating barley types), and (iii) changing suitability of barley areas.

Index of potential barley production capacity (1981–2010 = 100)

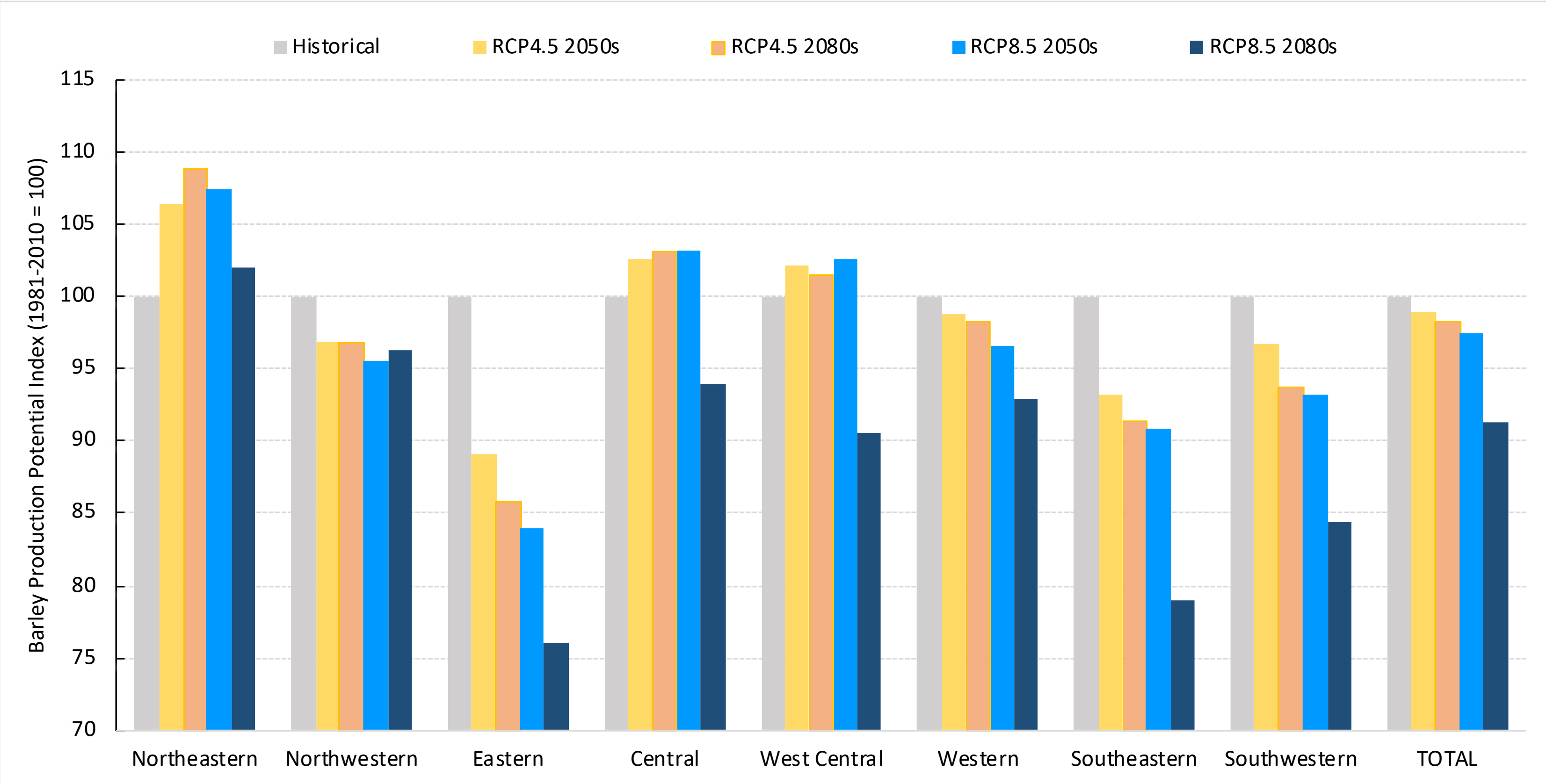


Figure 3.11

Figure 3.11 gives a graphical representation of results by region for respectively RCP4.5 and RCP8.5, using an index of potential barley production in the 2050s and the 2080s and where each region's potential production during 1981–2010 is set to 100.

The results confirm, as was also found for wheat, that a rapid and considerable climate change, as would occur under RCP8.5, could curtail potential initial benefits in northern territories and in central highlands and would produce large losses of barley production potential in Eastern, Southwestern and Southeastern region.

Figure 3.12 indicates for historical climate and future climate scenarios the contribution of each region to the national barley production potential. The NAEZ results clearly indicate that with more intense climate change scenarios an increasing share of the barley production potential will be contributed by the Northeastern, Northwestern, Central and West-Central regions whereas especially the Southwestern, Southeastern and Eastern region experience losses of production capacity. As climatic requirements of barley are quite similar to wheat, it does not come as a surprise that the trends of changes in the regional composition of the country's barley production potential due to climate change are quite similar to those observed for wheat in the previous section, i.e., a gradual shift of production capacity from southwest to northeast.

Changes of regional composition of potential barley production capacity

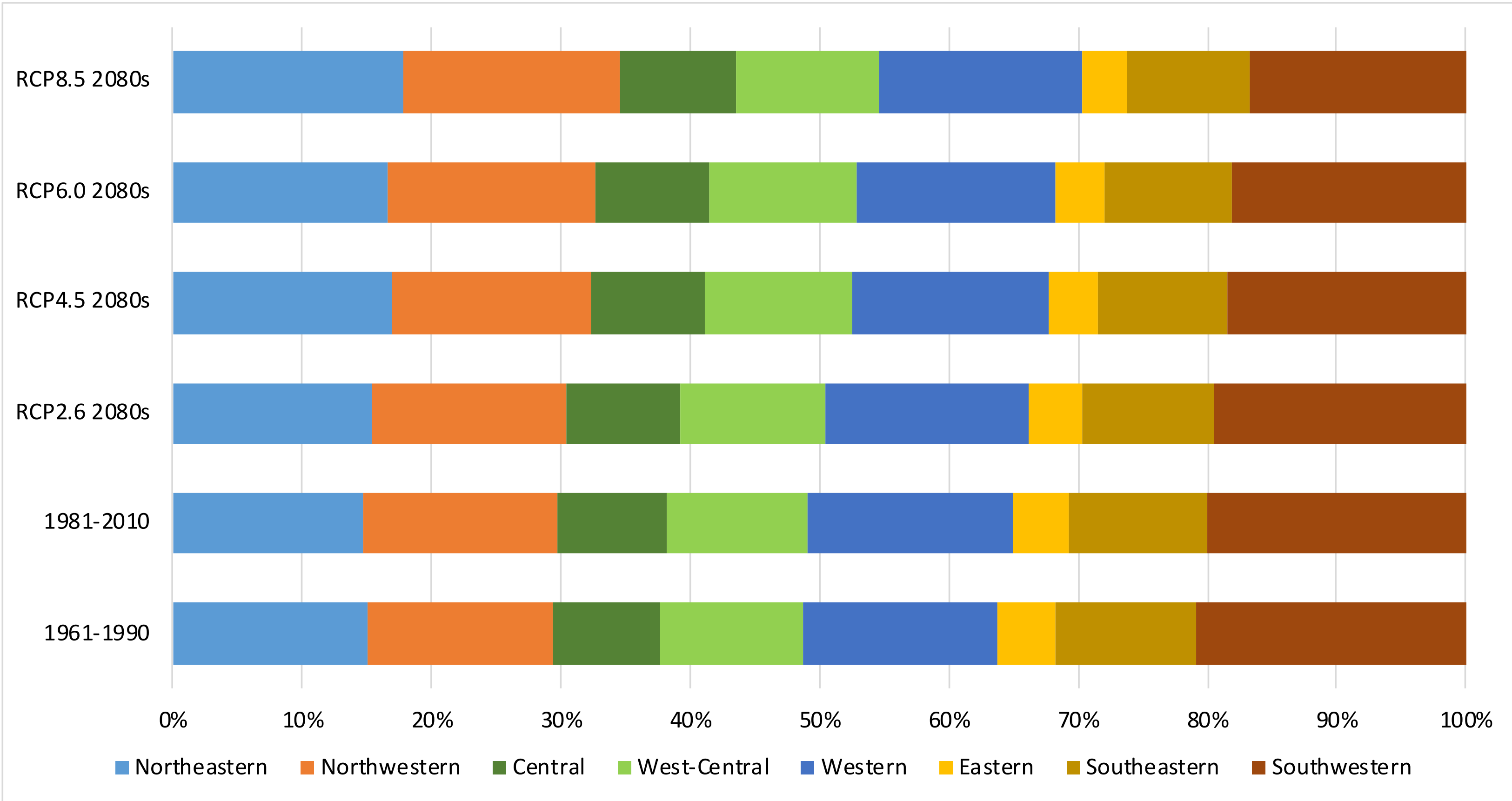


Figure 3.12

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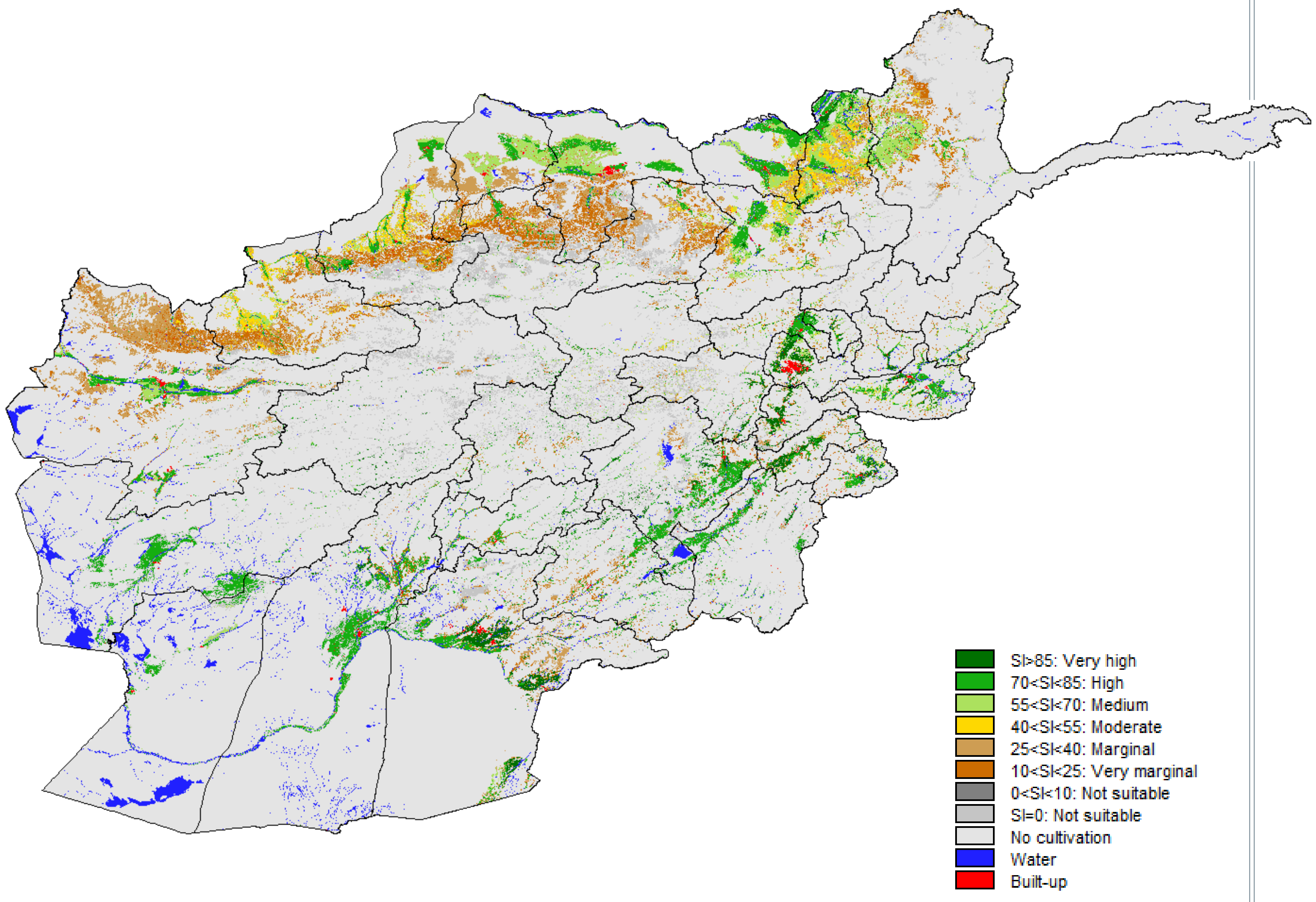
Using the normalized suitability index SI, Figure 3.13 presents classes of cropland suitability for barley cultivation at intermediate input level for historical and future climate conditions.

Agro-climatic requirements of barley are quite similar to wheat. For winter rainfall areas the disappearance or substantial shortening of the cold period means that the crop will develop when soil moisture conditions are still better suited for rain-fed cultivation before the land dries up in summer. The shift of crop calendar largely explains why the rainfed production potential in the important rain-fed production areas of the Northeastern, Northwestern and Western region - and overall for Afghanistan - is simulated to increase with projected climate changes.

For irrigated land, where soil moisture is assumed to be fully controlled, the consequences of climate change are not beneficial. The decisive factors for high attainable yields under irrigation are radiation, temperature regime and crop cycle length. Climate change results in negative impacts on attainable irrigated yield and production potential in all regions.

Combining maps of attainable intermediate-input barley yields and maps of current rain-fed and irrigated croplands, Figure 3.14 shows the production potential of barley for the base period 1981–2010.

Barley suitability index class of current cropland Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current cropland refer to average suitably class per 7.5 arc-seconds grid cell of the resource inventory.

Figure 3.13a

Ensemble mean, RCP8.5, 2041–2070–2099

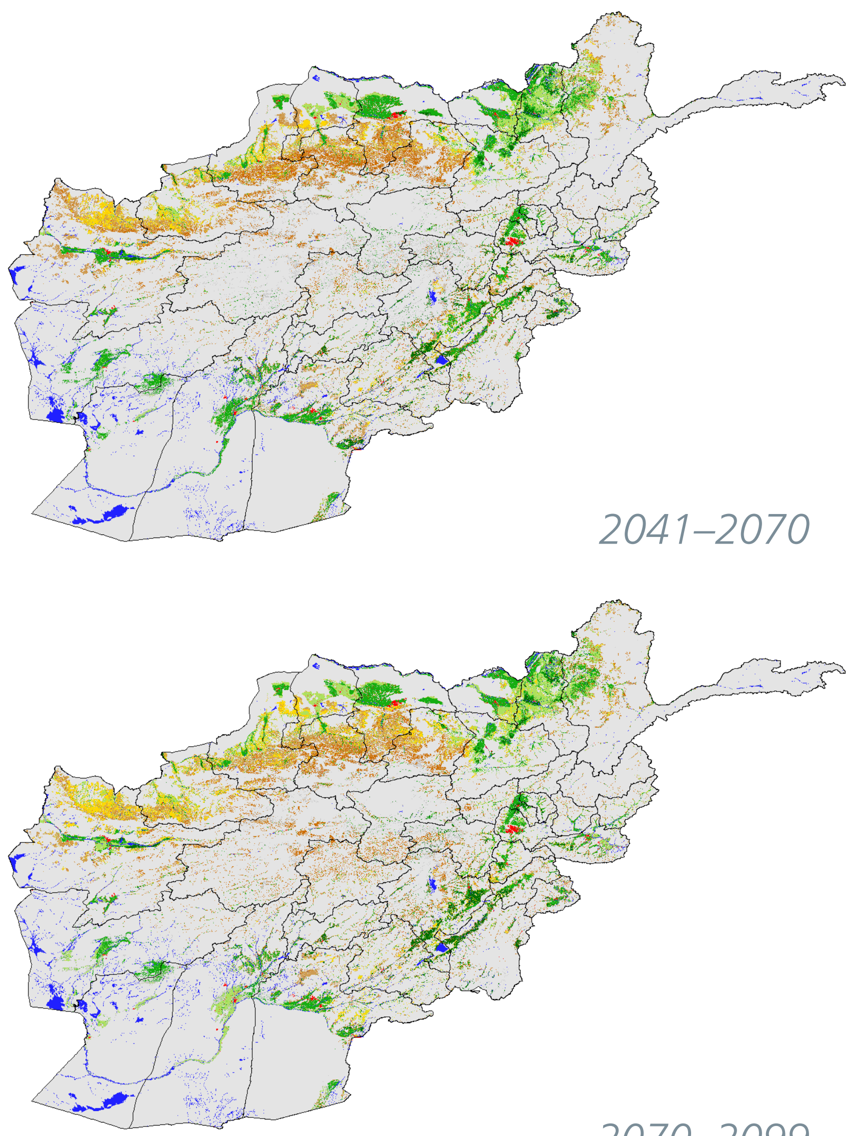
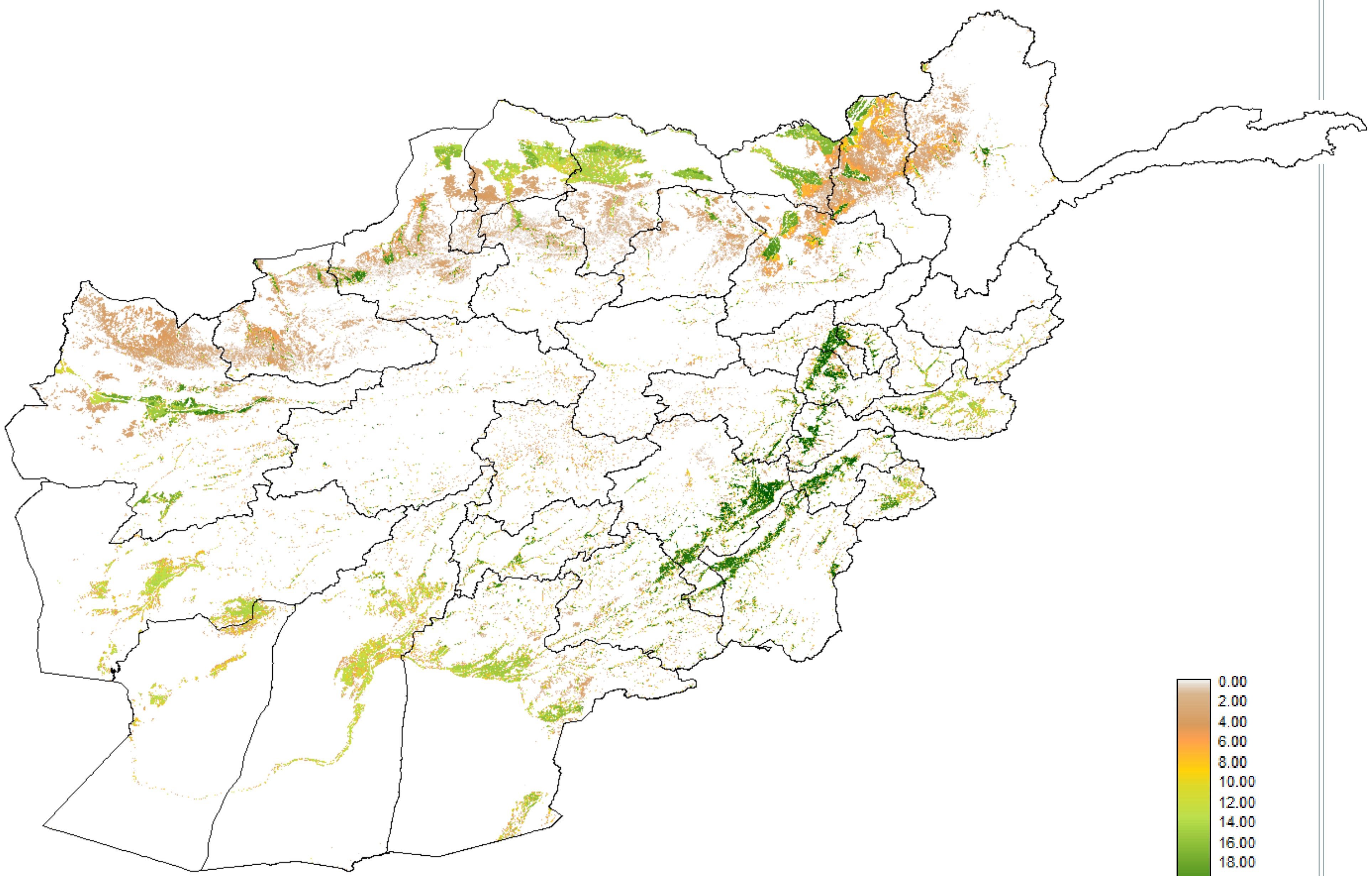


Figure 3.13b, 3.13c

Potential barley production on current cropland (tons), reference climate 1981–2010



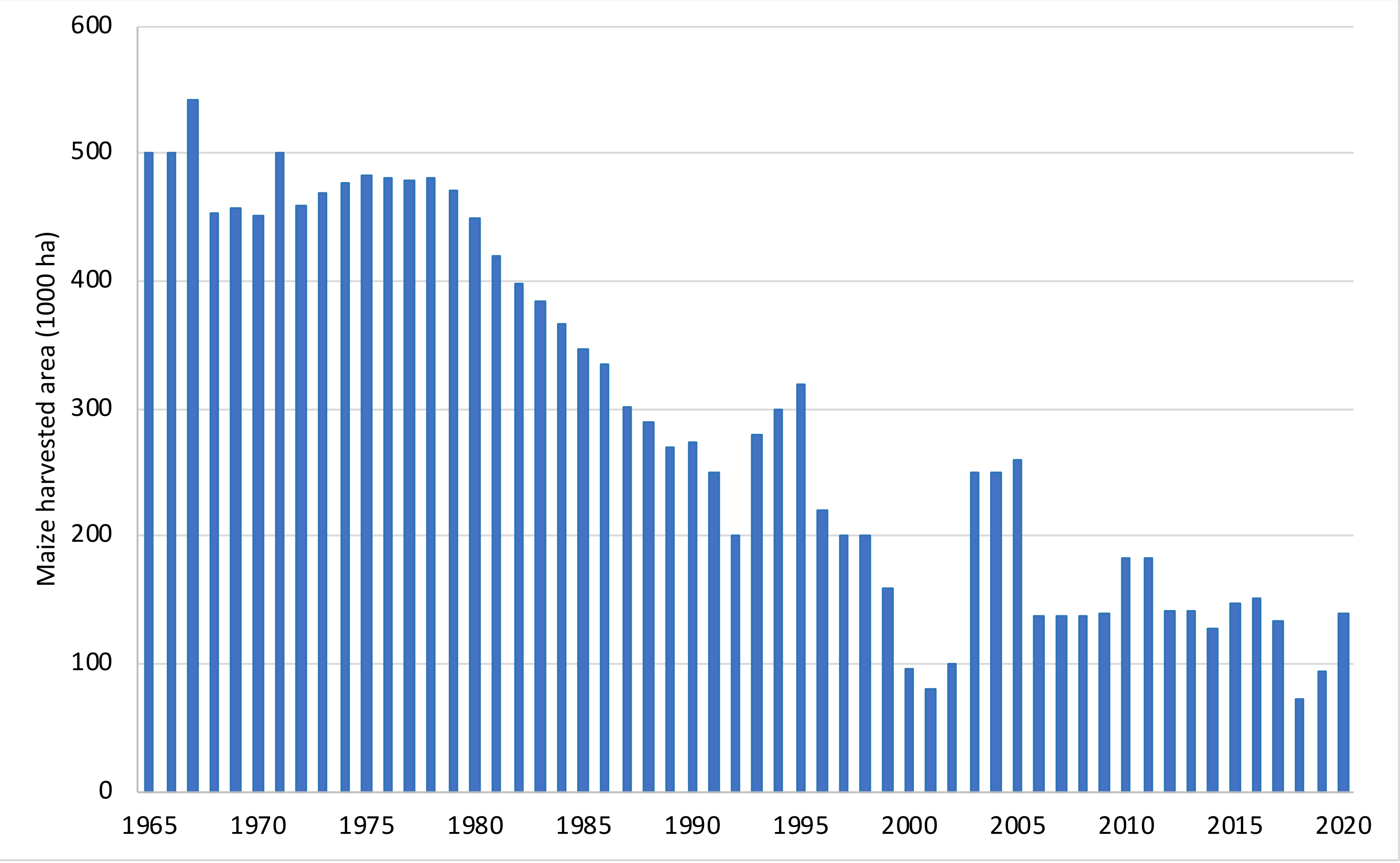
Source: Simulations using historical climate of 1981-2010. Values shown for current cropland refer to potential barley production at intermediate input level per 7.5 arc-seconds grid cell, i.e. about 5 hectares.

Figure 3.14

3.4 Climate change impacts on maize suitability and production

According to data reported in FAOSTAT and the Afghanistan Statistical Yearbook, maize cultivation in Afghanistan occupied a harvested area of more than 400 thousand hectares until the beginning of the 1980s (see Figure 3.15). Since then maize harvested area has been slowly declining, reaching a low point of less than 100 thousand hectares during the drought in 2001, but recovered to an average of about 170 thousand hectares in 2009–11, and an average 142 thousand hectares harvested area in 2014–16 with an average production of 315 thousand tons. In the recent past, due to the drought conditions around 2018, the reported harvested area of maize was again below 100 thousand hectares, but increased to 140 thousand hectares in 2020.

Maize harvested area, Period 1965–2020



Source: FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021; Afghanistan Statistical Yearbook 2020 (NSIA, 2021).

Figure 3.15

Maize (Zea mais)

Maize (temperate and subtropical cultivars for grain and silage maize with growth cycles of 90 to 180 days) is an annual crop belonging to the group of crops with a C4 photosynthesis pathway (C4 II), which is characterized with optimum photosynthesis and growth at temperatures between 20°C and 30°C. Temperatures above 30°C lead to lower photosynthesis and temperatures between 35°C and 40°C may cause heat stress and eventually plant damage, especially during the reproductive phase. Both are leading to lower yields. Maize cannot withstand frost at any stage of its growth. Minimum temperature for germination is 10°C and ideally above 15°C.

Annual rainfall requirements for maize may vary from 500 mm up to 2,000 mm depending on cultivar and environment. Maize is grown in Afghanistan during the dry summer period and is most suitably grown with supplementary or full irrigation.

Table 3.13 Suitability of grain maize on rain-fed and irrigated cropland in 1981-2010, by region

Regions	Rain-fed Cropland	Suitable area and potential production			Irrigated Cropland	Suitable area and potential production		
		Area	Production	Yield		Area	Production	Yield
	1000 ha	1000 ha	1000 tons	tons/ha	1000 ha	1000 ha	1000 tons	tons/ha
Northeastern	1 001.4	158.1	169	1.19	386.9	283.5	1 687	6.61
Northwestern	1 457.3	10.4	8	0.83	636.4	534.7	2 870	5.97
Eastern	0.5	0	0	1.02	165.9	111.7	736	7.32
Central	51.2	0	0	0	250.5	152.8	837	6.09
West-central	76.7	0	0	0	375.7	210.6	1 299	6.85
Western	1 026.3	6.9	5	0.82	610.3	419.6	2 294	6.08
Southeastern	14.7	1	0	1.22	273.8	219.9	1 389	7.02
Southwestern	106.5	0	0	0	900.7	673.9	3 766	6.21
TOTAL	3 734.5	175.6	182	1.16	3 600.2	2 606.8	14 878	6.34

Note: The values shown are suitable extents and potential production on all current rain-fed and irrigated cropland, based on LCDA 2010 land cover. For irrigation conditions the prime (VS), good (S) and moderately (MS) suitable land is included; for rain-fed conditions also marginally suitable areas (mS) are summed up. The assessment assumes an intermediate level of inputs and management.

Table 3.14 Suitability of silage maize on rain-fed and irrigated cropland in 1981-2010, by region

Regions	Rain-fed Cropland	Suitable area and potential production			Irrigated Cropland	Suitable area and potential production		
		Area	Production	Yield		Area	Production	Yield
	1000 ha	1000 ha	1000 tons	tons/ha	1000 ha	1000 ha	1000 tons	tons/ha
Northeastern	1 001.4	284.1	740	2.90	386.9	286.3	2 417	9.38
Northwestern	1 457.3	216.7	377	1.93	636.4	539.3	4 016	8.27
Eastern	0.5	0	0	2.39	165.9	110.6	1 088	10.93
Central	51.2	0.1	0	3.87	250.5	156.8	1 684	11.94
West-central	76.7	0	0	0	375.7	221.3	2 555	12.83
Western	1 026.3	110.3	181	1.83	610.3	424.1	3 315	8.68
Southeastern	14.7	0.3	1	4.92	273.8	222.3	2 504	12.52
Southwestern	106.5	0.4	1	1.67	900.7	680.5	5 331	8.70
TOTAL	3 734.5	611.9	1 301	2.36	3 600.2	2 641.1	22 909	9.64

Note: The values indicate suitable extents and production on all rain-fed and irrigated cropland, based on LCDA 2010 land cover. For irrigation conditions the prime (VS), good (S) and moderately (MS) suitable land is included; for rain-fed conditions also marginally suitable areas (mS) are summed up. The assessment assumes an intermediate level of inputs and management. Production and yield is given as dry weight.

Maize does not tolerate frost and must be grown in summer. Hence, its crop calendar is not directly in competition with wheat or barley, but during the dry summer period irrigation is required for cultivation in nearly all cropland areas of Afghanistan. Only about 5% of the rainfed cropland was assessed as potentially suitable for rain-fed maize production, most of which was found in the Northeastern region. With irrigation, maize can be grown in all regions, but farmers will often prefer to grow higher value alternative crops rather than grain maize. Comparing the simulated land suitability and potential production of the period 1961–1990 and the period 1981–2010, the national results are nearly the same, with minor improvements of irrigated production potential and some reduction in the relatively small rain-fed potential.

The largest total extents of suitable land for irrigated grain maize are located in Southwestern region, followed by the Northwestern and Western region (see Table 3.13). The same ranking holds for potential production. Average attainable irrigated yield of intermediate-input grain maize at the national level is 6.3 tons per hectare, ranging across regions from 6.0 tons per hectare (Northwestern region) to 7.3 tons per hectare (Eastern region).

Suitability of rain-fed maize is somewhat better when grown for silage rather than for grain, but suitable extents and yields without irrigation remain low (see Table 3.14). With irrigation, 2.6 million hectares out of 3.6 million hectares irrigated cropland were assessed as suitable with an average attainable above-ground dry matter yield of 9.6 tons per hectare and a range of average potential yields across regions of 8.3 (Northwestern region) to more than 12 tons per hectare (West-Central and Southeastern region).

Table 3.15 presents an overview of climate change impacts on the extents of cropland suitable for grain maize on current rain-fed land and on cropland equipped for irrigation. Results refer to the ensemble means of crop simulation outcomes using climate projections of five climate models and for two RCPs, namely RCP4.5 and RCP8.5.

At the national level and in almost all regions, except Southwestern region, the extents suitable for grain maize increase with climate change by the 2050s. This trend continues to the 2080s. Only for the Southwestern region the suitable area decreases somewhat with progressing climate change. In contrast, for the ensemble mean of results, the national average potential grain maize yield calculated over all suitable cropland decreases slightly with climate change in the 2050s and by -2% to -7% in the 2080s, depending on climate scenario.

There are quite large differences between different regions in magnitude and direction of changes of average attainable yields for grain maize. While Central, West-Central and Southeastern regions experience some increases of average grain maize yields, the opposite occurs in all other regions, especially in the Northeastern region where, however, the largest increase of suitable grain maize area occurs.

Table 3.15 Climate change impacts on suitable cropland and attainable yield for grain maize

Regions	Suitable Area (1000 ha)	% Change relative to 1981-2010				Attainable Yield (tons/ha)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	441.6	20.7	33.8	23.7	35.5	4.67	-9.9	-16.2	-12.0	-19.2
Northwestern	545.1	1.6	2.5	1.4	3.7	5.87	-3.5	-4.7	-4.2	-14.0
Eastern	111.7	0.5	0.7	0.7	0.4	7.32	-1.5	-1.8	-2.9	-6.6
Central	152.8	10.1	11.9	12.2	18.5	6.09	18.3	20.6	20.7	21.0
West-central	210.6	11.6	13.1	13.1	15.4	6.85	6.9	7.3	7.2	6.9
Western	426.5	1.5	1.6	1.7	1.7	5.99	-0.3	-1.1	-2.1	-6.1
Southeastern	220.1	1.8	1.9	1.7	1.5	7.01	6.7	7.3	6.8	4.7
Southwestern	673.9	-0.8	-1.2	-1.6	-5.4	6.21	-0.8	-1.5	-1.9	-5.1
TOTAL	2 782.3	5.2	7.6	5.7	7.6	6.01	-0.6	-2.4	-1.5	-6.6

Note: Percentage changes were calculated relative to the outcomes of historical period 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland.

Table 3.16 Climate change impacts on suitable cropland and attainable yield for silage maize

Regions	Suitable Area (1000 ha)	% Change relative to 1981-2010				Attainable Yield (tons/ha)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	570.4	7.6	28.5	8.9	29.6	6.15	-2.1	-11.9	-1.8	-10.2
Northwestern	756.1	-4.5	-3.6	-8.8	-13.8	6.46	-11.2	-11.1	-7.2	-7.8
Eastern	110.6	-0.6	0.9	-0.1	0.9	10.93	6.9	10.1	9.7	7.3
Central	156.8	11.6	11.3	12.5	18.3	11.94	7.6	5.0	6.4	-5.8
West-central	221.3	10.2	13.1	11.4	13.3	12.83	-9.1	-16.9	-12.5	-19.2
Western	534.5	-1.8	0.2	-5.3	6.1	7.27	-5.7	-4.3	0.6	-8.6
Southeastern	222.6	0.9	2.8	1.1	1.3	12.51	-7.3	-11.1	-8.8	-14.2
Southwestern	680.9	-0.7	-0.7	-1.4	-3.1	8.70	-5.2	0.6	1.7	5.3
TOTAL	3 253.1	1.1	5.7	-0.2	4.2	8.27	-4.5	-6.7	-1.6	-6.6

*NE: Northeastern; NW=Northwestern; EA=Eastern; CE=Central; WC=West Central; WE=Western; SE=Southeastern; SW=Southwestern

Note: Percentage changes were calculated relative to the outcomes of historical period 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland. Yield is given as dry weight.

Table 3.16 presents an overview of climate change impacts on attainable yields and the extents of cropland suitable for silage maize. Results refer to the ensemble means of crop simulation outcomes using climate projections of five climate models and for two RCPs, namely RCP4.5 and RCP8.5.

For suitable areas, there are substantial increases projected mainly for the Northeastern region (2050s: 8-9%; 2080s: 28-30%), Central region (2050s: 12%; 2080s: 11-18%) and West-Central region (2050s: 10-11%; 2080s: 13%). Some reduction of suitable silage maize area may occur in the Northwestern and Southwestern region.

Average attainable silage maize yield at the national level decreases in the different scenarios by -2 to -5% in the 2050s and by -7% in the 2080s, which in all scenarios is more than the net increases of suitable areas. The largest yield decreases occur in the regions where suitable area increases most, which indicates that the gained additional suitable area will be less productive than the average of current suitable cropland.

When combining changes of suitable areas and average attainable yields, increases of potential grain maize production relative to 1981–2010 (see Table 3.17) are found in Central region (2050s: 31-36%; 2080s: 35-43%), West-Central region (2050s: 19-21%; 2080s: 21-23%), Northeastern region (2050s: 9%; 2080s: 10-12%) and Southeastern region (2050s: 9%; 2080s: 6-10%). Sizeable negative regional simulation outcomes for grain maize potential occur only under RCP8.5 in the 2080s, namely by for both the Northwestern (-11%) and Southwestern (-10%) region. Overall, at the national level, minor net increases of the grain maize potential were simulated in all scenarios in the range of 1-5%.

Table 3.17 summarizes also the changes in total net irrigation volumes (million m^3) required to achieve the potential grain maize production of irrigated land. Irrigation demand of grain maize increases in several regions quite substantially with climate change, which is the combined outcome of multiple factors, including (i) changing suitability of maize areas, (ii) changes in crop types selected as representative in a grid cell, and (iii) changing crop calendars. In the simulations the total irrigation water volume increases for grain maize at national level by 4-6%, with slight decreases due to lost production potential in Western and Southwestern region and much larger increases in the regions where suitable extents expand due to warming, particularly in the Central, West-Central and Southeastern region.

Table 3.17 Climate change impacts on grain maize production potential and net irrigation demand

Regions	Potential Production (1000 tons)	% Change relative to 1981-2010				Net Irrigation Volume (million m^3)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	1 856	8.7	12.1	8.8	9.4	1 395	11.4	13.5	13.0	16.3
Northwestern	2 878	-2.0	-2.3	-2.9	-10.9	3 505	2.0	1.6	2.2	-4.1
Eastern	736	-1.0	-1.1	-2.3	-6.2	446	17.4	23.5	23.2	30.3
Central	837	30.3	35.0	35.5	43.4	458	43.2	53.7	54.3	84.8
West-central	1 299	19.3	21.4	21.3	23.3	1 004	22.3	29.2	26.2	45.8
Western	2 299	1.1	0.5	-0.3	-4.5	3 981	-1.6	-1.0	-1.6	-3.6
Southeastern	1 389	8.6	9.4	8.6	6.3	879	17.8	25.4	22.1	39.0
Southwestern	3 766	-1.6	-2.6	-3.4	-10.2	5 294	-2.5	-2.5	-4.4	-6.7
TOTAL	15 060	4.6	5.1	4.1	0.6	16 962	4.1	5.6	4.6	5.4

Note: Percentage changes were calculated relative to the historical averages of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland. Crop water demand and soil moisture deficits were calculated for irrigated cropland that is very suitable, suitable or moderately suitable for grain maize. Water volumes refer to net irrigation water requirements (i.e., the amount to be taken up by the plants) assuming all water deficits are fully met by irrigation.

Table 3.18 Climate change impacts on silage maize production potential and net irrigation demand

Regions	Potential Production (1000 tons)	% Change relative to 1981-2010				Net Irrigation (million m³)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	3 158	5.4	13.2	6.9	16.4	913	-2.4	-2.0	0.9	5.5
Northwestern	4 393	-15.2	-14.4	-15.3	-20.5	2 275	-13.5	-14.3	-12.2	-21.4
Eastern	1 088	6.3	11.1	9.6	8.2	349	22.8	29.6	32.3	34.6
Central	1 684	20.1	16.9	19.7	11.5	437	40.6	43.7	48.6	56.3
West-central	2 555	0.2	-6.1	-2.5	-8.4	978	15.9	9.5	15.8	16.2
Western	3 496	-7.4	-4.1	-4.7	-3.1	2 695	-12.1	-9.4	-8.3	-10.6
Southeastern	2 505	-6.4	-8.6	-7.8	-13.1	814	11.4	10.6	14.2	18.0
Southwestern	5 331	-5.9	-0.1	0.3	2.0	3 649	-5.5	-1.3	-1.4	1.0
TOTAL	24 210	-3.4	-1.4	-1.8	-2.7	12 109	-2.9	-1.4	0.4	-0.1

Note: Percentage changes were calculated relative to the historical averages of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland. Crop water demand and soil moisture deficits were calculated for irrigated cropland that is very suitable, suitable or moderately suitable for grain maize. Production is given as dry weight. Water volumes refer to net irrigation water requirements (i.e., the amount to be taken up by the plants).

The general directions of climate changes impacts on potential silage maize production are quite similar to the impacts found for grain maize. Results are summarized in Table 3.18. At the national level small negative changes of the potential production of silage maize are projected in all scenarios. Increases of production will foremost occur in Northeastern, Central and Eastern region. Substantial losses are projected for Northwestern and Southeastern region.

Associated changes of net irrigation volumes, needed to achieve the respective silage maize potential production, are small at aggregate national level. Regional outcomes of irrigation demand vary greatly across regions. They depend on crop calendar shifts and are affected by changes in regional suitable area and potential production. Large increases of ensemble mean potential irrigation demand for silage maize can be expected in Central, West-Central, Eastern and Southeastern region. Reductions of irrigation demand due to negative climate change impacts on potential production were simulated mainly for the Northwestern region and the Western region.

Index of potential grain maize production capacity (1981–2010 = 100)

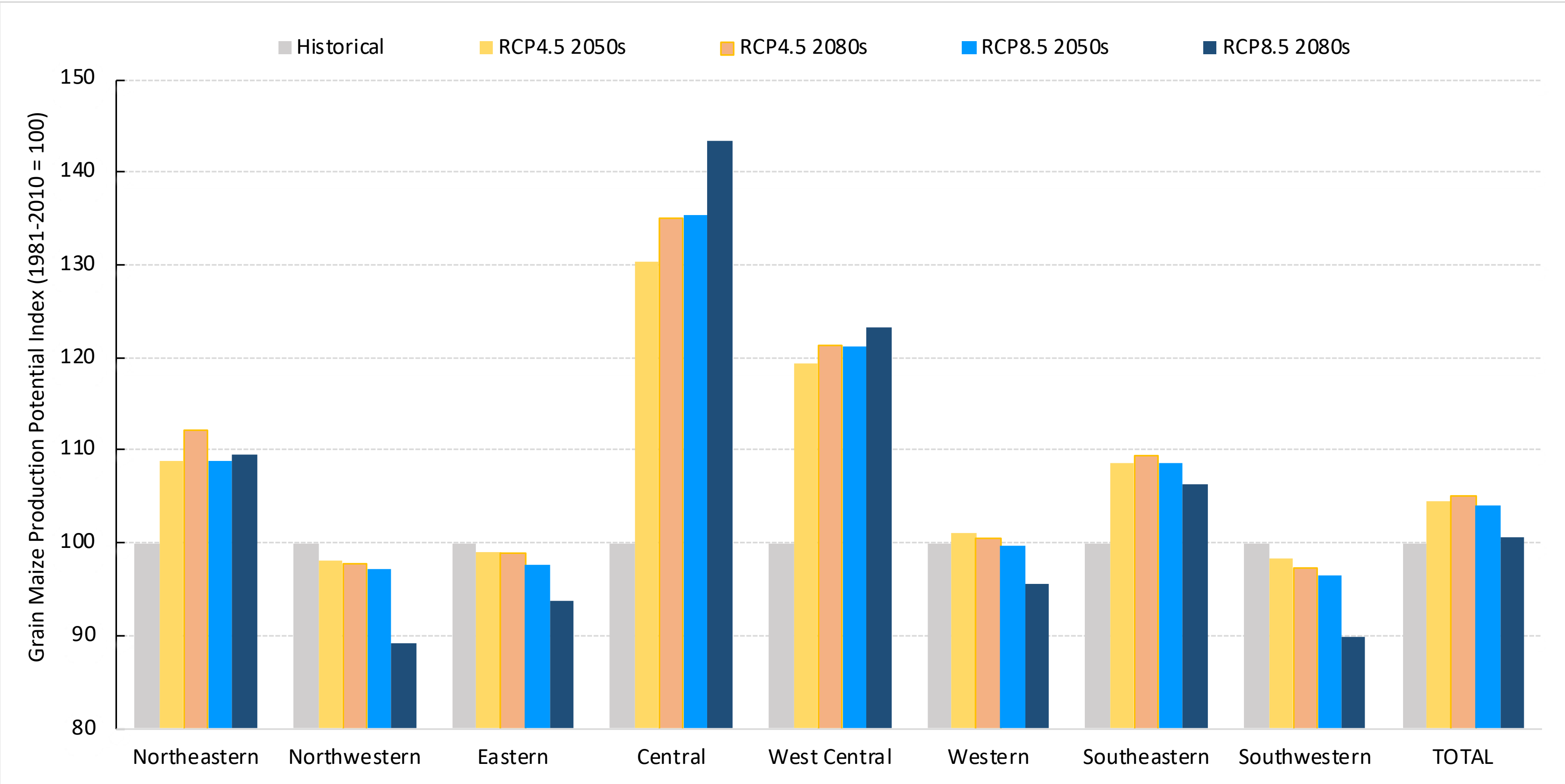


Figure 3.16

Figure 3.16 shows a bar-chart with results for grain maize by region for respectively RCP4.5 and RCP8.5, using an index of potential grain maize production in the 2050s and the 2080s and where each region's potential production during 1981–2010 is set to 100. It highlights the large improvements of maize production capacity in Central and West-Central region, which together with gains in Northeastern and Southeastern region produce a moderate improvement at the national level.

In contrast, Northwestern, Southwestern and Eastern region experience with climate change increasing losses of grain maize production capacity.

Figure 3.17 presents results of projected production changes for silage maize. In this case the regional pattern of impacts is quite similar to that of grain maize but produces small overall losses at national level due to the fact that the model parameterization for silage maize is less tolerant to high temperatures than for grain maize.

Index of potential silage maize production capacity (1981–2010 = 100)

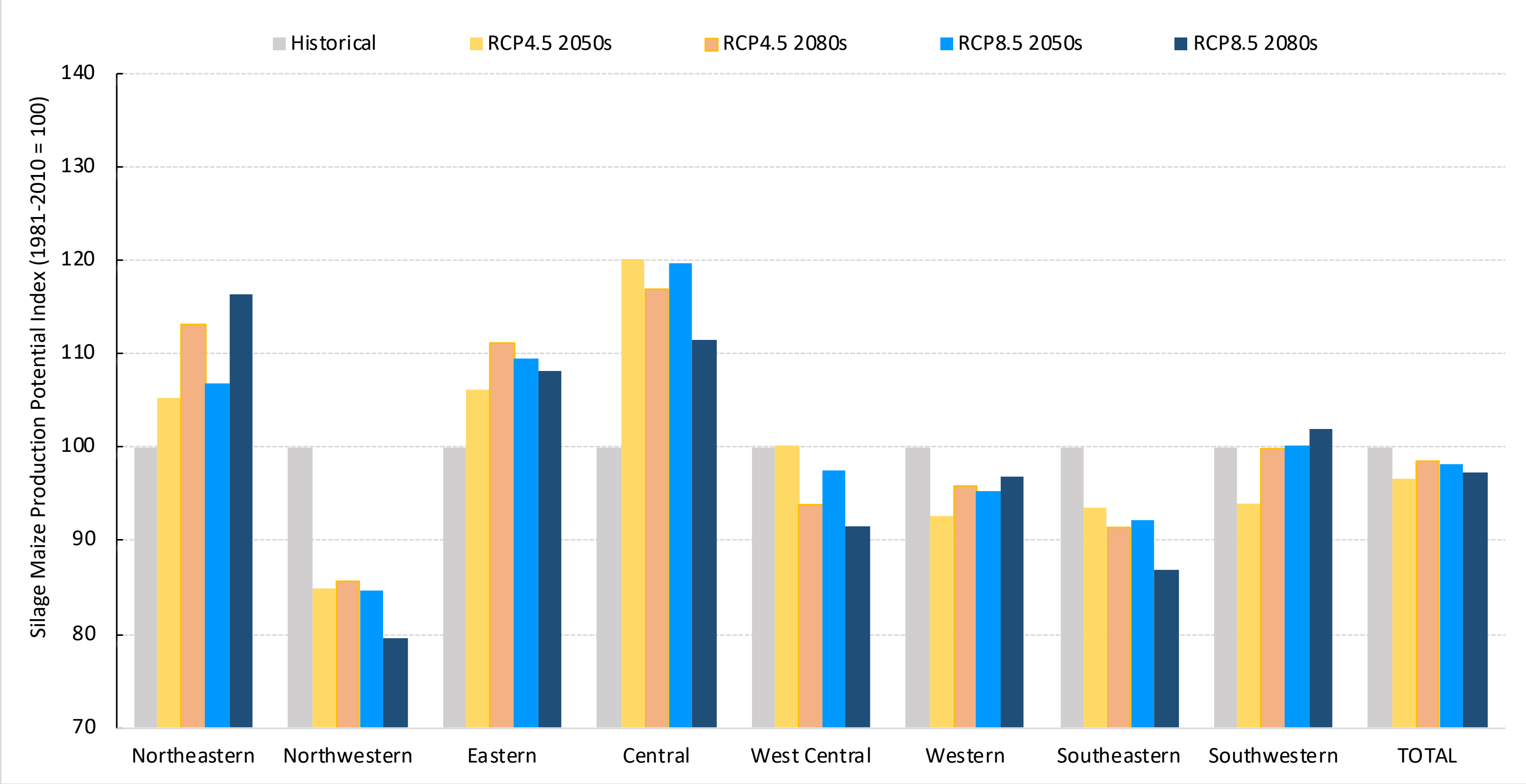


Figure 3.17

Figure 3.18 indicates for historical climate and future climate scenarios the impact of climate change on net irrigation water volumes (i.e., without accounting for irrigation system efficiency) required to achieve the potential grain maize production on suitable irrigated cropland. The NAEZ results clearly indicate that with more intense climate change scenarios a substantially higher irrigation water demand will occur in the regions where potential production conditions improve most.

As shown in Figure 3.18, increases of required irrigation water volumes are particularly large in Central, West-Central, Southeastern and Eastern region.

Index of net irrigation water volume for grain maize (1981–2010 = 100)

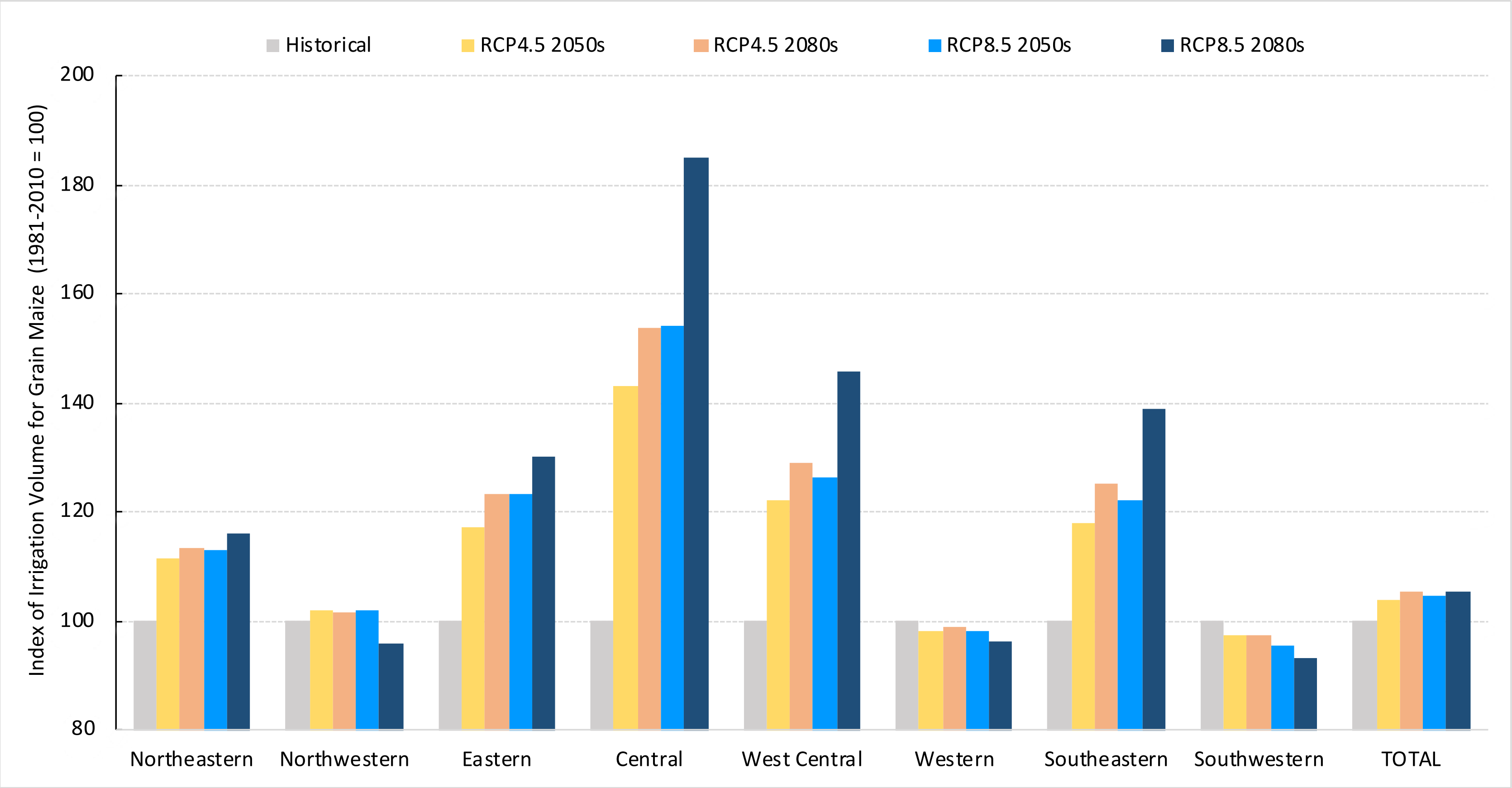
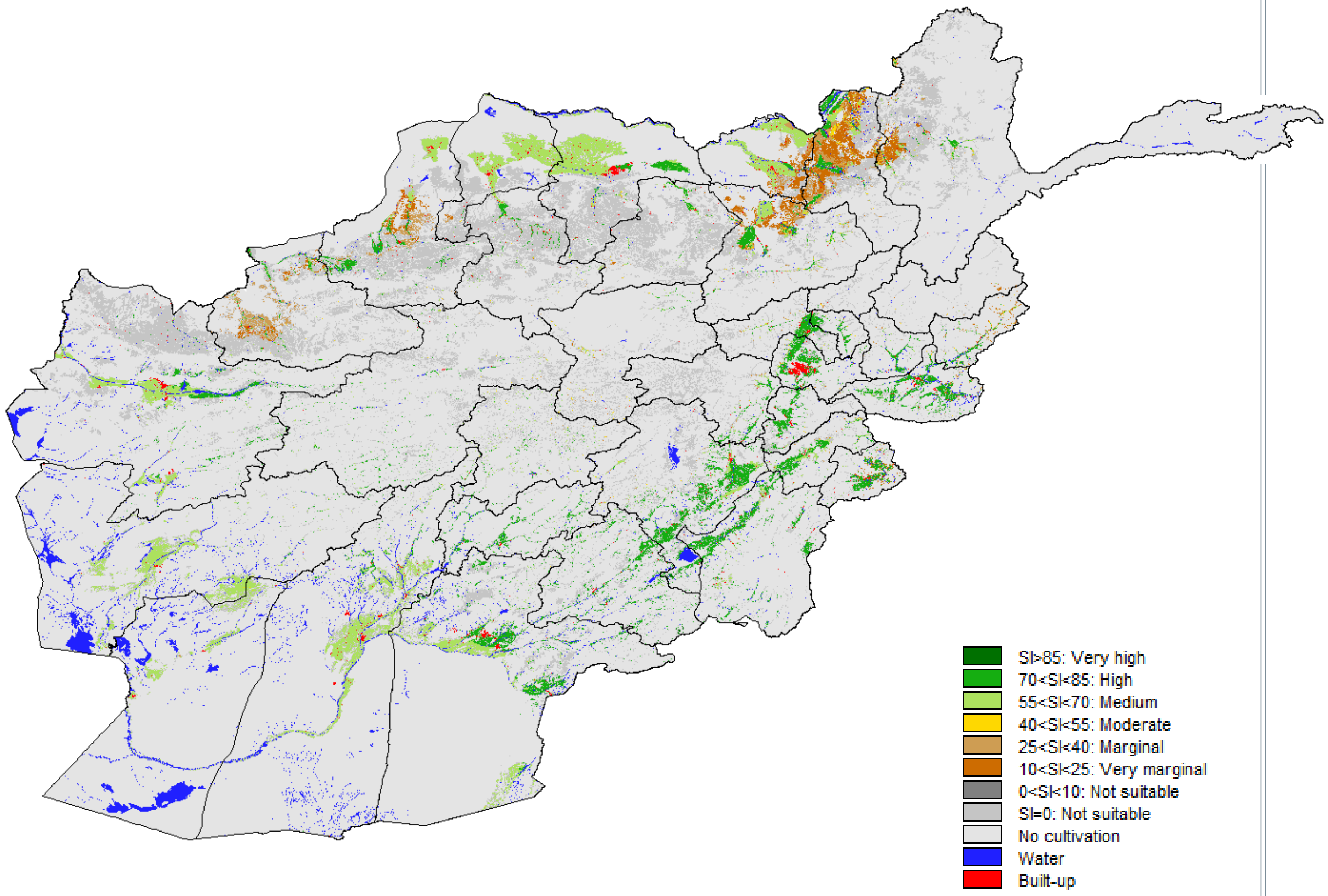


Figure 3.18

The normalized suitability index SI is used in Figure 3.19 to portray cropland suitability for grain maize cultivation at intermediate input level for historical period 1981–2010 and an ensemble mean of results for RCP8.5 in periods 2041–2070 and 2070–2099.

Note, except for the Northeastern region, suitable grain maize areas under historical climate are mainly limited to irrigated croplands.

Grain maize suitability index class of current cropland Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current cropland refer to average suitably class.

Figure 3.19a

Ensemble mean, RCP8.5, 2041–2070–2099

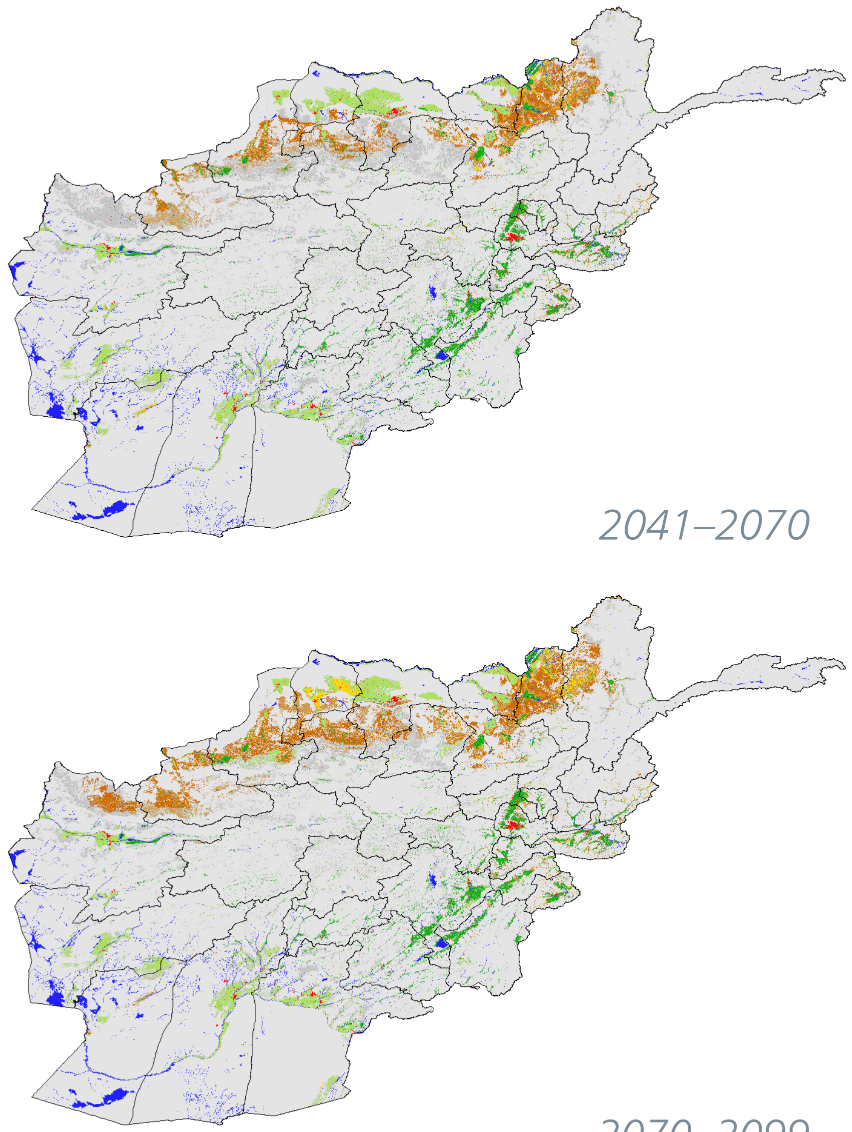
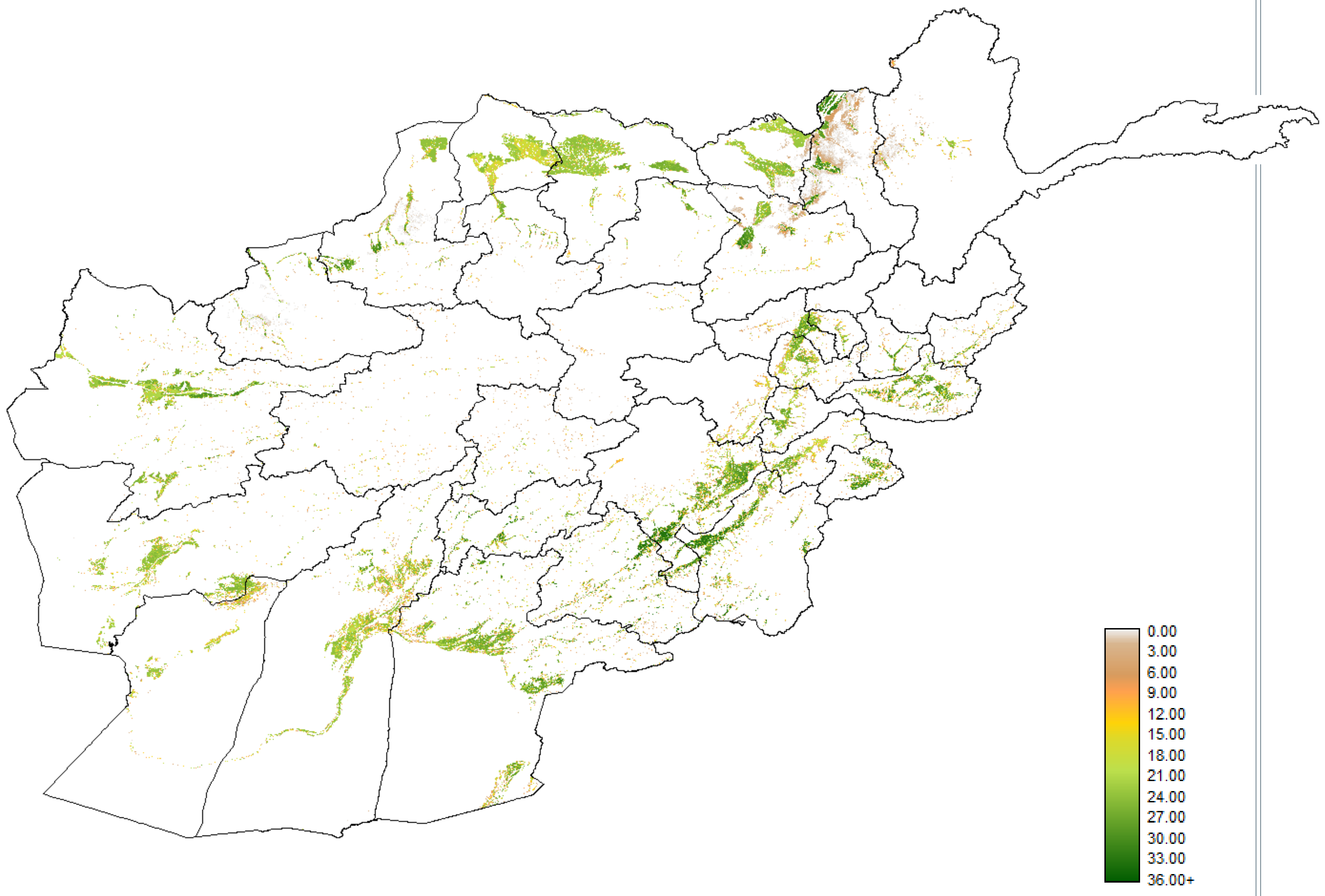


Figure 3.19b, 3.19c

By combining yields and the occurrence of suitable cropland, Figure 3.20 maps the spatial production potential of grain maize in the reference period 1981–2010 in grid cells with rain-fed or irrigated cropland. As for suitable areas, potential grain maize production mainly occurs on irrigated croplands.

Figure 3.21 shows maps of net irrigation requirements (mm) for grain maize cultivation on current irrigated cropland respectively for the historical period 1981–2010 (Figure 3.21a) and for an ensemble mean of simulations under RCP8.5 in the 2050s (Figure 3.21b) and 2080s (Figure 3.21c). The maps indicate large increases in irrigation requirements especially for the Central, West-Central, Northeastern, Eastern and Southeastern region. These are also the areas where the largest increases of suitable areas and potential yield occur.

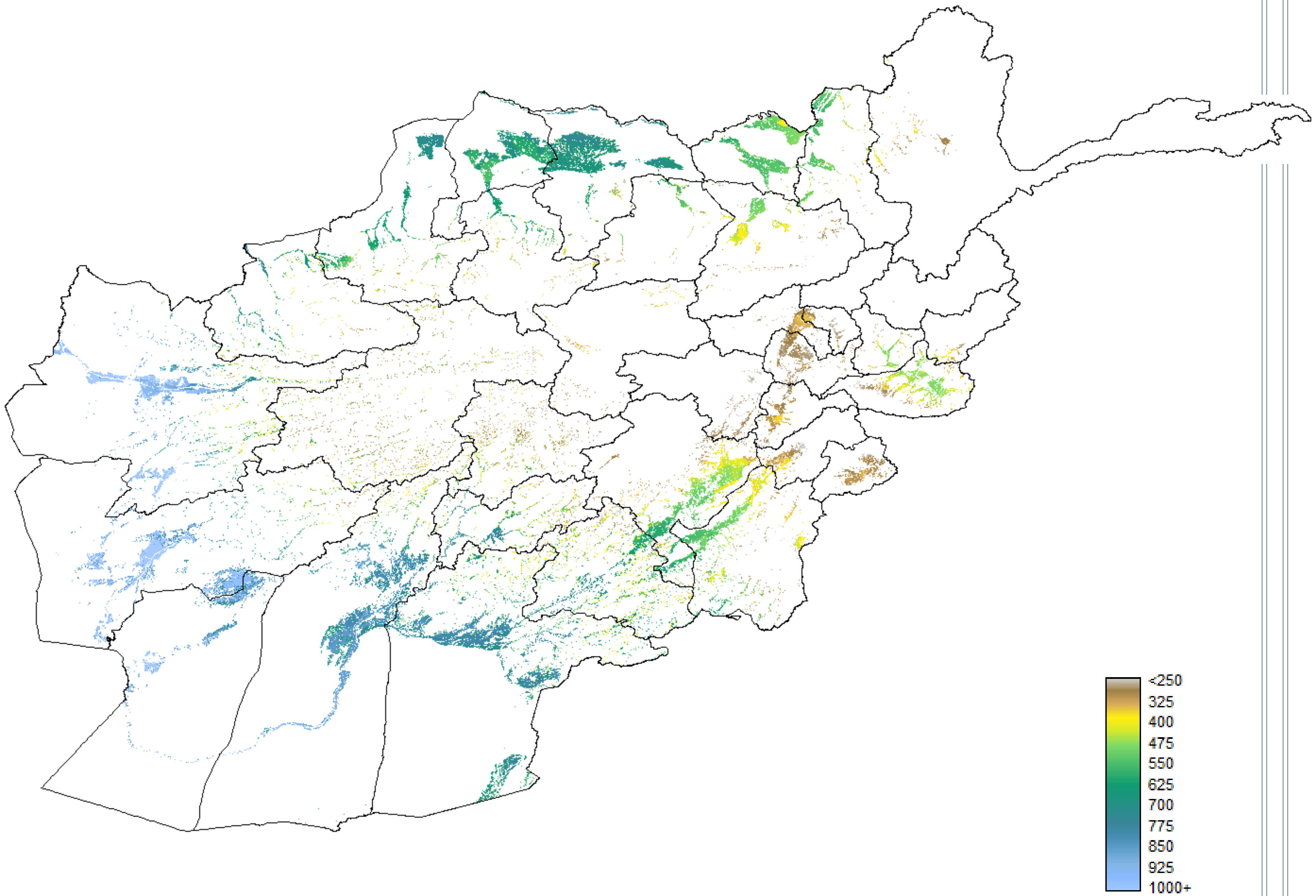
Potential grain maize production on current cropland (tons), Reference climate 1981–2010



Source: Values shown for current cropland refer to potential maize production per 7.5 arc-seconds grid cell, i.e. about 5 hectares.

Figure 3.20

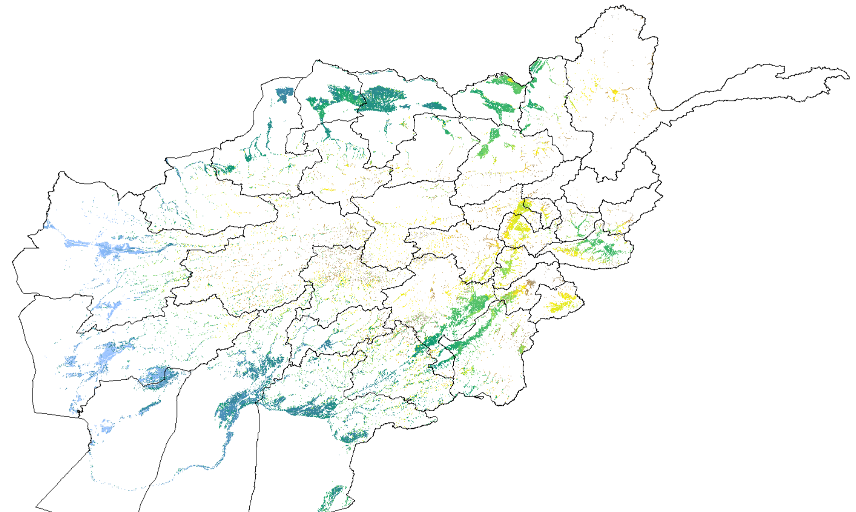
Water deficit (mm) during the grain maize growth cycle, Reference climate 1981–2010



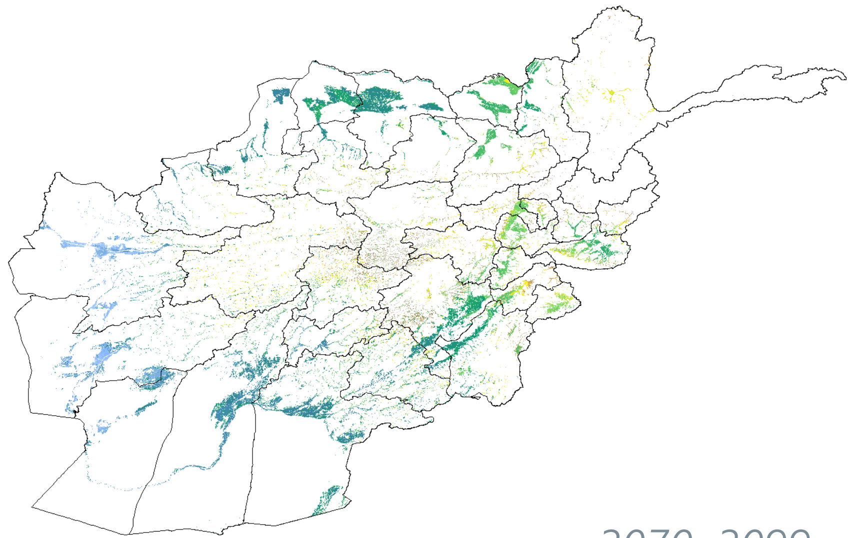
Source: Simulations using historical climate of 1981-2010. Water deficits (mm) shown indicate for 7.5 arc-second grid cells the net irrigation demand to fully meet water requirements for grain maize cultivation on current irrigated cropland.

Figure 3.21a

Ensemble mean, RCP8.5, 2041–2070–2099



2041–2070



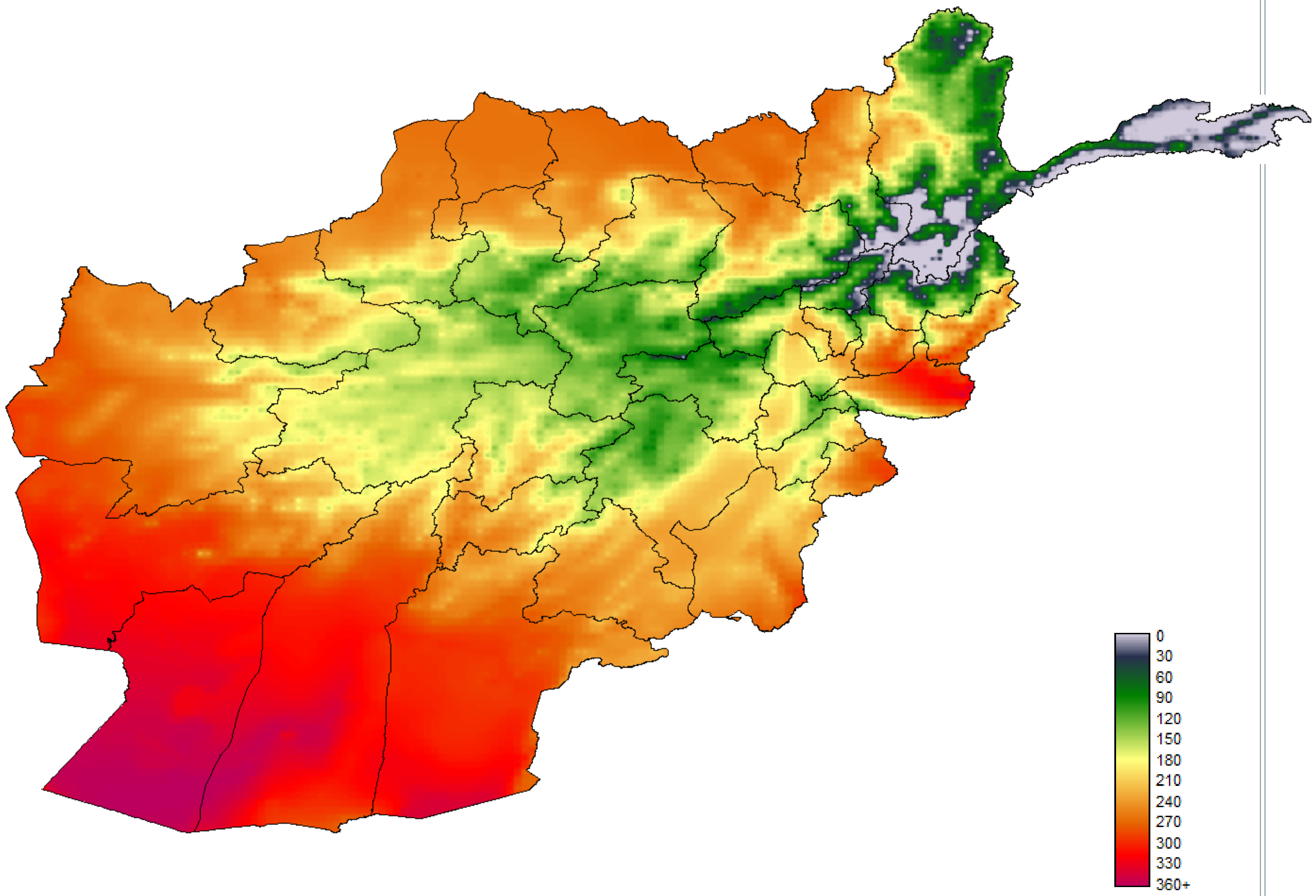
2070–2099

Figure 3.21b, 3.20c

As can be seen when comparing days shown in Figure 3.22b and Figure 3.22c with the number of days shown for the base period in Figure 3.22a, the considerable increase of the time period during a year when mean daily temperature exceeds 10°C (Figure 3.22) allows shifting the crop calendar of grain maize closer towards the beginning of the year. For winter rainfall areas, such as in Afghanistan, this means that rain-fed grain maize production can benefit where rain-fed production is possible by exploiting better soil moisture conditions prevailing in winter and spring provided the harvesting date of the winter crop (earlier than now due to shorter cold periods) allows for such shifts. The consequences for maize production on irrigated land depend on factors such as radiation, temperature regime and crop cycle length and negative impacts on attainable irrigated yield occur in several regions.

The NAEZ analysis assessed crop suitability and production potential of irrigated land but did not quantify reliability of irrigation supply and climate change impacts on water resources and water availability for agriculture. Note, about 31% of the irrigated land (excluding fruit trees and vineyards) is classified as 'Poorly irrigated' in LCDA 2010. While the share of the poorly irrigated cropland is only 7.5% in the Northeastern region, it is about a third in West-Central (33.6%) and Southwestern (32.0%) region, 40.8% in Western region and half (50.2%) in Southeastern region.

Length of the period with average daily temperature above 10°C (days), Historical mean, period 1981–2010



Source: Simulations using historical climate of 1981-2010. Values shown indicate the number of days with average daily temperature Ta > 10°C.

Figure 3.22a

Ensemble mean, RCP8.5, period 2041–2070–2099

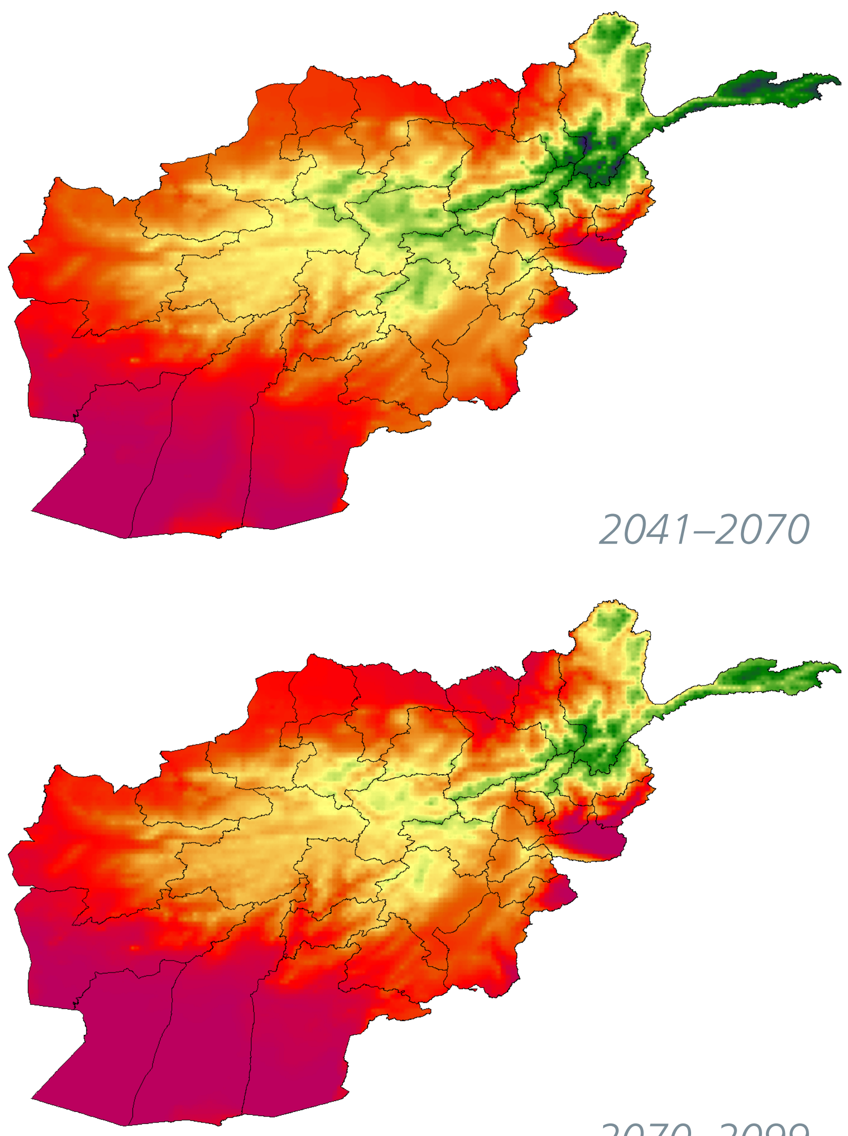


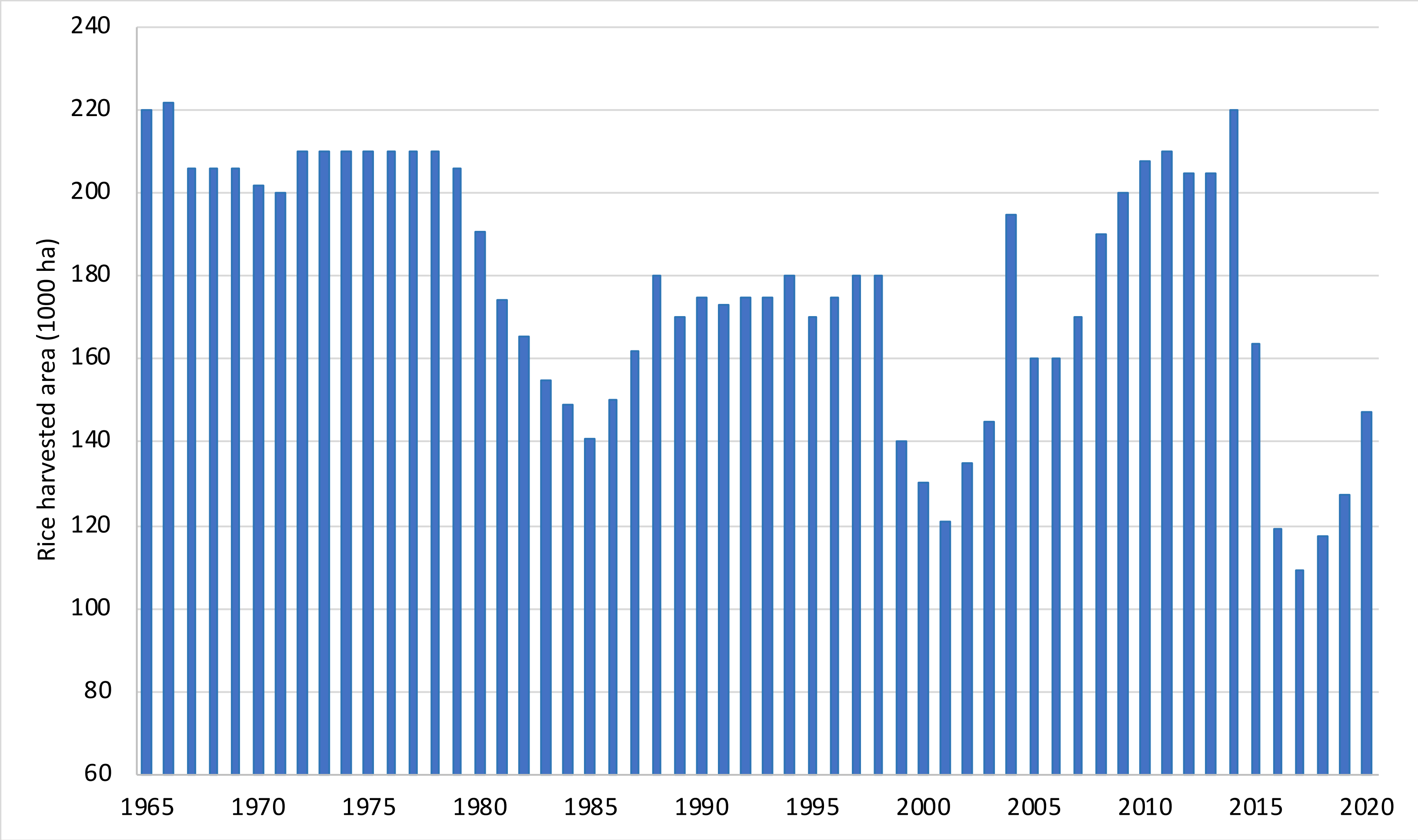
Figure 3.22b, 3.22c

3.5 Climate change impacts on rice suitability and production

According to data reported in FAOSTAT (Source: http://www.fao.org/faostat/en/#data/QC), rice cultivation in Afghanistan occupied a harvested area of about 210 thousand hectares until the beginning of the 1980s (see Figure 3.23). After somewhat lower rice acreages in the 1980s and 1990s, average planted rice area was 206 thousand hectares in 2009–11, and 168 thousand hectares in 2014–16 with an average production of 435 thousand tons. The lowest recorded rice acreages of 120 thousand hectares and less were observed due to drought conditions in 2001 and around 2018.

The climatic characteristics and requirements of japonica rice allow to grow it in moderately warm to warm environments on flat terrain where ample and reliable irrigation is available. For historical climate such conditions were best realized in Afghanistan in the Northeastern region (about 70% of rice cultivated area in Afghanistan during 2014–16) and the Eastern region (about 20% of total rice area in 2014–16).

Rice harvested area, Period 1965–2020



Source: FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021; Afghanistan Statistical Yearbook 2020 (NSIA, 2021).

Figure 3.23

Rice (Oryza sativa)

In general, paddy rice can be grown under a wide range of climatic conditions, from temperate to hot tropical climates. Growth is optimal at air temperatures between 24°C and 36°C. Standing water temperature should exceed 18°C.

More specifically, japonica rice (with growth cycles of 105 to 195 days) and indica rice (with growth cycles of 105 to 150 days) belong to the C3 crop group (C3 II) and are characterized with optimum photosynthesis and growth at temperatures between 25°C and 30°C. For both japonica rice and indica rice temperatures above 30°C lead to lower photosynthesis and high temperatures, in particular for the less heat tolerant japonica rice, above 35°C cause heat stress and when occurring during reproductive phase may cause sterility. On the other hand, indica rice is less cool temperature tolerant than japonica, which can be transplanted at substantially lower temperatures, making it more suitable in subtropical and temperate zones. Both rice types are here assumed to be grown under irrigated conditions in bunded fields with water-level control. Low rainfall/water supply, in particular during flowering or at maturity, may adversely affect yields. Rice cultivation in bunded fields involves large amounts of water, which renders it more appropriate to grow in sub-humid and humid environments.

Table 3.19 presents suitability and potential production of Afghanistan's cropland (spatial distribution of cropland has been derived from LCDA 2010 land cover and amounts to about 7.3 million ha) when assessed for producing paddy rice. According to agronomic criteria the largest potentially suitable extents for rice exist in the Southwestern and Western region, followed by Northeastern region. While rice has been actually widely cultivated in the Northeastern region and to some extent in the Western region, rice is hardly ever cultivated in the Southwestern region where water is scarce, the climate allows year-round cultivation and rice has to compete with alternative higher value options available to farmers, e.g., such as fruits and melons. Comparing the simulated land suitability and potential production of the period 1961-1990 and the period 1981–2010, the results suggest a modest improvement (a plus of 1-4%) in northern regions and central highlands.

Table 3.19 Suitability of paddy rice on rain-fed and irrigated cropland in 1981-2010, by region

Regions	Rain-fed Cropland	Suitable area and potential production			Irrigated Cropland	Suitable area and potential production		
		Area	Production	Yield		Area	Production	Yield
	1000 ha	1000 ha	1000 tons	tons/ha	1000 ha	1000 ha	1000 tons	tons/ha
Northeastern	1 001.4	0	0	0	386.9	184.4	527	3.17
Northwestern	1 457.3	0	0	0	636.4	121.7	334	3.05
Eastern	0.5	0	0	0	165.9	81.7	242	3.29
Central	51.2	0	0	0	250.5	109.2	329	3.35
West-central	76.7	0	0	0	375.7	165.3	482	3.24
Western	1 026.3	0	0	0	610.3	260.4	685	2.92
Southeastern	14.7	0	0	0	273.8	164.5	483	3.27
Southwestern	106.5	0	0	0	900.7	455.9	1 207	2.94
TOTAL	3 734.5	0	0	0	3 600.2	1 543.2	4 290	3.09

Note: The values shown are suitable extents and potential production on current cropland, based on LCDA 2010 land cover. For irrigation conditions the prime (VS), good (S) and moderately (MS) suitable land is included. The assessment assumes an intermediate level of inputs and management.

Table 3.20 Climate change impacts on suitable cropland and attainable yield for paddy rice

Regions	Suitable Area (1000 ha)	% Change relative to 1981-2010				Attainable Yield (tons/ha)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	184.4	-4.0	-5.6	-7.6	-30.7	3.17	-0.6	-0.9	-0.9	0.2
Northwestern	121.7	-1.8	-2.2	-3.7	-13.4	3.05	-2.9	-3.9	-3.9	-8.9
Eastern	81.7	0.1	-0.8	-1.8	-7.8	3.29	-1.9	-2.1	-2.8	-6.7
Central	109.2	18.0	18.8	18.7	21.0	3.35	5.6	6.5	6.3	5.7
West-central	165.3	7.8	8.7	9.1	10.8	3.24	2.3	2.3	1.9	0.0
Western	260.4	-8.4	-5.9	-6.2	-19.5	2.92	-1.7	-3.1	-3.9	-8.5
Southeastern	164.5	9.9	10.0	10.1	9.3	3.27	0.9	0.9	0.2	-2.4
Southwestern	455.9	-9.8	-8.4	-9.0	-19.5	2.94	-3.3	-4.3	-4.9	-9.0
TOTAL	1 543.2	-1.7	-1.0	-1.6	-10.6	3.09	-0.2	-0.8	-1.2	-3.7

Note: The shown percentage changes were calculated relative to the historical average of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland.

Table 3.20 presents an overview of climate change impacts on the extents of current cropland suitable for rice and lists changes of average attainable potential rice yields. Results refer to the ensemble means of crop simulation outcomes using climate projections of five climate models and for two RCPs, namely RCP4.5 and RCP8.5.

At the national level the total extents suitable for rice change only little with climate change by the 2050s, but show quite noticeable positive and negative changes at the regional level. By the 2080s under RCP8.5 a decrease of suitable areas by -10.6% is simulated, with some gains in the Central, West-Central and Southeastern region and considerable decreases in all other regions (see Table 3.20). A similar but less pronounced result emerges for attainable rice yields, which are projected to decrease in several regions. This can be explained by less favorable temperature profile conditions, with heat stress in low-lying areas in summer, a shift from japonica to indica rice types, and a shortening of the crop cycle length. When heat avoiding crop calendar shifts and/or substitution between rice types becomes exhausted, selection and breeding for cultivars with increased tolerance to heat stress during sensitive reproductive stages and tolerance to excess heat units during the growth cycle may overcome part of the projected yield decreases.

The combined impacts of suitable area and yield changes on potential rice production are listed in Table 3.21. As presented there, the national rice production capacity in the 2050s is projected to experience only minor changes with climate change, however with quite large variations across regions. There are substantial increases of rice production potential simulated in Central, West-Central and Southeastern regions, and decreases are obtained in all other regions, in particular for the climate projected under RCP8.5 in the 2080s. By the 2050s the regional gains and losses nearly balance at national level and as a result a decrease of the rice production potential of -1.9% to -2.8% is obtained. In the 2080s the different concentration pathways result in quite different outcomes. Under RCP4.5 the decrease at national level remains small (-1.8%); for RCP8.5 rapid warming causes a more severe decrease of production potential of -13.8%. These results do not include possible beneficial effects of increased future atmospheric CO_2 concentrations.

Net irrigation amounts (mm), required to achieve the simulated rice production potential, increase in Central, West-Central and Southeastern region. There are little changes in Northeastern and Northwestern region, and decreases occur in Western and Southwestern region. At national level average irrigation requirements decrease slightly due to the changes in the distribution of suitable areas (Table 3.21).

Table 3.21 Climate change impacts on paddy rice production potential and net irrigation requirements

Regions	Potential Production (1000 tons)	% Change relative to 1981-2010				Net Irrigation (mm)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	527	-4.6	-6.5	-8.5	-30.6	612	1.5	2.5	2.5	1.2
Northwestern	334	-4.6	-6.0	-7.5	-21.1	739	-0.4	-0.1	0.6	-2.5
Eastern	242	-1.8	-2.9	-4.5	-14.0	562	8.2	10.1	10.1	11.0
Central	329	24.7	26.5	26.1	28.0	456	21.2	26.7	28.6	42.3
West-central	482	10.3	11.2	11.2	10.9	618	9.4	13.3	11.1	18.5
Western	685	-10.0	-8.8	-9.9	-26.3	1 012	-4.8	-6.6	-7.5	-14.8
Southeastern	483	10.9	11.0	10.4	6.7	561	8.4	13.2	10.7	19.1
Southwestern	1 207	-12.7	-12.3	-13.5	-26.7	886	-6.2	-9.9	-10.2	-16.1
TOTAL	4 290	-1.9	-1.8	-2.8	-13.8	752	-1.6	-1.7	-2.3	-4.0

Note: The shown percentage changes were calculated relative to the historical average of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland. Average crop water demand was calculated for irrigated cropland that is suitable for rice. The values refer to net irrigation water requirements (i.e., the amount to be taken up by the plants) assuming all water deficits are fully met. The estimates include an initial allowance of 200 mm standing water for bunded rice fields.

Figure 3.24 gives a graphical representation of results by region for respectively RCP4.5 and RCP8.5, using an index of potential rice production in the 2050s and the 2080s and where each region's potential production during 1981–2010 is set to 100.

As shown, rice production potential is expected to increase in Central, West-Central and Southeastern region, where cultivation conditions improve at higher altitudes. In all other regions the rice production potential decreases with climate change.

As shown, the rice production potential is expected to increase in Central, West-Central and Southeastern region where thermal cultivation conditions improve at higher altitudes.

Index of potential paddy rice production capacity (1981–2010 = 100)

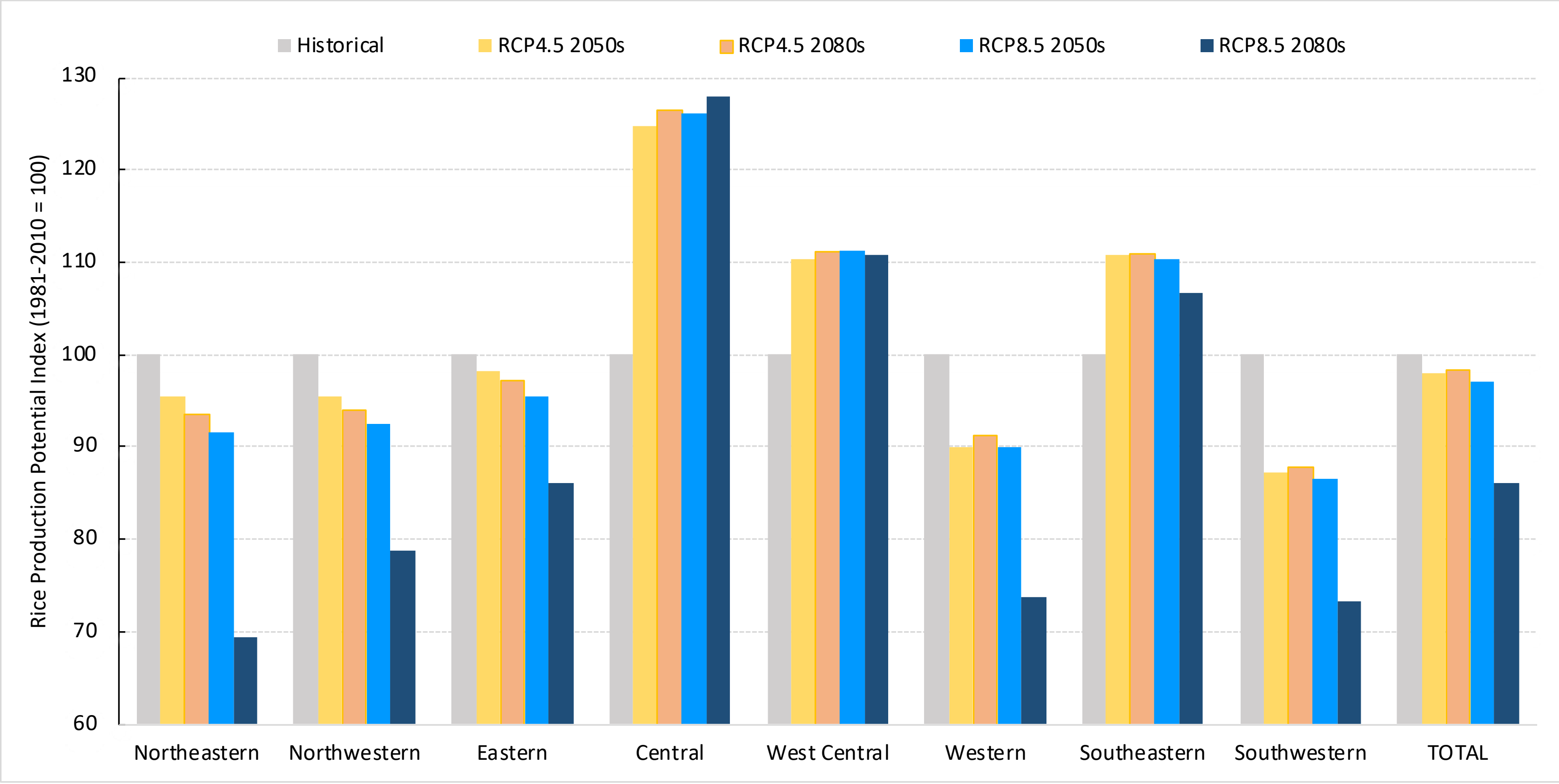


Figure 3.24

Index of net irrigation water volume for paddy rice (1981–2010 = 100)

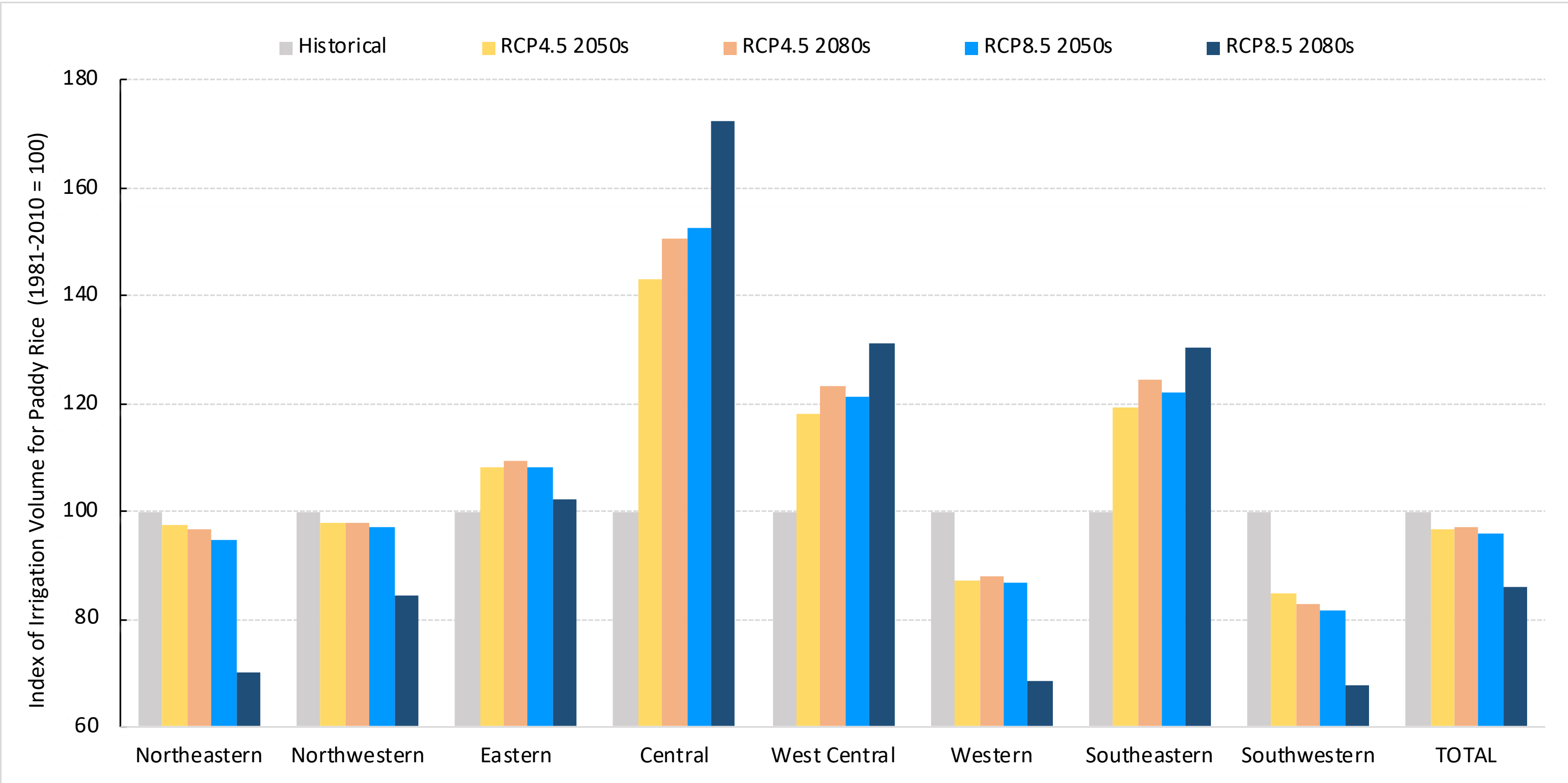


Figure 3.25

Figure 3.25 indicates for historical climate and future climate scenarios the impact of climate change on net irrigation water volumes (i.e., without accounting for irrigation system efficiency) which are needed to achieve the potential production on all suitable irrigated cropland. The national outcome is affected by changes in the distribution of potentially suitable rice areas, the selected rice LUTs and their crop cycle length as well as shifts in crop calendars.

The results indicate that under more intense climate change scenarios a substantially higher irrigation water demand will occur in the regions where potential production conditions improve most, namely Central, West-Central and Southeastern region. On the other hand, intense climate change (e.g., such as under RCP8.5 in the 2080s) will harm the rice production potential in several other regions and with the reduced production capacity would come a reduction of overall irrigation water demand for rice.

Note: The estimates include an initial allowance of 200 mm standing water for bunded rice fields.

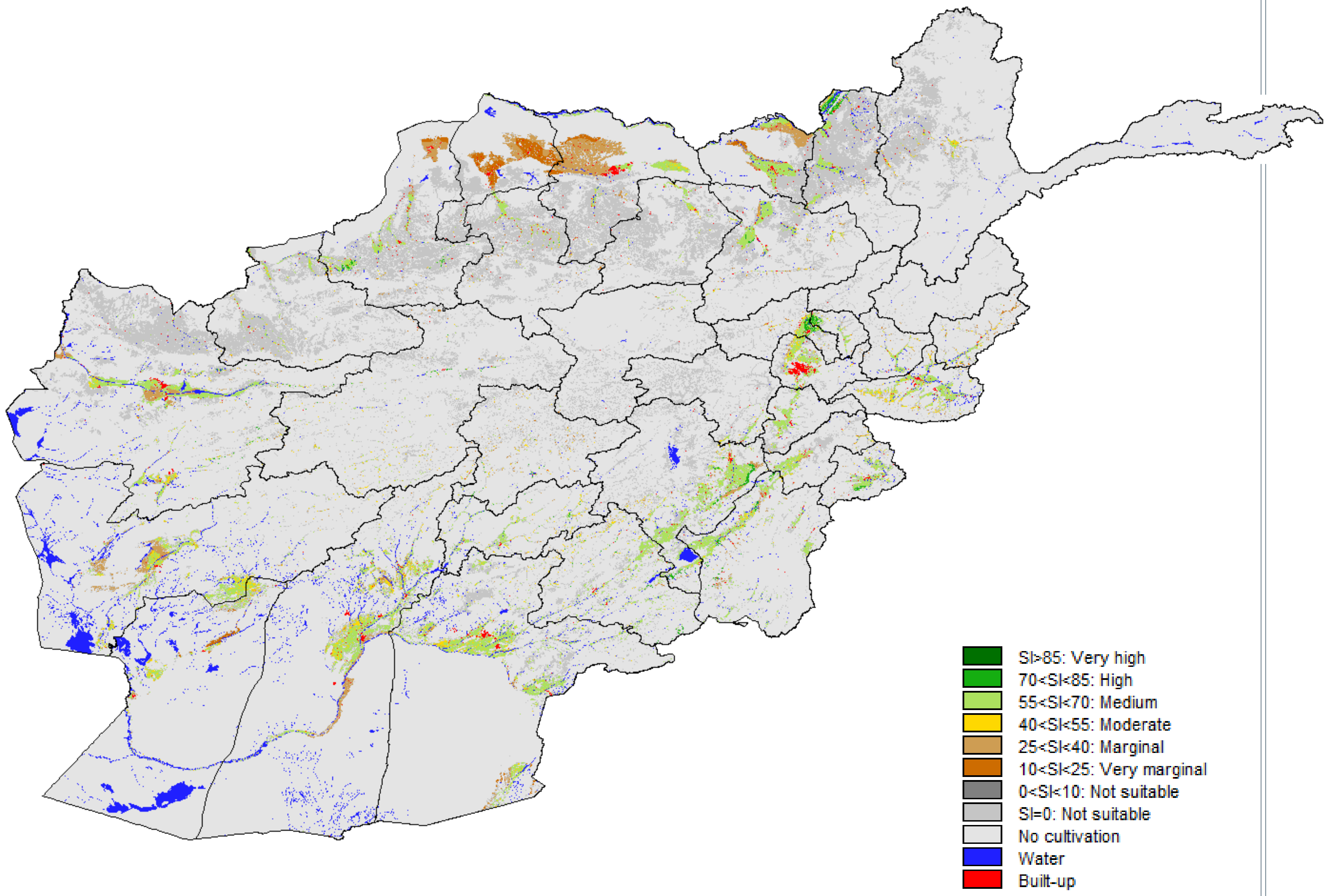
The NAEZ simulations consider in each grid cell two varieties of rice, japonica rice and indica rice simulated in terms of 11 different sub-types. The simulation determines the most productive sub-type as representing the rice production potential of a grid cell. It is important for understanding the impact of climate change that the rice type to grow, the length of the crop cycle and hence the crop calendar will usually change with global warming.

Figure 3.26 presents cropland suitability for paddy rice cultivation at intermediate input level for historical and future climate conditions. The maps use the normalized suitability index SI, combining both the agro-climatic and agro-edaphic evaluation of the selected rice types. A decisive factor is how well the LUT crop cycle fits with the prevailing temperature profile of a location to avoid frost and low temperature risks at early crop development stages as well as damages from excessive heat stress during the reproductive phase. Although impacts will vary with altitude and latitude, the regions of the currently most important rice production areas in Afghanistan (in Northeastern and Eastern region) appear to be negatively affected by climate change, especially in the long-term (by the 2080s) under RCP8.5.

By combining suitable areas and attainable yields, Figure 3.27 shows the simulated production potential of paddy rice in grid cells with irrigated cropland in the base period 1981–2010.

Note, rice is a very 'thirsty' crop. Ensuring a stable and adequate irrigation water supply will be a prerequisite for paddy rice cultivation and may hinder the exploitation of the emerging rice production potential in the Central, West-Central and Southeastern regions.

Paddy rice suitability index class of current cropland Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values refer to average suitably class per 7.5 arc-seconds grid cell of the resource inventory.

Figure 3.26a

Ensemble mean, RCP8.5, 2041–2070–2099

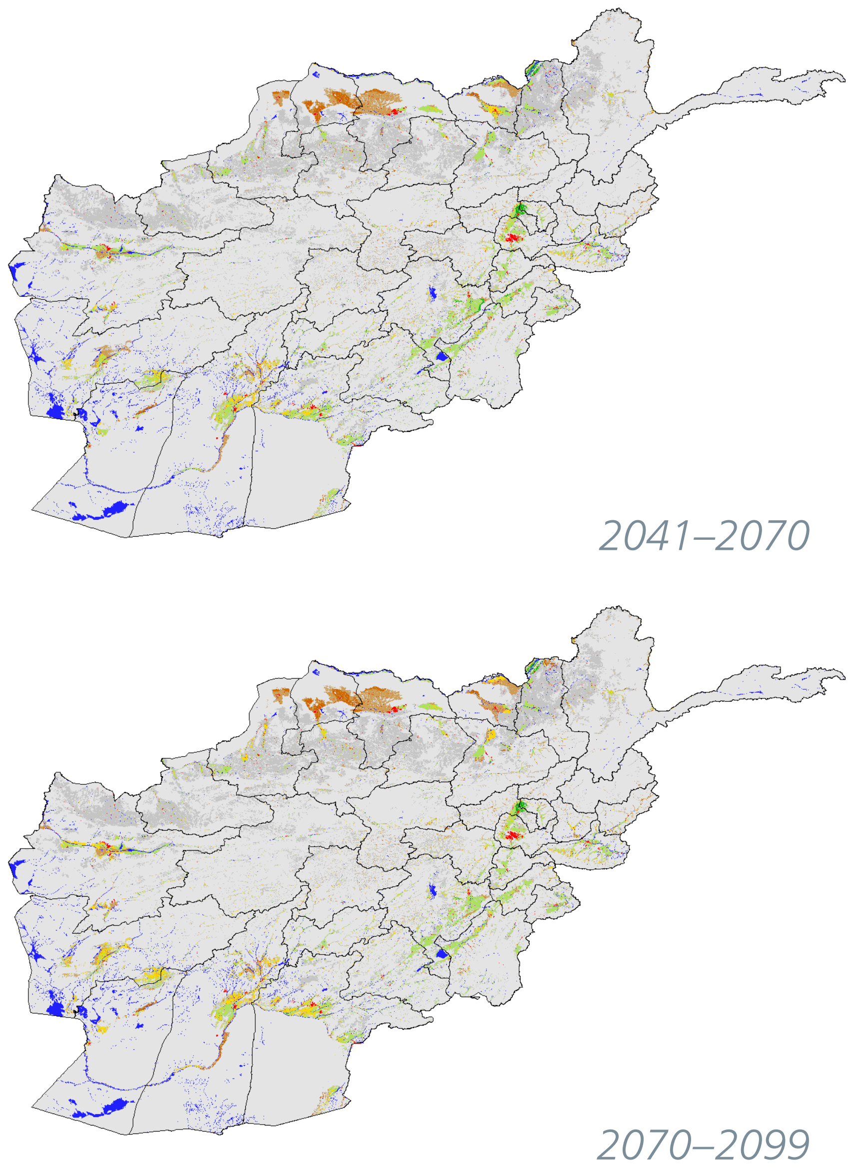
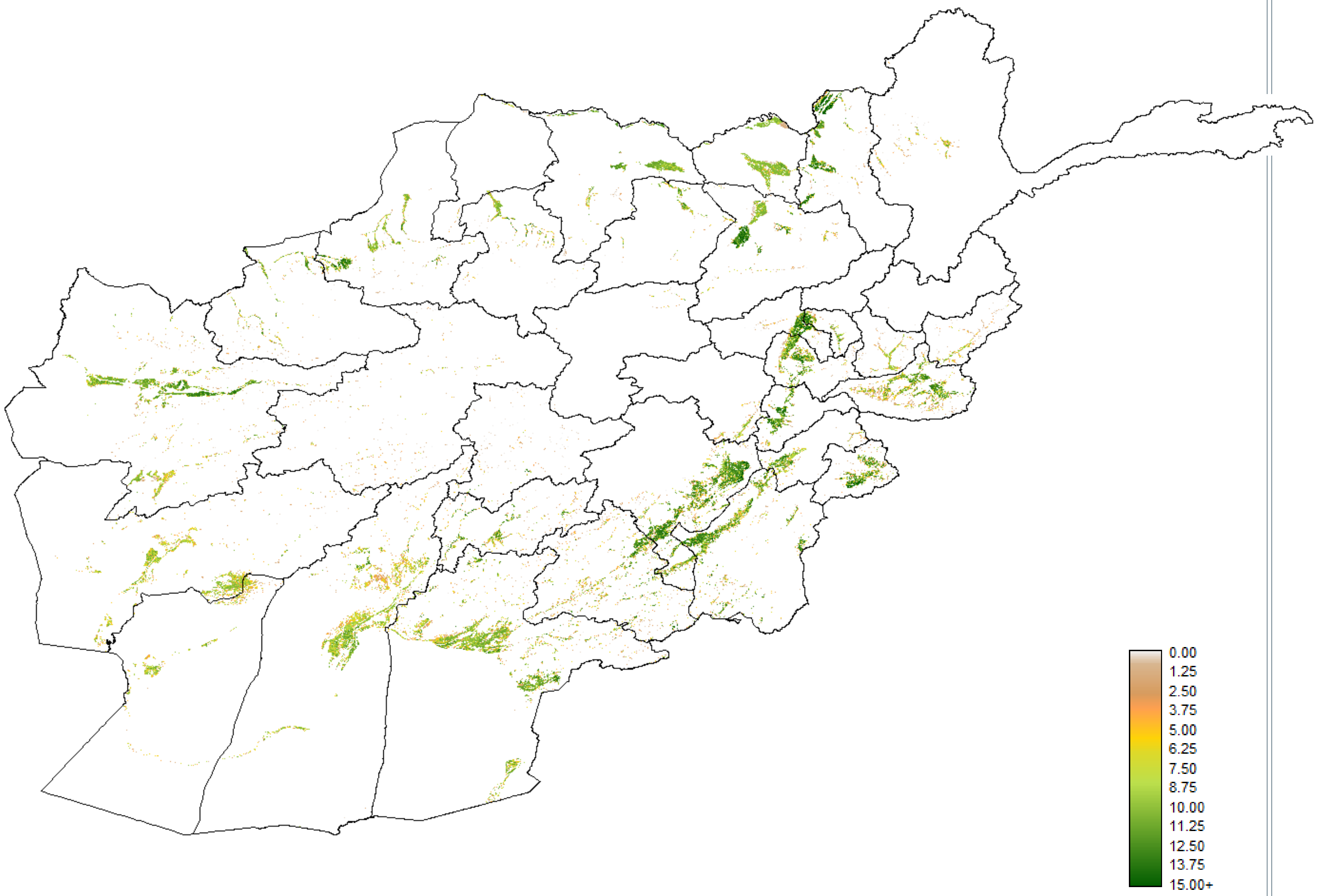


Figure 3.26b, 3.26c

Potential paddy rice production on current cropland (tons), reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010. Values shown for current irrigated cropland refer to potential rice production at intermediate input level per 7.5 arc-seconds grid cell, i.e. about 5 hectares.

Figure 3.27

3.6 Overall climate change impacts on cereal suitability

In the previous sections the simulated crop-wise climate change impacts have been listed for selected cereal crops at the national and regional levels. For each crop a production potential was estimated assuming all potentially suitable cropland would be cultivated with the particular crop. However, the agro-ecological benefit of land decreases with suitability class, from very suitable (VS) to marginally suitable (mS).

Here we go a step further. We jointly consider the cereal crops available in NAEZ-Afghanistan (wheat, barley, maize, rice, oat, rye, millet, sorghum and buckwheat) and we select in each grid cell the best performing cereal crop (in terms of production value) to represent the potential of a particular grid cell. We then compute an indicator of suitable land (SI4), choosing class weights consistent with the definition of suitability classes, according to:

SI4 = grid-cell-area x (90 x VS + 70 x S + 50 x MS + 30 x mS) / 90

with values stretching over the interval from 0 to total size of a grid cell and where VS, S, MS and mS are the shares of area extents of different suitability classes in a 7.5 arc-second grid cell. (VS: Very suitable; prime land offering best conditions for economic crop production; S: Suitable; good land for economic production; MS: Moderately suitable; moderate land with substantial constraints. Economic production requires high product prices for profitability; mS: Marginally suitable; commercial production is not viable. Land could be used for subsistence production when no other land is available). In this way the SI4 indicator of a grid cell expresses its cropland area in terms of prime land (VS) equivalent hectares. Results were separately calculated for rain-fed and irrigated cropland.

Table 3.22 Climate change impacts on total suitable cropland for cereals (in SI4 equivalent ha)

Region	Historical 1981-2010			ENSEMBLE, RCP4.5, 2080s			ENSEMBLE, RCP8.5, 2080s		
	SI4 units (1000 ha)			SI4 Index (1981-2010=100)			SI4 Index (1981-2010=100)		
	Rain-fed	Irrigated	Total	Rain-fed	Irrigated	Total	Rain-fed	Irrigated	Total
Northeastern	346	257	602	139	101	123	127	94	113
Northwestern	218	447	669	137	99	112	156	90	112
Eastern	0	99	99	187	101	101	191	98	98
Central	9	203	213	136	99	101	135	94	96
West-central	4	262	266	298	105	107	260	96	98
Western	221	402	621	136	99	112	140	93	110
Southeastern	2	223	225	246	98	99	219	88	89
Southwestern	19	661	680	185	97	100	152	91	93
TOTAL	820	2 554	3 373	140	99	109	140	92	104

Note: To account for different land qualities and suitability, the SI4 indicator of a grid cell expresses the cropland area in terms of prime land equivalent hectares. Estimates are without accounting for the possible positive impacts of CO_2 fertilization.

Results shown in Table 3.22 denote potentially suitable area for cereals, expressed in SI4 equivalent hectares, on all current rain-fed and irrigated land (including land for fruit trees and vineyards), using an intermediate level of inputs and management under baseline climate. Changes are given for respectively RCP4.5 and RCP8.5 climate scenario ensemble means in the 2080s (without including CO_2 fertilization effects). Results of irrigated cereals on all land equipped with irrigation (3.8 million ha, as derived from LCDA 2010 land cover) find a suitable area for cereals of 3.2 million ha (or 2.6 million SI4 equivalent ha). For rain-fed land (3.7 million ha according to LCDA) the suitable area, including marginally suitable extents, amounts to 1.9 million ha (or 0.8 million SI4 equivalent ha).

Figure 3.28 summarizes the normalized SI4 index values (relative to reference period 1981–2010 = 100) for respectively RCP4.5 and RCP8.5 climate scenario ensemble means in the 2050s and 2080s (without including CO_2 fertilization effects).

At the national level, when considering jointly all cereal crops, the analysis of total suitable areas finds moderate increases in all scenarios, with best outcomes occurring when climate change progresses in the long term only moderately such as under RCP4.5.

The net gain is primarily achieved because of improvements on rain-fed land, due to better use of soil moisture in the winter months and gains of temperature growing period days at higher altitudes mainly in the Northeastern region and central highlands. Under high-end climate change scenarios the irrigated cropland in southern regions experiences considerable losses.

Index of climate change impacts on suitable cropland for cereals (SI4 prime equivalent ha, 1981–2010=100)

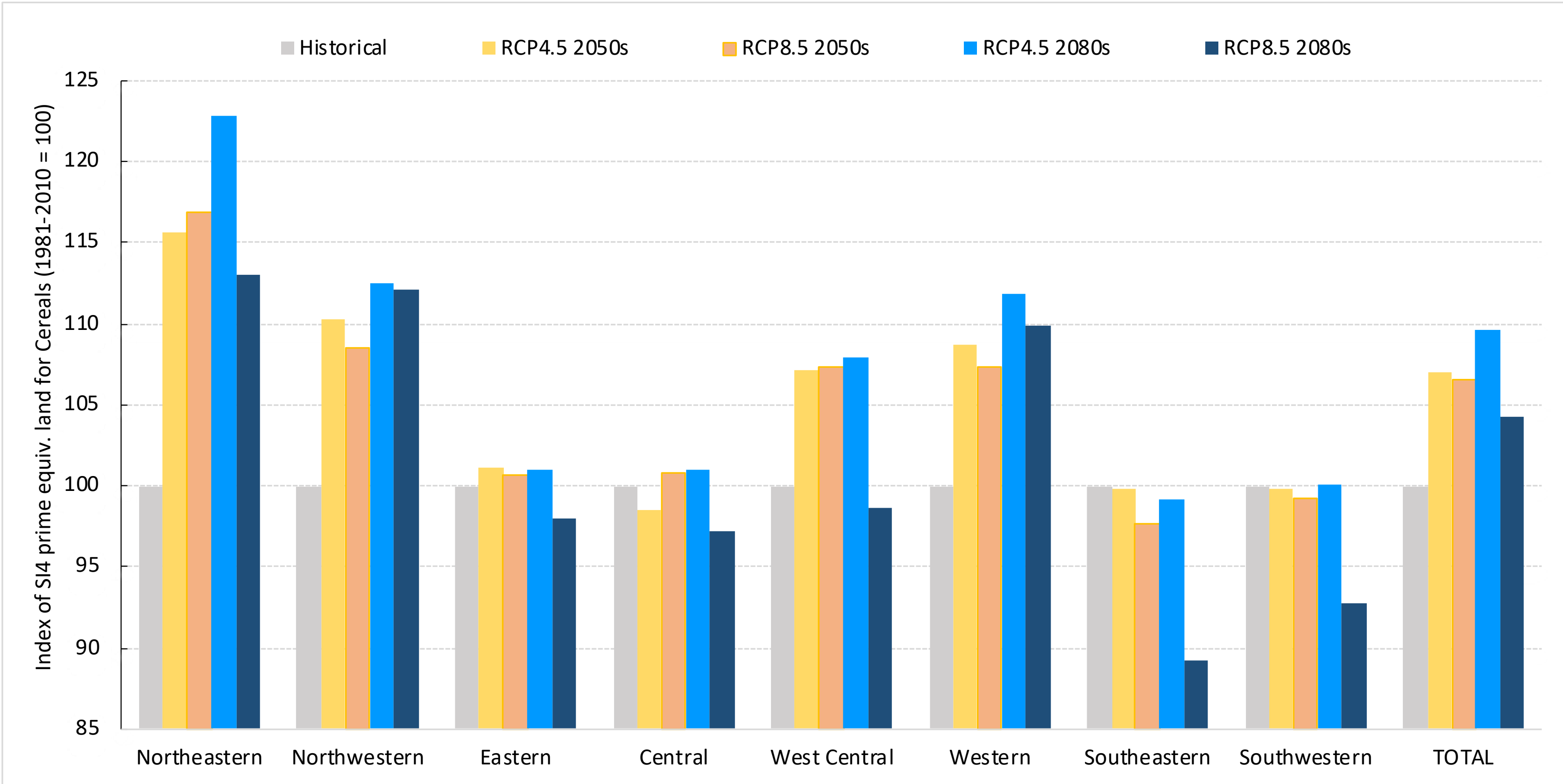


Figure 3.28

Suitability for cereals in current cropland, suitability index class, Reference climate 1981–2010

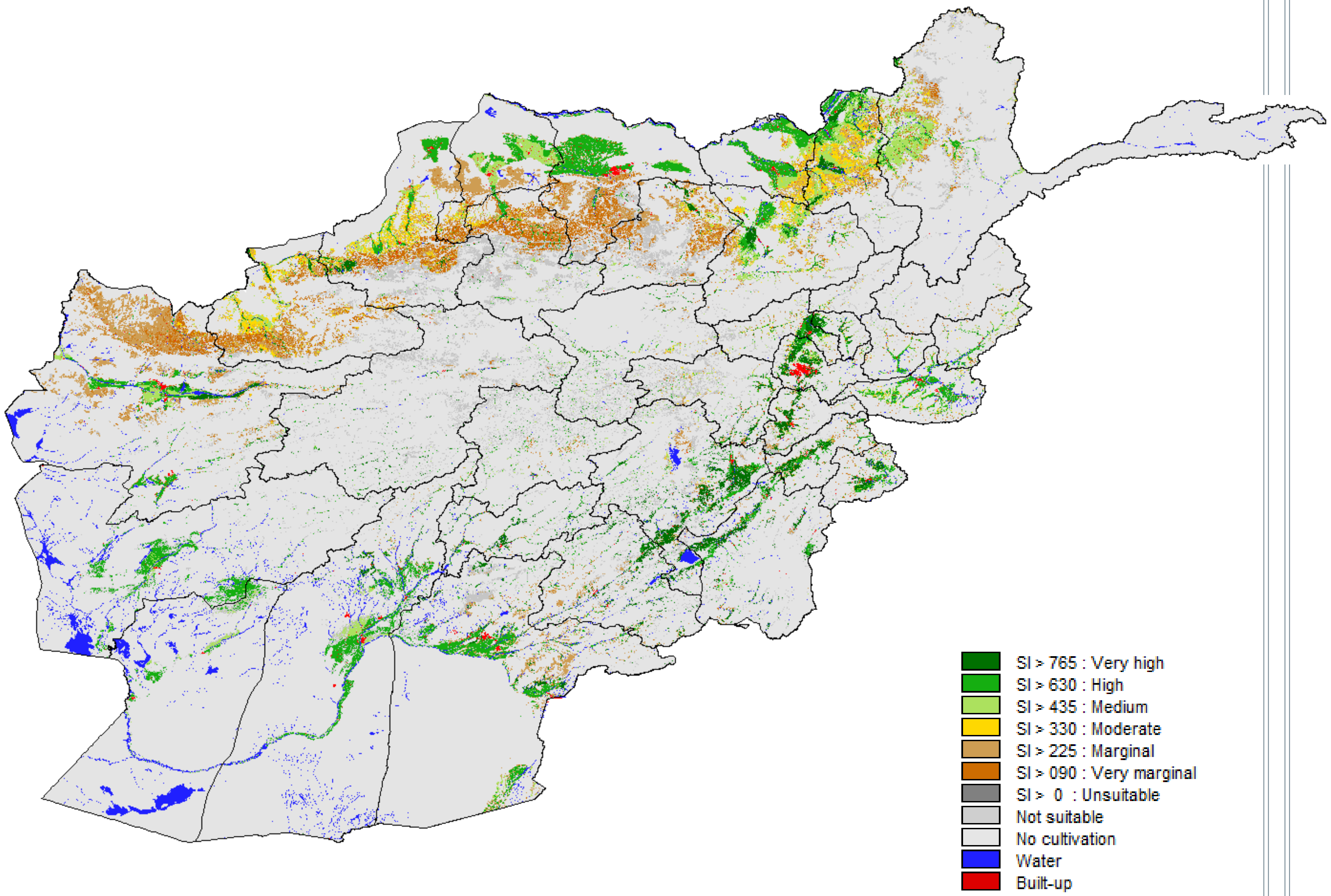


Figure 3.29a

Ensemble mean Period 2041–2070–2099

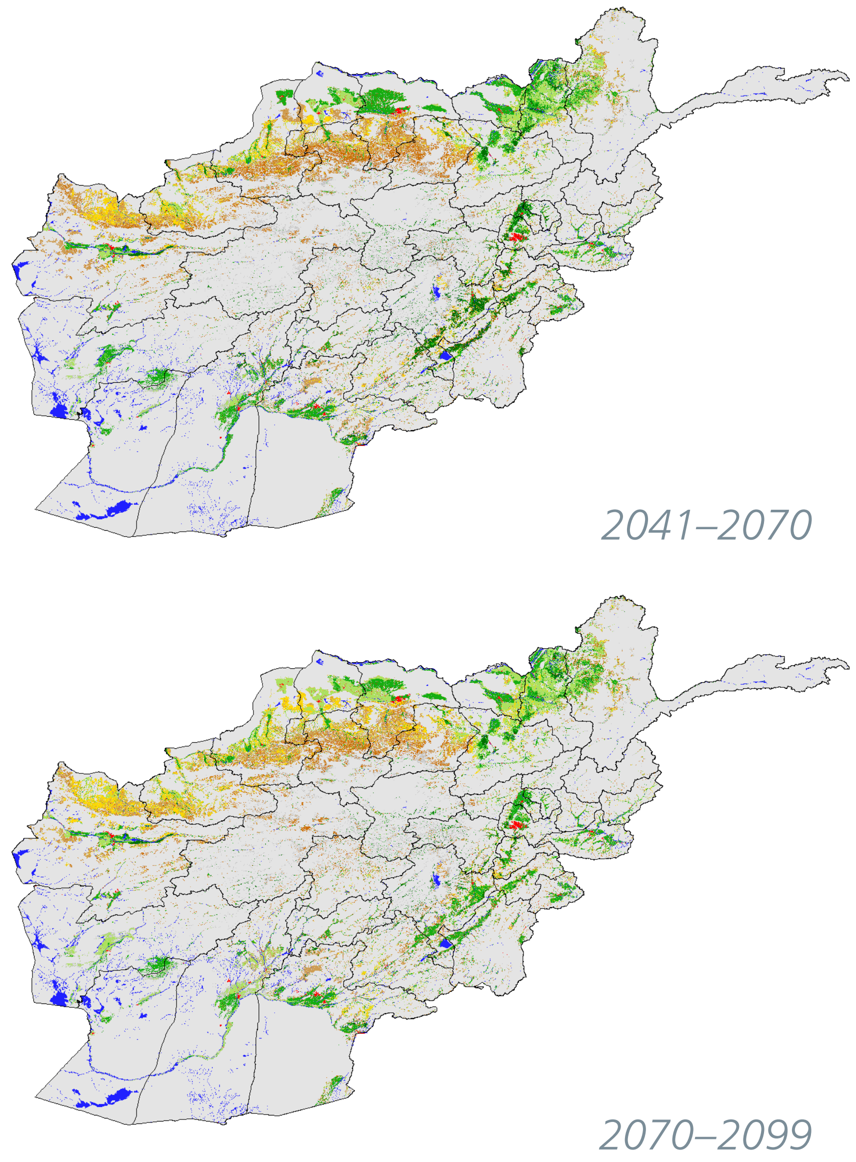


Figure 3.29a, 3.29c

Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current cropland refer to average suitably class per 7.5 arc-seconds grid cell of the resource inventory. Suitability of each grid cell is defined by the suitability of the chosen 'best' cereal type.

However, as noted earlier, in reality not all areas classified as irrigated will likely be available for cereal cultivation due to water deficits in the 'Poorly irrigated' land class (1.1 million ha of 3.8 million ha irrigated land) and because perennial crops raised in orchards and vineyards occupy about 0.2 million hectares of irrigated land. At the national level about 30% of irrigated land is classified as 'Poorly irrigated'. Varying across regions, these classes account for 11.5% (in Northeastern region) to more than 50% (in Southeastern region). When excluding the 'Poorly irrigated', 'Orchards' and 'Vineyards' land classes from irrigated land, the area suitable for irrigated cereals reduces from 3.2 million to 2.0 million hectares (or from 2.6 million to 1.6 million SI4 equivalent hectares). Table 3.23 lists the areas suitable for irrigated cereals in various LCDA 2010 irrigated cropland classes differentiated in the resource inventory. Note, upon the advice of experts consulted at FAO-Afghanistan, poorly irrigated areas listed in Table 3.23 were included when estimating overall suitability presented in Table 3.22.

The results in Table 3.23 suggest that the total suitable area for cereals in Afghanistan can be nearly maintained or even slightly increased in scenarios of moderate climate change, such as RCP8.5 in the 2050s or RCP4.5 in the 2080s. With rapid and intense warming, as projected under RCP8.5 for the 2080s, substantial losses are expected to occur in most regions. Safeguarding the cereal production potential will require effective adaptation of crop calendars, changes of primary cereal crop types where possible and necessary, and provision of adequate and timely volumes of irrigation water.

Table 3.23 Changes in suitability of cereals on different classes of irrigated land, by region

Region	SI4 indicator for irrigated Cereals (1000 ha)				Change of SI4 suitable land, RCP8.5, 2050s			
	Intensively Irrigated	Active Karez	Orchard & Vineyard	Poorly Irrigated	Intensively Irrigated	Active Karez	Orchard & Vineyard	Poorly Irrigated
Northeastern	235	1	8	14	↔	↓↓	↑	↑↑
Northwestern	297	0	17	133	↔	n.a.	↓	↔
Eastern	82	1	4	12	↔	↔	↔	↔
Central	106	10	31	56	↑	↓	↔	↓
West-central	80	60	18	104	↑↑	↔	↔	↔
Western	195	30	8	169	↔	↓	↔	↓
Southeastern	72	33	3	116	↓	↔	↓	↓
Southwestern	345	64	44	208	↓	↓	↓	↓
TOTAL	1 410	199	131	813	↔	↓	↔	↔

Region	Change of SI4 suitable land, RCP4.5, 2080s				Change of SI4 suitable land, RCP8.5, 2080s			
	Intensively Irrigated	Active Karez	Orchard & Vineyard	Poorly Irrigated	Intensively Irrigated	Active Karez	Orchard & Vineyard	Poorly Irrigated
Northeastern	↔	↓↓	↑	↑↑	↓	↓↓	↔	↑↑
Northwestern	↔	n.a.	↓	↔	↓↓	n.a	↓	↓
Eastern	↔	↔	↔	↔	↓	↓	↔	↓
Central	↔	↓	↔	↓	↓	↓↓	↓	↓
West-central	↑↑	↔	↔	↔	↑↑	↓↓	↓	↓
Western	↔	↓	↔	↔	↓	↓↓	↓	↓
Southeastern	↓	↔	↔	↔	↓↓	↓↓	↓	↓↓
Southwestern	↓	↓	↓	↓	↓	↓↓	↓	↓
TOTAL	↔	↓	↔	↔	↓	↓↓	↓	↓

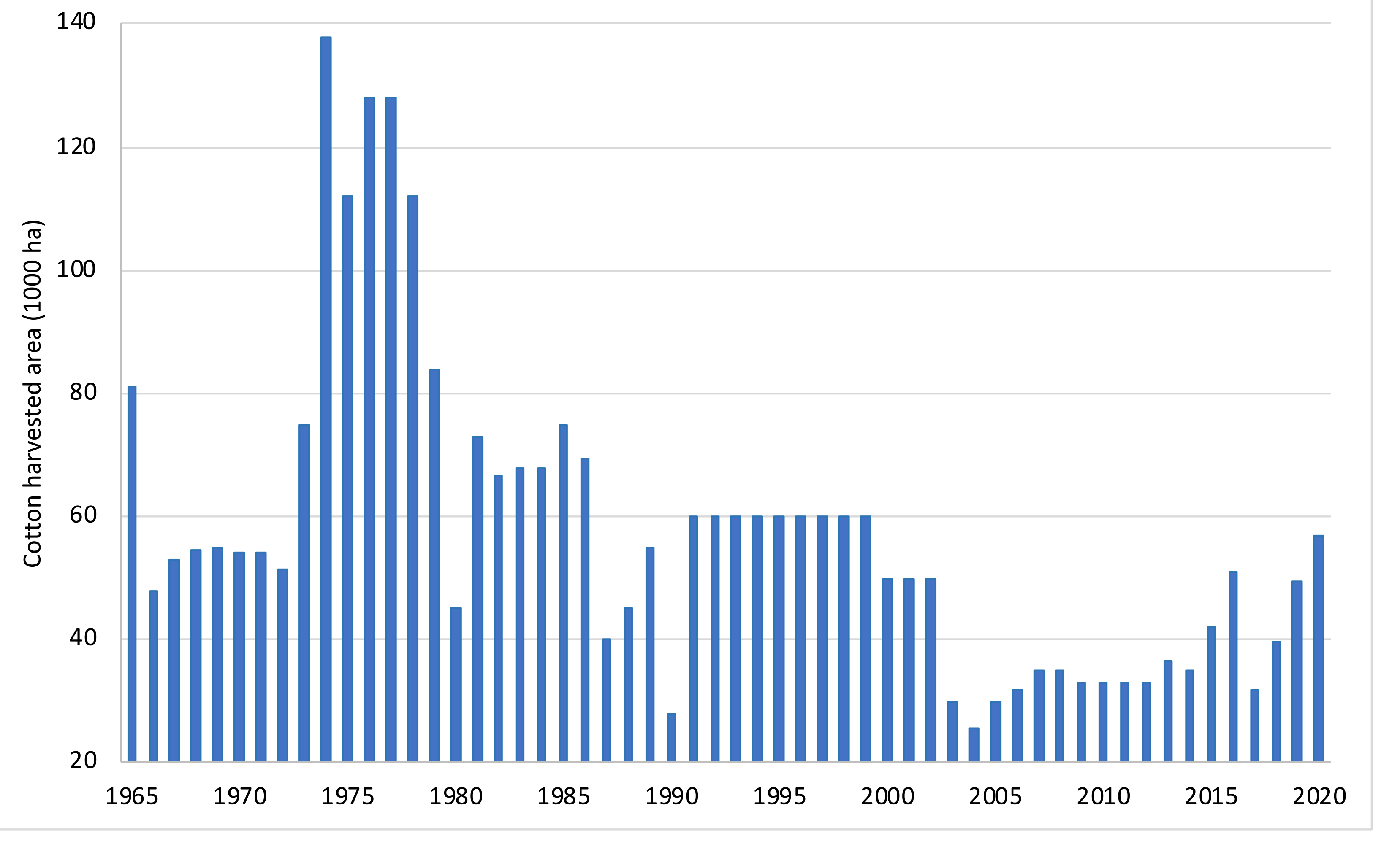
Note: The values listed are suitable extents (in SI4 equivalent 1000 ha) on irrigated land, as delineated based on LCDA 2010 land cover. The SI4 indicator used is the weighted sum of the prime (VS, weight=1.0), good (S, weight=0.777), moderately (MS, weight=0.555) suitable and marginally suitable (mS, weight=0.333) irrigated land. The assessment assumes an intermediate level of inputs and management. Arrows refer to results without CO_2 fertilization effects and indicate changes of less than 2% (↔), 2%-5% (↓, ↑), 5%-10% (↓, ↑) and more than 10% (↓↓, ↑↑) compared to baseline conditions.

3.7 Climate change impacts on cotton suitability and production

According to data reported in FAOSTAT (Source: http://www.fao.org/faostat/en/#data/QC), cotton cultivation in Afghanistan, after a short period of high levels above 100 thousand hectares in the late 1970s, occupied a harvested area of about 70 thousand hectares in the middle of the 1980s (see Figure 3.30). After somewhat lower cotton acreages in the late 1980s, average planted cotton area was an estimated 60 thousand hectares in the 1990s. The cotton area then decreased to 30 thousand hectares in 2003 and remained at a low level until 2014. Since then cotton cultivation has been increasing somewhat reaching 56.7 thousand hectares in 2020.

The climatic characteristics and requirements of cotton allow to grow it in moderately warm to warm environments where irrigation is available. For historical climate such conditions were best found in low-lying areas of Afghanistan. MAIL reported for 2014–16 the largest cotton areas in Balkh province (Northwestern region), Helmand province (Southwestern region), Nangarhar province (Eastern region), and some provinces in the Northeastern region, with the four regions together accounting for 97% of all cotton harvested area in Afghanistan.

Cotton harvested area, Period 1965–2020



Source: FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021; Afghanistan Statistical Yearbook 2020 (NSIA, 2021).

Figure 3.30

Cotton (Gossypium hirsutum)

Cotton (subtropical cultivars with growth cycles of 135 to 180 days) is an annual crop belonging to the C3 crop group (C3 II) which is characterized with optimum photosynthesis and growth at temperatures between 25°C and 30°C. Temperatures above 30°C cause a reduction of photosynthesis and lead to gradually lower yields. Cotton however tolerates high temperatures between 35°C to 40°C depending on moisture availability. Higher temperatures may cause heat stress and plant damage leading to lower yields. Cotton requires rainfall between 500 - 1200 mm during its growth cycle. The rainfall should be distributed in accordance with crop requirements. Relatively little rainfall is required at early phenological stages while most rainfall is required during the reproductive phase. Rainfall during maturation and harvest is harmful, moderate air humidity (<65%) during ripening is best.

Table 3.24 presents suitability and potential production of Afghanistan's cropland when assessed for producing cotton. According to agronomic criteria the largest potentially suitable extents for cotton exist in the Southwestern, Western and Northwestern region, followed by Northeastern region. This suitability distribution matches well with the locations where cotton has actually been growing in the recent past. Comparing the simulated land suitability and potential production of the period 1961–1990 and the period 1981–2010, the results suggest some improvement overall (a plus of 3%) and in most regions.

Table 3.24 Suitability of cotton on rain-fed and irrigated cropland in 1981-2010, by region

Regions	Rain-fed Cropland	Suitable area and potential production			Irrigated Cropland	Suitable area and potential production		
		Area	Production	Yield		Area	Production	Yield
	1000 ha	1000 ha	1000 tons	tons/ha	1000 ha	1000 ha	1000 tons	tons/ha
Northeastern	1 001.4	0.0	0.0	0	386.9	238.4	120.2	0.56
Northwestern	1 457.3	0.0	0.0	0	636.4	353.8	162.2	0.51
Eastern	0.5	0.0	0.0	0.26	165.9	103.2	55.0	0.59
Central	51.2	0.0	0.0	0	250.5	24.2	8.5	0.39
West-central	76.7	0.0	0.0	0	375.7	153.4	60.5	0.44
Western	1 026.3	0.0	0.0	0	610.3	362.1	175.2	0.54
Southeastern	14.7	0.1	0.0	0.33	273.8	147.6	67.1	0.51
Southwestern	106.5	0.0	0.0	0	900.7	593.2	296.8	0.56
TOTAL	3 734.5	0.2	0.0	0.33	3 600.2	1 975.8	945.5	0.53

[1] Cotton is grown for commercial processing and land with only marginal suitability for cotton has not been included in the accounts shown in Table 3.24.

Note: The values shown are suitable extents and potential production on current cropland, based on LCDA 2010 land cover. For rain-fed and irrigation conditions the prime (VS), good (S) and moderately (MS) suitable land is included[1]. The assessment assumes an intermediate level of inputs and management. Production and yields refer to cotton lint.

Table 3.25 Climate change impacts on suitable cropland and attainable yield for cotton

Regions	Suitable Area (1000 ha)	% Change relative to 1981-2010				Attainable Yield (tons/ha)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	238.4	10.1	9.1	8.4	7.9	0.56	-0.7	-1.5	-2.0	-7.3
Northwestern	353.8	-0.3	-3.9	-3.6	-18.0	0.51	0.0	-0.8	-1.6	-7.5
Eastern	103.2	1.1	1.1	1.1	1.1	0.59	1.0	0.3	-0.7	-6.1
Central	24.2	426.0	461.5	472.6	552.5	0.39	28.6	33.2	37.9	49.7
West-central	153.4	15.4	18.3	18.0	28.3	0.44	31.1	29.9	32.9	33.3
Western	362.1	3.6	4.1	4.1	0.1	0.54	-1.9	-2.8	-3.7	-9.3
Southeastern	147.7	27.1	30.1	30.9	34.9	0.51	15.8	15.6	16.4	17.0
Southwestern	593.2	-0.4	-0.6	-0.7	-2.9	0.56	-3.1	-4.5	-5.0	-11.3
TOTAL	1 976.0	10.2	10.4	10.5	8.5	0.53	1.9	1.1	1.1	-2.4

Note: Percentage changes were calculated relative to the historical average of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated and rain-fed cropland. Yields are given as tons lint per hectare.

Table 3.25 gives an overview of climate change impacts on the extents suitable for cotton on current cropland. Results refer to the ensemble means of crop simulation outcomes using climate projections of five climate models and for two RCPs, namely RCP4.5 and RCP8.5.

At the national level the land extents suitable for cotton increase with climate change by about 10% both for the 2050s and 2080s. At the regional level the simulated suitable extents decrease with climate change in Northwestern and Western region and increase to a varying degree in all other regions. Substantial increases occur in Central and Southeastern region, followed by West-Central and Northeastern region (see Table 3.25).

Average attainable yield at national level changes little, but with large variations across different regions, showing substantial gains in central Afghanistan (albeit from low potential yields in the historical period) and some reduction in Southwestern and Western region.

The combined impacts of suitable area and yield changes on potential cotton production are listed in Table 3.26. As presented there, the national cotton production capacity is projected to increase by 12% in the 2050s compared to the historical level. By the 2080s the national cotton production potential would still be larger than during 1981–2010 but lower than in the 2050s.

Very large increases were simulated for Central, West-Central and Southeastern region, although starting from relatively low levels under historical climate. In contrast, large negative impacts may occur in Northeastern (-24%) and Southwestern (-14%) region for intense climate change, as projected under RCP8.5 in the 2080s, where both the suitable area and average attainable cotton yield decrease due to warming.

Table 3.26 Climate change impacts on cotton production potential and net irrigation requirements

Regions	Potential Production (1000 tons)	% Change relative to 1981-2010				Net Irrigation (mm)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	120.2	9.2	7.5	6.2	0.0	499	15.0	17.7	19.0	15.2
Northwestern	162.2	-0.4	-4.8	-5.2	-24.2	643	12.1	14.4	14.6	20.0
Eastern	55.0	2.1	1.5	0.5	-4.9	408	18.3	22.5	21.6	22.5
Central	8.5	576.0	647.2	688.6	876.7	291	31.5	35.4	41.6	63.0
West-central	60.5	51.2	53.7	56.8	71.1	455	16.2	22.0	19.1	32.9
Western	175.2	1.8	1.3	0.3	-9.2	1 026	-0.3	1.0	-0.2	0.2
Southeastern	67.1	47.2	50.5	52.5	57.8	401	16.3	22.6	19.1	31.5
Southwestern	296.8	-3.5	-5.0	-5.7	-13.8	849	-1.7	-3.0	-2.7	-3.4
TOTAL	945.6	12.3	11.7	11.8	6.1	708	1.3	2.3	2.0	3.3

Note: Percentage changes were calculated relative to the historical average of 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated and rain-fed cropland. Average crop water deficits were calculated for irrigated cropland that is suitable for cotton. The values refer to net irrigation water requirements (i.e., the amount to be taken up by the plants) assuming water deficits are fully met by irrigation. Production is given as 1000 tons of lint.

Figure 3.31 gives a graphical representation of results by region for respectively RCP4.5 and RCP8.5, showing potential cotton production (1000 tons lint) in the 2050s and the 2080s relative to each region's potential production during 1981–2010.

The chart illustrates that large increases of potential cotton production are projected in Central, West-Central and Southeastern region, but also shows that the Southwestern and Western region will continue to dominate Afghanistan's cotton production potential despite of negative impacts due to climate change.

Cotton production potential (1000 tons lint)

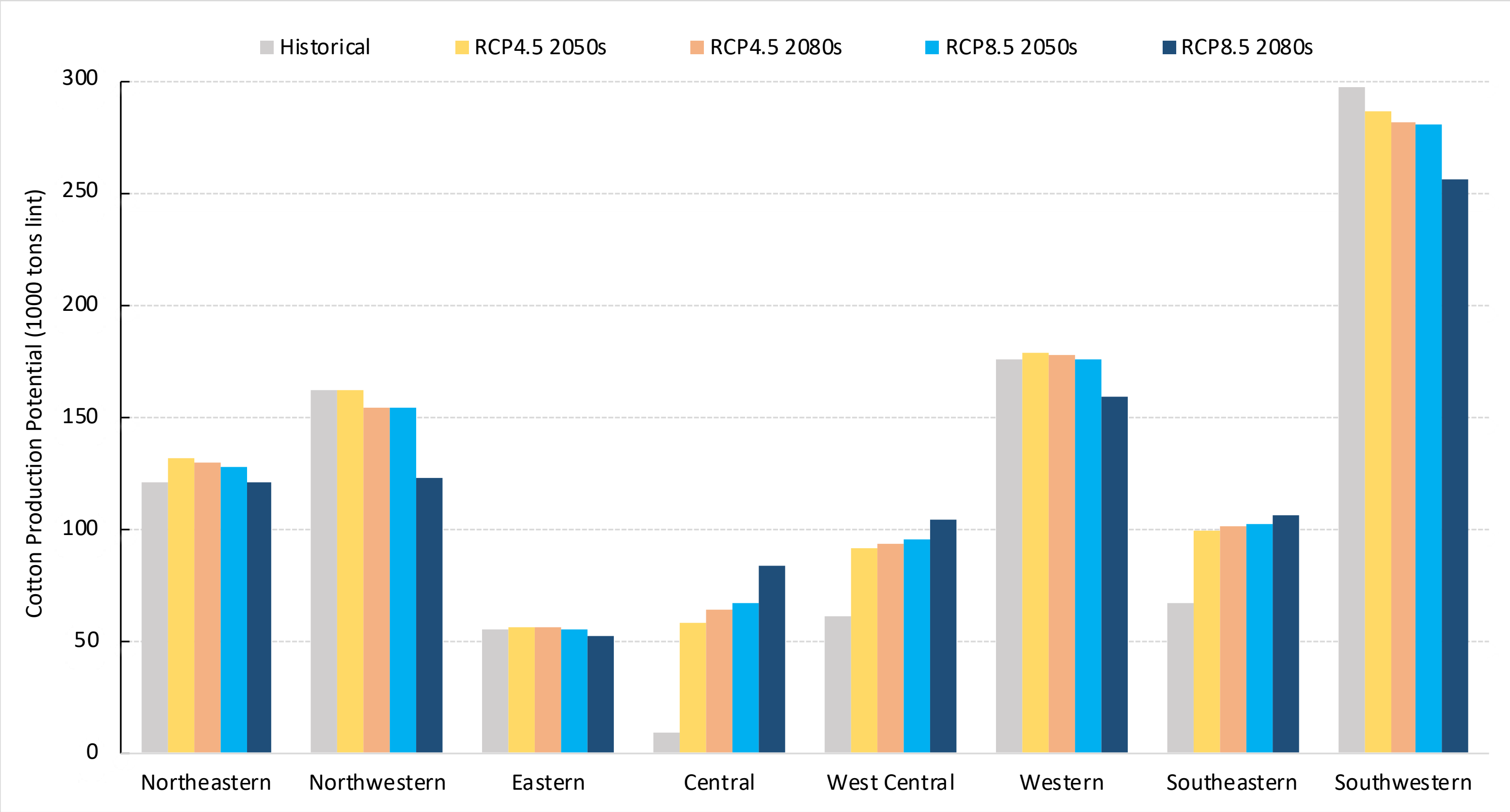


Figure 3.31

Average regional net irrigation water requirements of cotton (mm)

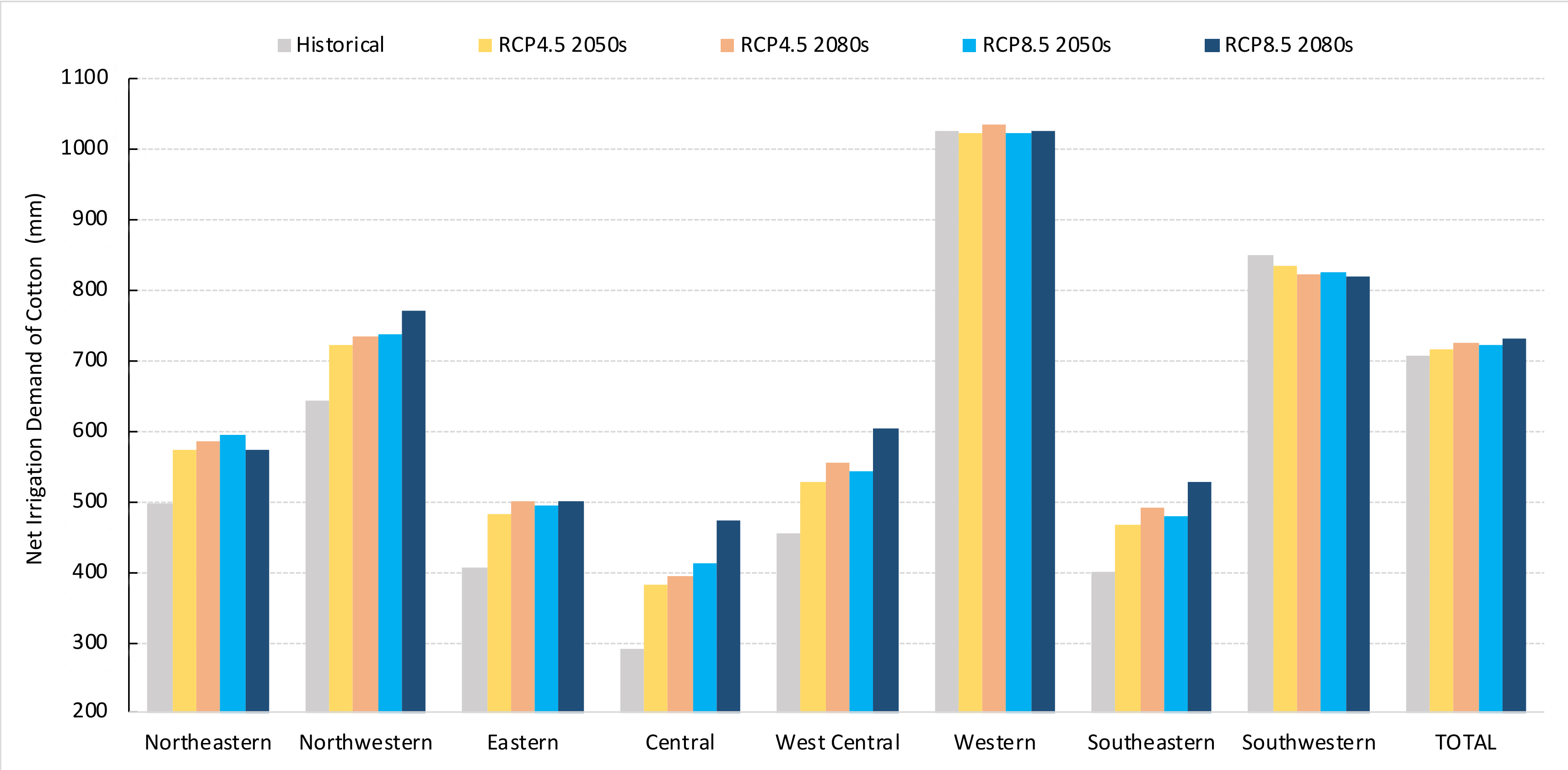


Figure 3.32

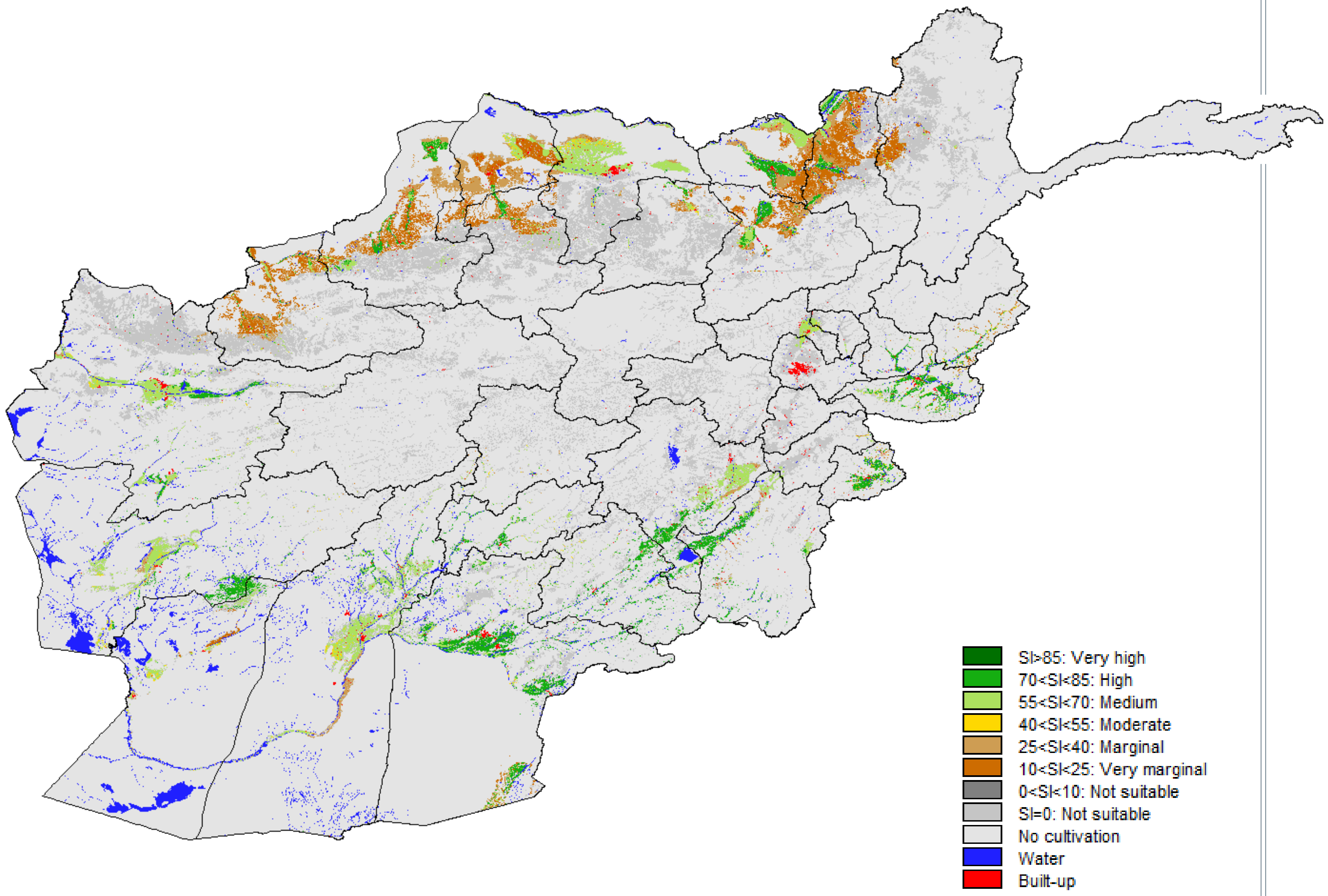
Figure 3.32 indicates for historical climate and future climate scenarios the impact of climate change on net irrigation requirements (i.e., amounts needed to reach the plants) to achieve the simulated potential production on all suitable irrigated cropland. The NAEZ results indicate that with warming a higher irrigation water demand will occur in terms of national average and in most regions. Cotton cultivation consumes considerable volumes of water which will further increase with warming and for commercial production requires cropland with reliable water supply.

Figure 3.33 presents cropland suitability for cultivation of cotton at intermediate input level for historical and future climate conditions. The maps use a classification of the normalized suitability index SI, combining both the agro-climatic and agro-edaphic evaluation for grid cells with current cropland. The maps confirm that rain-fed cropland is of very marginal suitability (in brown colors) for cotton. Green colors indicate good suitability, which for the base period is mostly found in irrigated cropland at lower altitudes.

By combining the occurrence of irrigated cropland and the estimated attainable cotton yields, Figure 3.34 shows the spatial distribution of the cotton production potential (tons lint per grid cell) in the base period 1981–2010.

Note, cotton is a water-intensive crop. Ensuring a stable and adequate irrigation water supply will be a prerequisite for cotton cultivation and lack of water may hinder the exploitation of the emerging cotton production potential in the regions where an increase seems possible in terms of agronomic conditions.

Cotton suitability index class of current cropland Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values refer to average suitably class per 7.5 arc-seconds grid cell of the resource inventory.

Figure 3.33a

Ensemble mean, RCP8.5, 2041–2070–2099

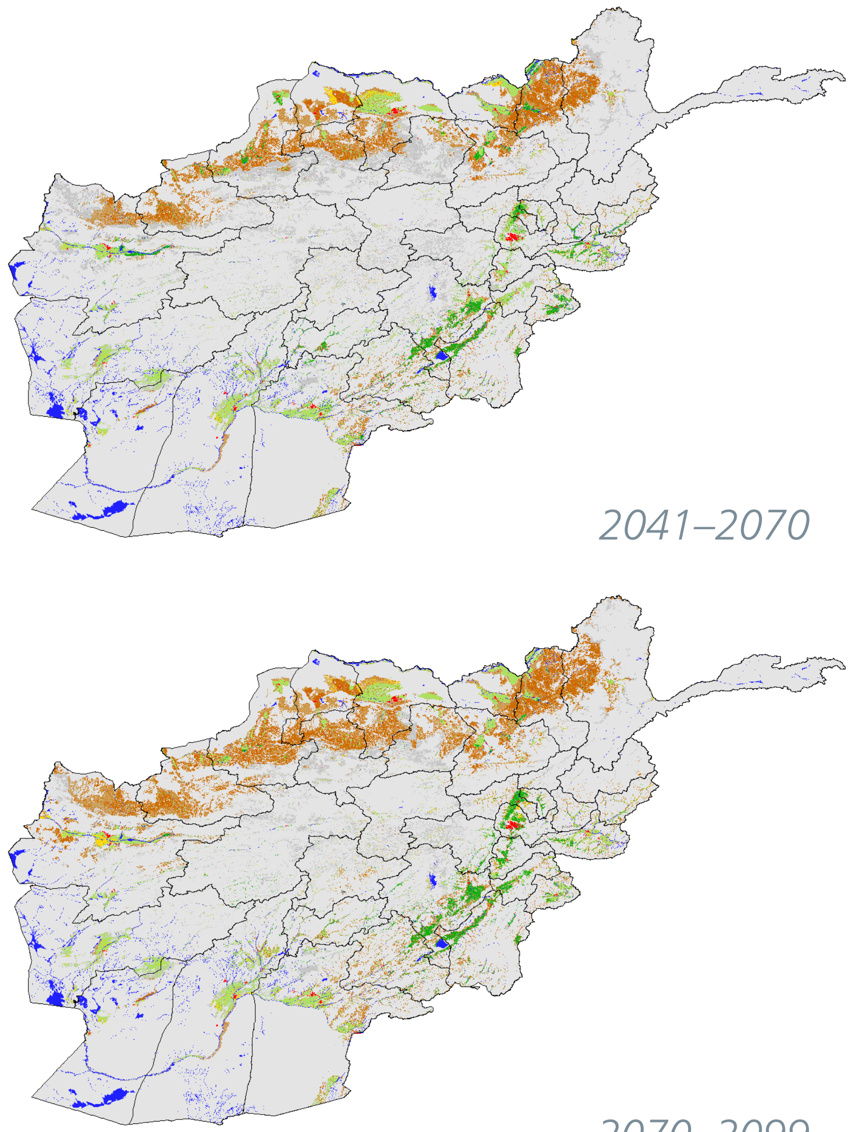
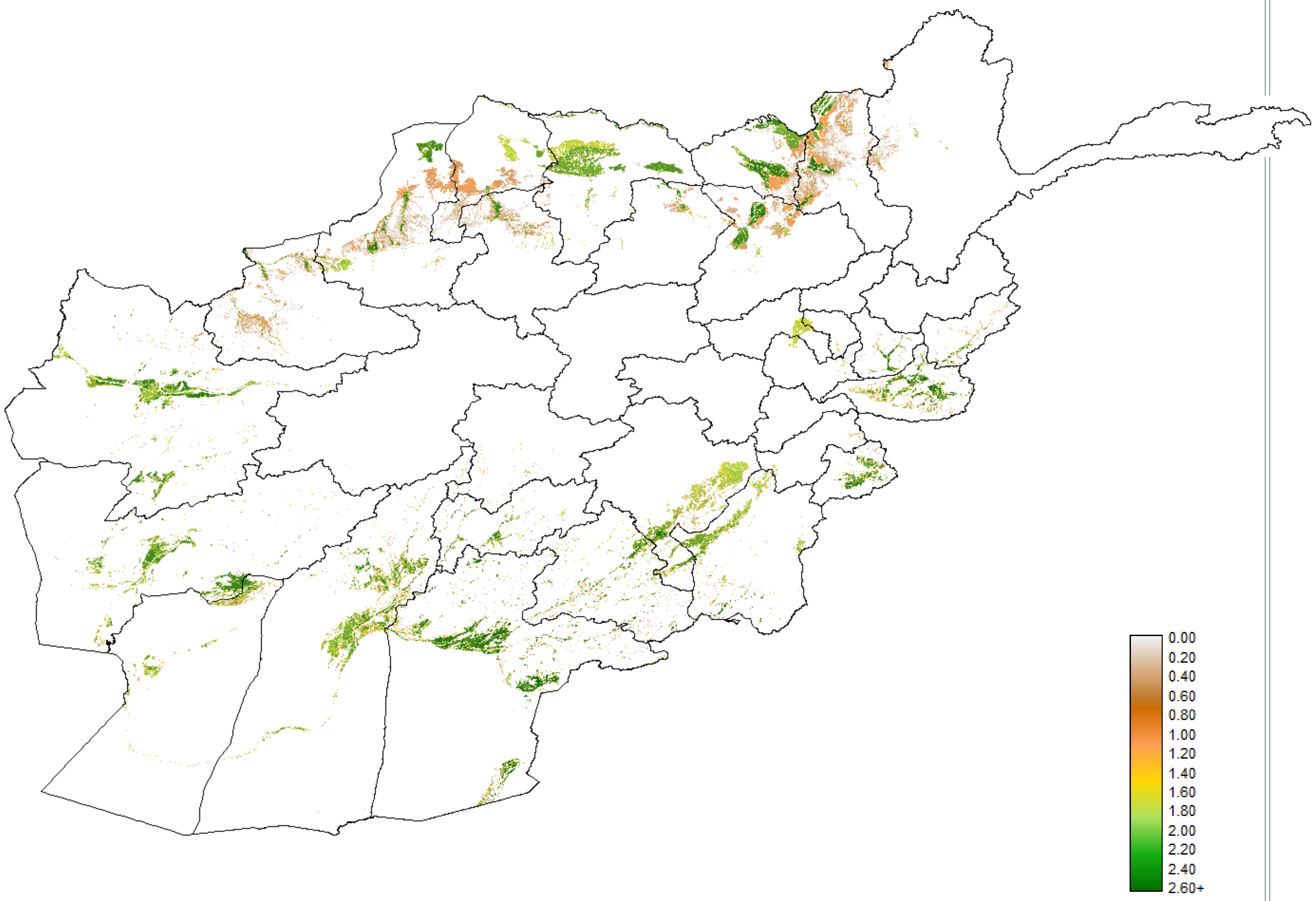


Figure 3.33b, 3.33c

Potential cotton production on current cropland (tons lint)

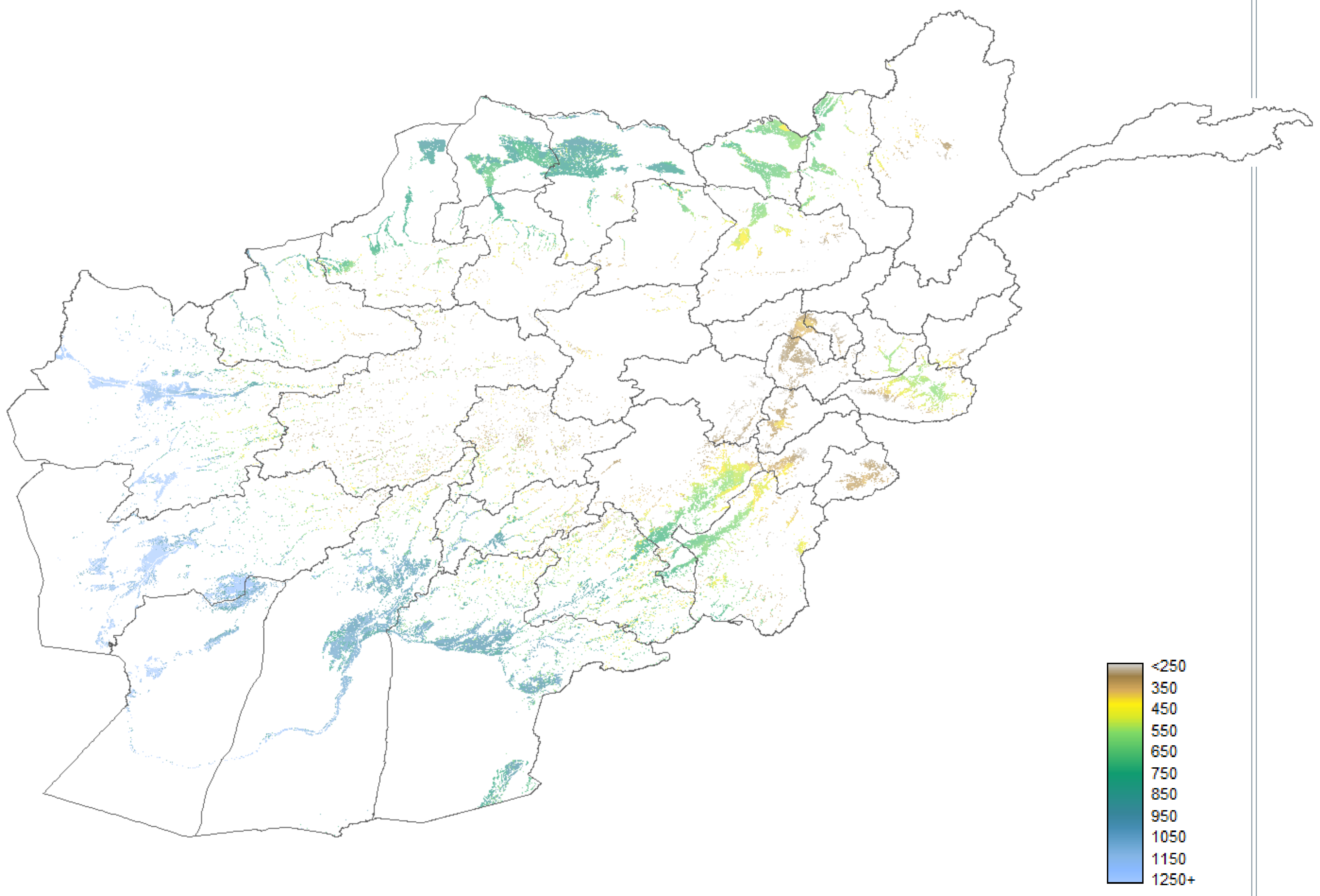


Source: Simulations using historical climate of 1981-2010. Values refer to potential cotton lint production per 7.5 arc-seconds grid cell.

Figure 3.34

Figure 3.35 shows maps of net irrigation requirements (mm) for cotton cultivation on current irrigated cropland respectively for the historical period 1981–2010 (Figure 3.35a) and for an ensemble mean of simulations under RCP8.5 in the 2050s (Figure 3.35b) and 2080s (Figure 3.35c). The maps indicate large increases of irrigation requirements especially in the Central, West-Central and Southeastern region where a substantial increase of suitable area and attainable yield for cotton occurs with warming.

Water deficit (mm) during the cotton growth cycle
Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010. Water deficits (mm) shown indicate for 7.5 arc-second grid cells the net irrigation demand to fully meet water requirements for cotton cultivation on current irrigated cropland.

Figure 3.35a

Ensemble mean, RCP8.5, 2041–2070–2099

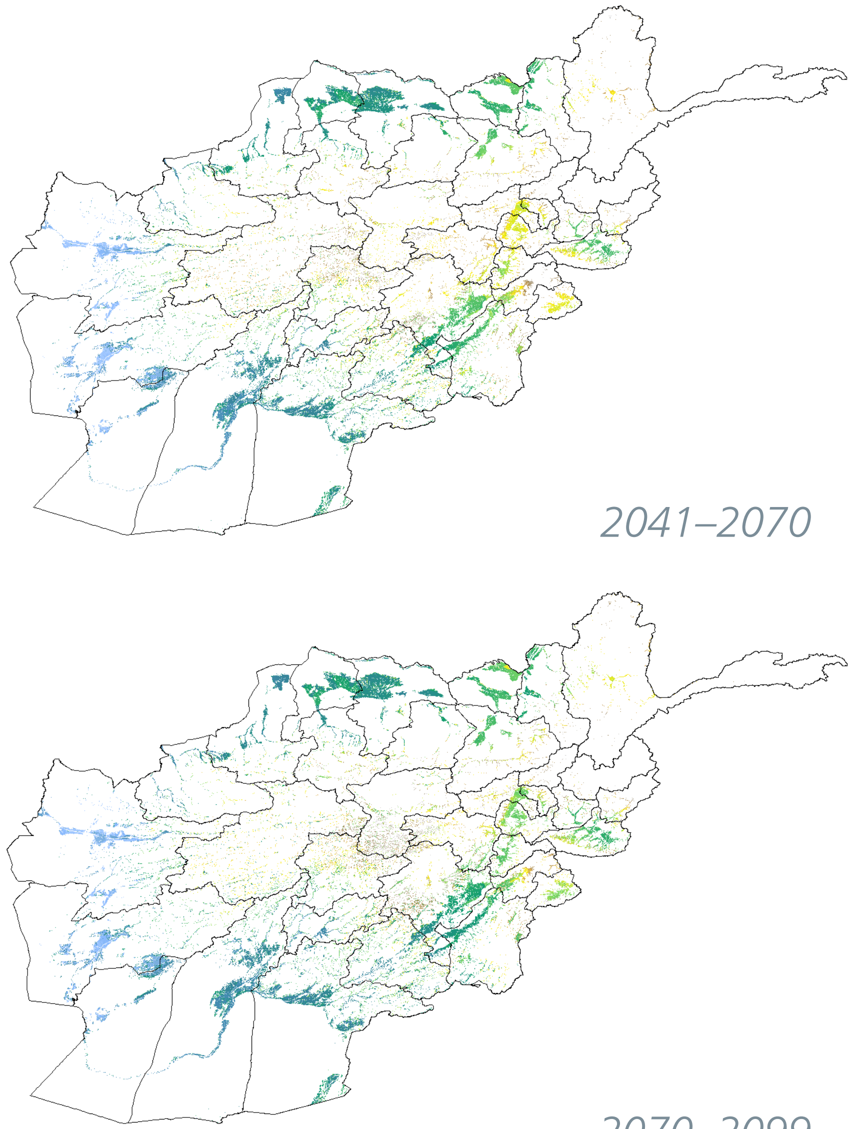


Figure 3.35b, 3.35c

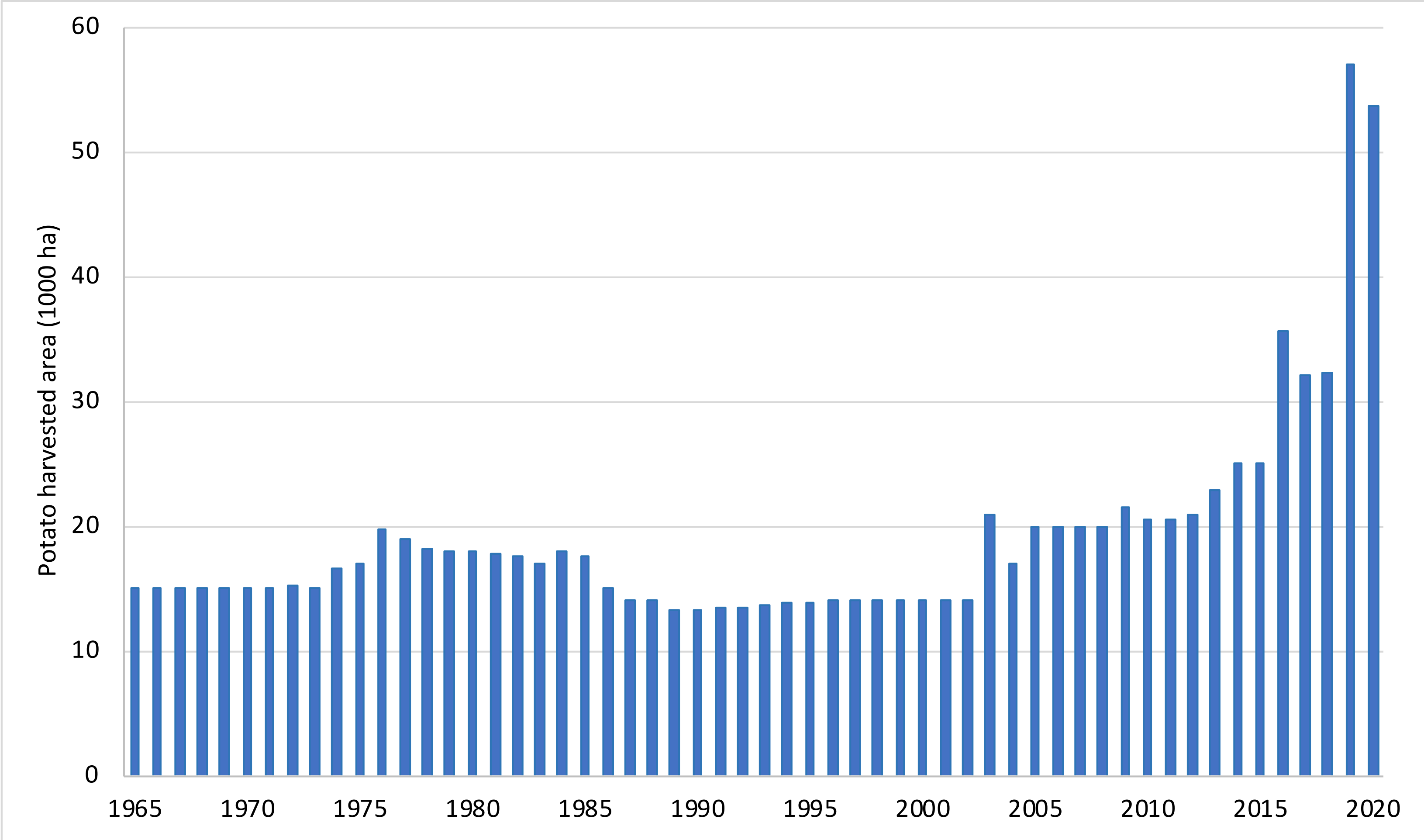
3.8 Climate change impacts on potato suitability and production

According to data reported in FAOSTAT (Source: http://www.fao.org/faostat/en/#data/QC), potato cultivation in Afghanistan occupied a harvested area of between 10 to 20 thousand hectares until about 2010 (see Figure 3.36). Since then potato harvested areas have been increasing to more than 30 thousand hectares in 2016 and have recently exceeded 50 thousand hectares in 2019 and 2020.

The climatic characteristics and requirements of white potato allow to grow it in cool and moderately warm environments. During 2014–16 the area of cultivation of white potato in Afghanistan was reported largest for Central and West-Central region (respectively 27% and 26% of total potato harvested area), followed by Northeastern region (15%); some cultivation of potato occurred in all eight regions.

For a good potato yield in Afghanistan, cultivation will usually require some irrigation. The NAEZ assessment finds the largest potentially suitable extents on irrigated land in West-Central, Southeastern, Central and Northeastern region. In addition, mainly the Northeast region allows potato cultivation on rain-fed cropland.

Potato harvested area, Period 1965–2020



Source: FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021; Afghanistan Statistical Yearbook 2020 (NSIA, 2021).

Figure 3.36

White potato (Solanum tuberosum)

White potato (with growth cycles: 90, 105, 120, 135, 150, 165 and 180 days) belongs to the C3 crop group (C3 I) which is characterized with optimum photosynthesis and growth at temperatures between 15 and 20°C. Temperatures above 20°C lead to lower photosynthesis, while temperatures above 27°C inhibit growth of tubers. High soil temperatures at planting cause the seeds to rot and lead to poor emergence. Low night-time temperatures (below 15°C) and generally cool weather favor tuber formation. During its growth cycle white potato requires 300 to 700 mm rainfall. Excessive rainfall causes diseases and hampers mechanized harvest operations.

Table 3.27 presents suitability and potential production of Afghanistan's cropland when assessed for producing white potato. According to agronomic criteria the largest potentially suitable extents for potato exist in the Northeastern and West-Central region, followed by Southeastern region. Note that only about 10% of the rain-fed suitable extents are assessed as prime or moderately suitable. The vast majority of rain-fed cropland with some suitability for potato is considered marginal because of widespread water deficits and limitations for cultivation due to soil characteristics imperfectly meeting the soil requirements of potatoes. Applying the SI index to summarize and express the results in prime land equivalent hectares, indicates that only about 15% of all suitable area occurs on rain-fed cropland. The share is highest in the Northeastern region (about 50%), followed by Northwestern region (some 22%) and Western region (around 16%). In all other regions the potential contribution from rain-fed land is 5% or less. Similarly, only about 15% of Afghanistan's potato production potential comes from rain-fed cropland.

Table 3.27 Suitability of potato on rain-fed and irrigated cropland in 1981-2010, by region

Regions	Rain-fed Cropland	Suitable area and potential production			Irrigated Cropland	Suitable area and potential production		
		Area	Production	Yield		Area	Production	Yield
	1000 ha	1000 ha	1000 tons	tons/ha	1000 ha	1000 ha	1000 tons	tons/ha
Northeastern	1 001.4	302.7	400	1.47	386.9	102.1	358	3.90
Northwestern	1 457.3	168.9	160	1.05	636.4	37.7	121	3.58
Eastern	0.5	0.0	0	1.49	165.9	104.2	434	4.63
Central	51.2	12.5	17	1.53	250.5	155.9	700	4.98
West-central	76.7	3.2	4	1.23	375.7	208.6	842	4.48
Western	1 026.3	87.5	83	1.06	610.3	35.3	126	3.97
Southeastern	14.7	3.3	4	1.45	273.8	206.9	852	4.57
Southwestern	106.5	0.3	0	1.16	900.7	102.3	362	3.94
TOTAL	3 734.5	578.2	668	1.28	3 600.2	952.9	3 795	4.42

Note: The values shown are suitable extents and potential production on all rain-fed and irrigated cropland, based on LCDA 2010 land cover. For irrigation conditions the prime (VS), good (S) and moderately (MS) suitable land is included; for rain-fed conditions also marginally suitable areas (mS) are summed up. The assessment assumes an intermediate level of inputs and management. Yield and production are given as dry weight.

Table 3.28 Climate change impacts on suitable cropland and attainable yield for potato

Regions	Suitable Area (1000 ha)	% Change relative to 1981-2010				Attainable Yield (tons/ ha)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	404.8	6.6	12.2	5.2	4.4	2.08	7.4	15.1	14.8	18.9
Northwestern	206.5	-5.2	-12.6	-17.3	-40.8	1.51	0.2	0.1	5.1	49.3
Eastern	104.2	-0.1	-4.3	-9.2	-49.4	4.63	-0.2	-0.3	-1.4	-2.8
Central	168.4	5.0	3.3	3.1	0.9	4.73	-10.0	-10.2	-9.9	-9.8
West-central	211.7	2.2	1.3	0.8	-1.0	4.44	-11.9	-9.9	-10.1	-2.8
Western	122.8	3.8	-7.0	3.2	-19.1	1.89	-13.9	-5.2	-12.7	-5.2
Southeastern	210.2	-5.6	-4.2	-4.6	-9.1	4.53	-7.0	-5.6	-4.7	-2.0
Southwestern	102.5	-5.8	12.9	12.4	5.9	3.93	-1.0	-1.5	5.0	6.5
TOTAL	1 531.2	1.0	1.5	-0.7	-10.1	3.24	-5.0	-2.0	-1.3	4.7

[2] Due to large uncertainties of rain-fed results especially in the Northwestern and Western region, the median of the crop simulation outcomes with the five climate model projections was used.

Note: Percentage changes were calculated relative to the outcomes of historical period 1981–2010. Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland.

Table 3.28 gives an overview of climate change impacts on the extents of cropland suitable for white potato. Results refer to the ensemble means[2] of crop simulation outcomes using climate projections of five climate models and for two RCPs, namely RCP4.5 and RCP8.5.

At the national level the extents suitable for potato change only little for three of the four climate scenarios presented in Table 3.28, but show quite noticeable positive and negative changes at the regional level. Only for severe climate warming under RCP8.5 in the 2080s a decrease of suitable areas by -10% is simulated. At the regional level the warming produces most pronounced negative impacts for potato suitable areas in the Northwestern, Eastern and Western region. For Northeastern and Central region a small plus occurs in all scenarios.

Average attainable potato yield at national level changes only slightly, with quite some variations across regions. Note that changes of regional average attainable yields are affected by both the changes of location-specific yields as well as changes in suitable areas. For instance, average yield of a region may increase when climatic conditions improve but also when some current less productive areas in a region become unsuitable.

The combined impact of suitable area and yield changes on potential potato production is somewhat negative at national level, with increases in Northeastern and Southwestern region and varying losses in all other regions, which are most pronounced in Northwestern, Western, Southeastern and Eastern region (see Table 3.29). As presented there, the national potato production potential in the 2050s is projected to experience moderate changes with climate change of -2% to -4%. In the 2080s the different concentration pathways result in more differentiated outcomes. Under RCP4.5 the decrease at national level remains small (-1%); for RCP8.5 rapid warming causes a more severe decrease of production potential of -6%.

Potatoes do not tolerate very high temperatures and crop calendars will have to be adjusted with warming. This shift of crop calendars towards cooler periods and the changes in the distribution of suitable land combine to result in relatively small changes of net irrigation demand.

Table 3.29 Climate change impacts on potato production potential and net irrigation requirements

Regions	Potential Production (1000 tons)	% Change relative to 1981-2010				Net Irrigation (mm)	% Change relative to 1981-2010			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1981-2010	2050s	2080s	2050s	2080s	1981-2010	2050s	2080s	2050s	2080s
Northeastern	758	14.5	29.1	20.7	24.2	63	0.6	1.1	13.3	13.3
Northwestern	281	-5.0	-12.5	-13.2	-11.7	151	-13.2	-11.9	-9.3	-1.3
Eastern	434	-0.3	-4.6	-10.5	-50.8	124	10.0	9.0	9.5	10.8
Central	717	-5.5	-7.3	-7.2	-9.0	159	-2.6	-8.5	-0.8	3.3
West-central	845	-9.9	-8.7	-9.4	-3.8	234	-8.7	-9.4	-6.9	5.3
Western	209	-10.7	-11.8	-9.9	-23.4	246	-6.9	-11.0	-7.3	-15.0
Southeastern	856	-12.2	-9.6	-9.2	-10.9	191	-0.6	2.1	3.9	18.1
Southwestern	363	-6.7	11.3	18.0	12.8	225	-0.8	-1.6	-2.1	-0.4
TOTAL	4 463	-4.0	-0.6	-2.0	-5.9	178	-3.6	-4.4	-1.0	7.4

Note: Percentage changes were calculated relative to the historical average of 1981–2010. Potential production (1000 tons dry weight) refers to very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and all suitability classes (VS, S, MS, mS) on rain-fed cropland. Average crop water deficits were calculated for irrigated cropland. The values indicate net irrigation water requirements assuming that irrigation will fully meet crop water requirements.

Figure 3.37 presents a bar-cart of the simulated results by region for respectively RCP4.5 and RCP8.5, showing the potential potato production in the 2050s and the 2080s in comparison to each region's potential production during 1981–2010.

The chart shows large increases of the potato production potential in Northeastern region and indicates some losses in most other regions.

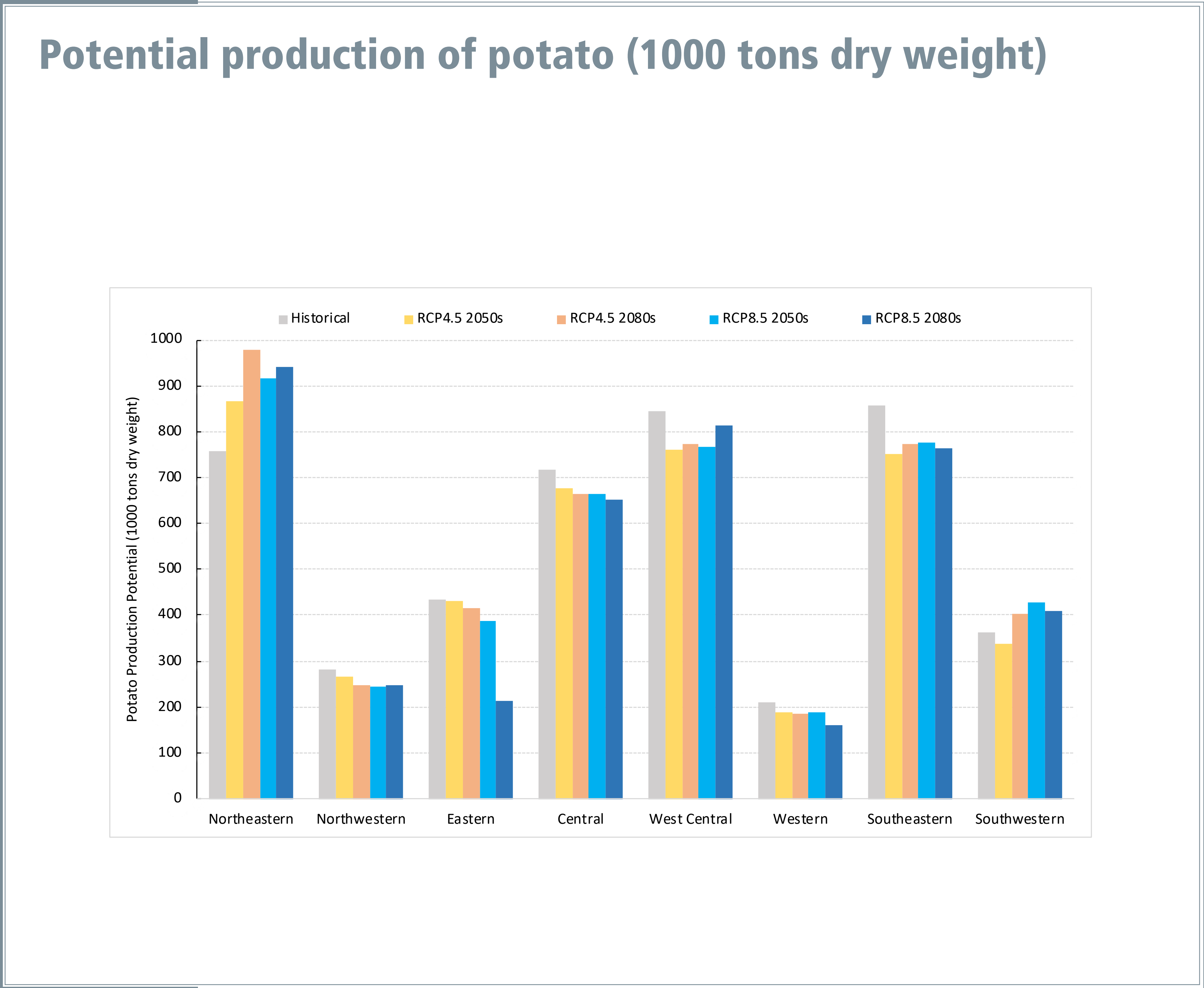


Figure 3.37

Net irrigation water requirements of potato (mm)

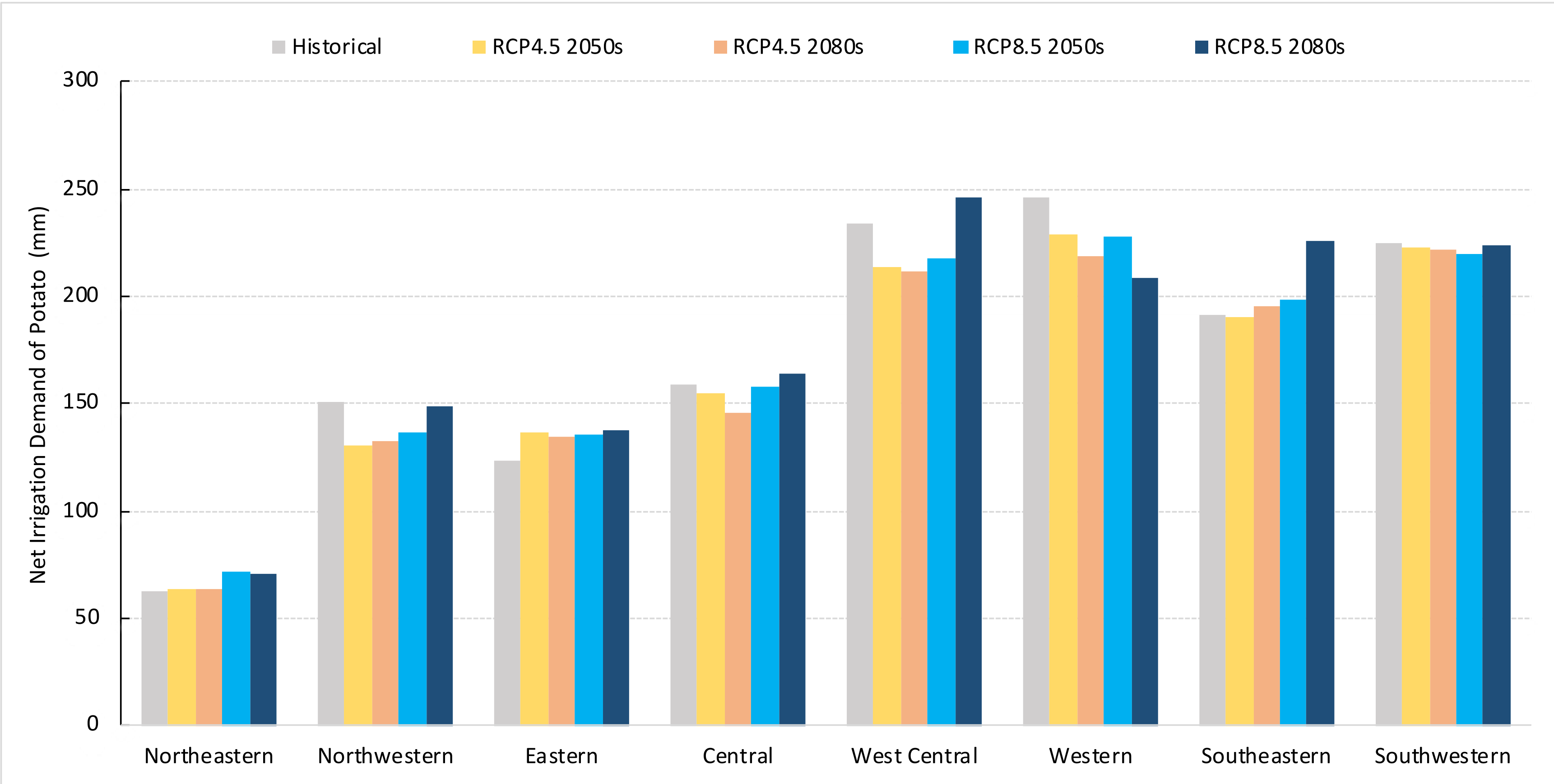


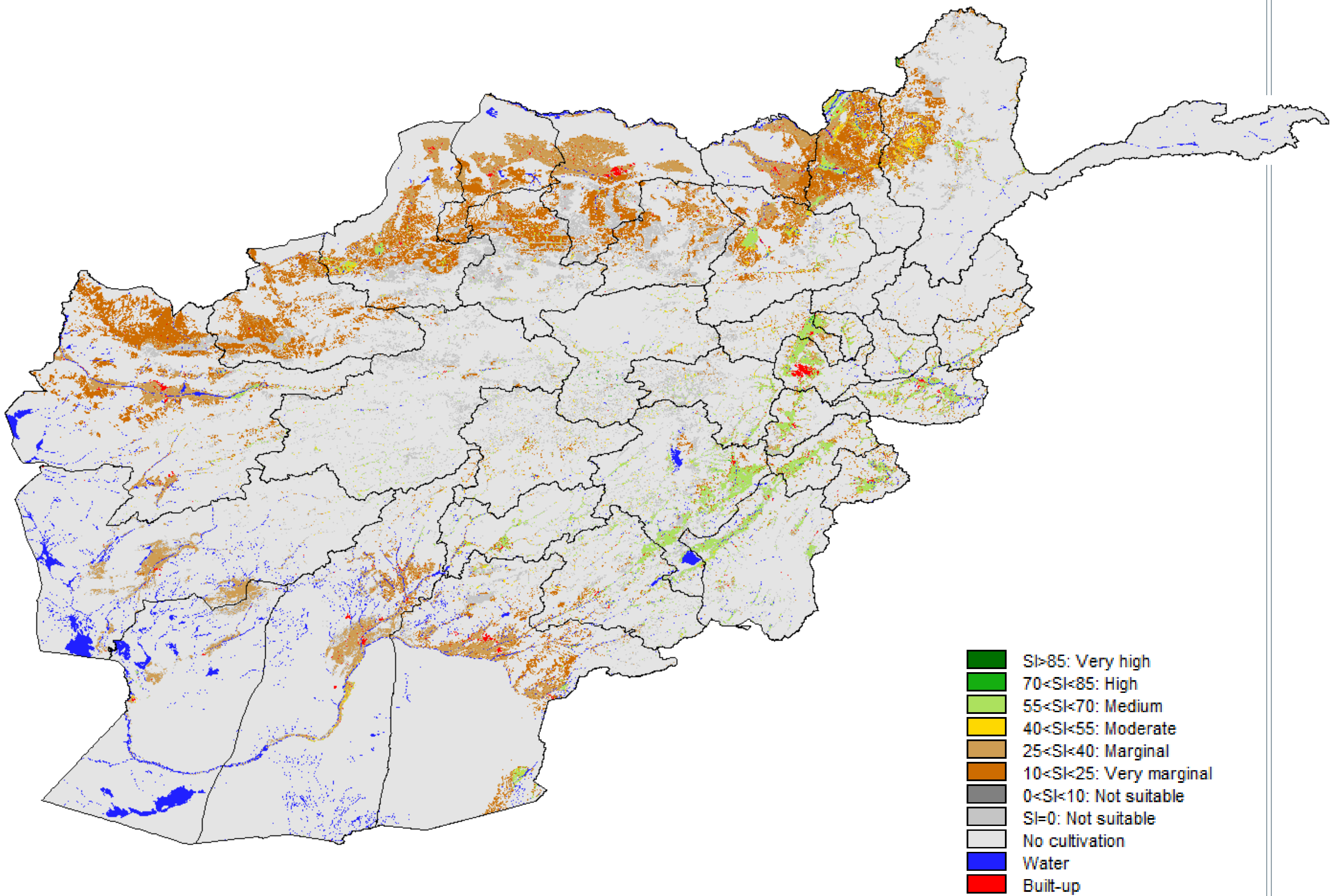
Figure 3.38

Figure 3.38 indicates for historical climate and future climate scenarios the impact of climate change on net irrigation water requirements (i.e., without accounting for irrigation system efficiency) needed to achieve the potential production on all potentially suitable irrigated cropland. While warming will generally increase net irrigation demand of crops, the combination of different decisive factors produces mixed outcomes across regions. The regional outcomes are affected by changes in the distribution of areas potentially suitable for potato, changes in the selected LUTs and their crop cycle length, as well as shifts in crop calendars. The NAEZ results suggest that for moderate warming the implied crop calendar changes will on average maintain or slightly reduce average regional irrigation requirements. However, under intense warming (e.g., as for RCP8.5 in the 2080s) and when options for crop calendar shifts are exhausted, the irrigation demand tends to increase.

Figure 3.39 displays cropland suitability for cultivation of white potato at intermediate input level for historical and future climate conditions. The maps use a classification of the normalized suitability index SI, combining both the agro-climatic and agro-edaphic evaluation for grid cells with current cropland. The maps confirm that cropland in the upper range of suitability (in green colors) is mostly found in regions with cool and moderately warm temperatures, i.e., in cropland of Central, Eastern and Southeastern region. Some land of sufficient suitability is also shown in parts of Northeastern and Northwestern region.

Figure 3.40 combines the occurrence of cropland and the simulated attainable potato yield (at intermediate input level) to show the spatial distribution of the production potential of potato (tons dry weight per 7.5 arc-second grid cell) for the base period 1981–2010.

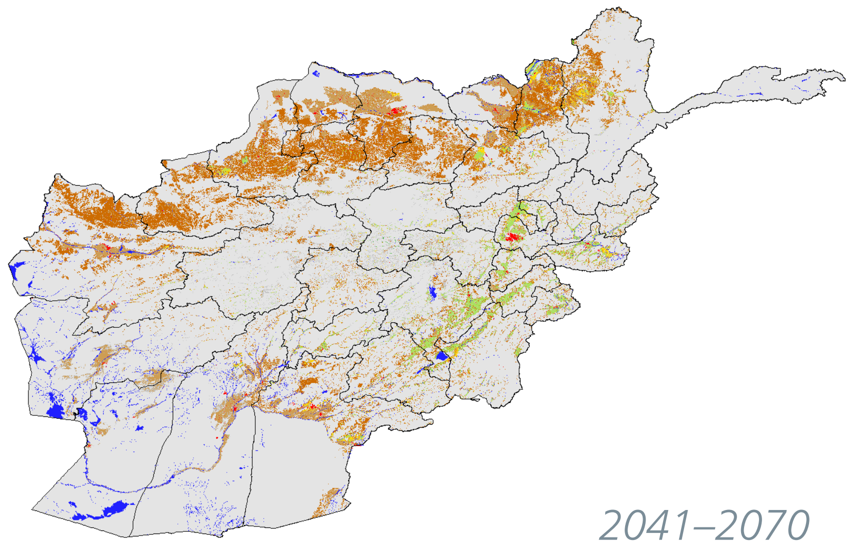
Potato suitability index class of current cropland Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current cropland refer to average suitably class per 7.5 arc-seconds grid cell of the resource inventory.

Figure 3.39a

Ensemble mean, RCP8.5, 2041–2070–2099



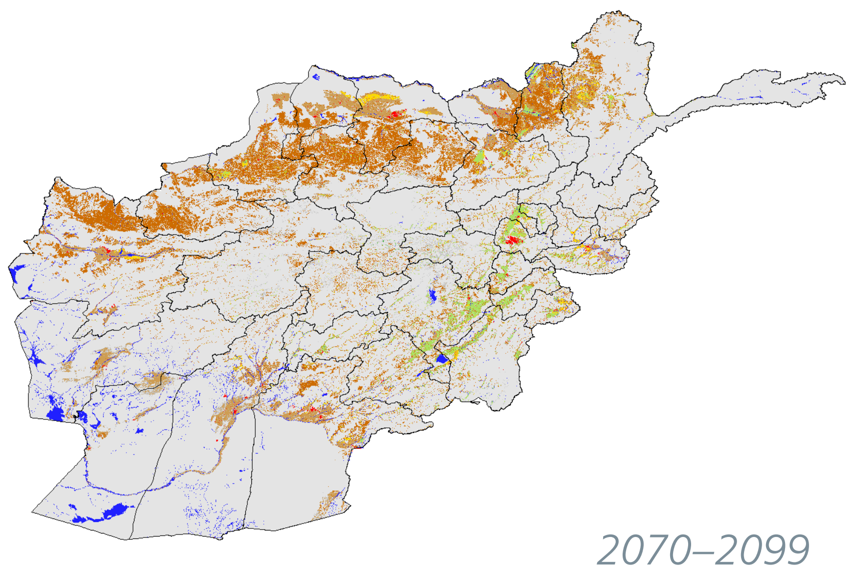
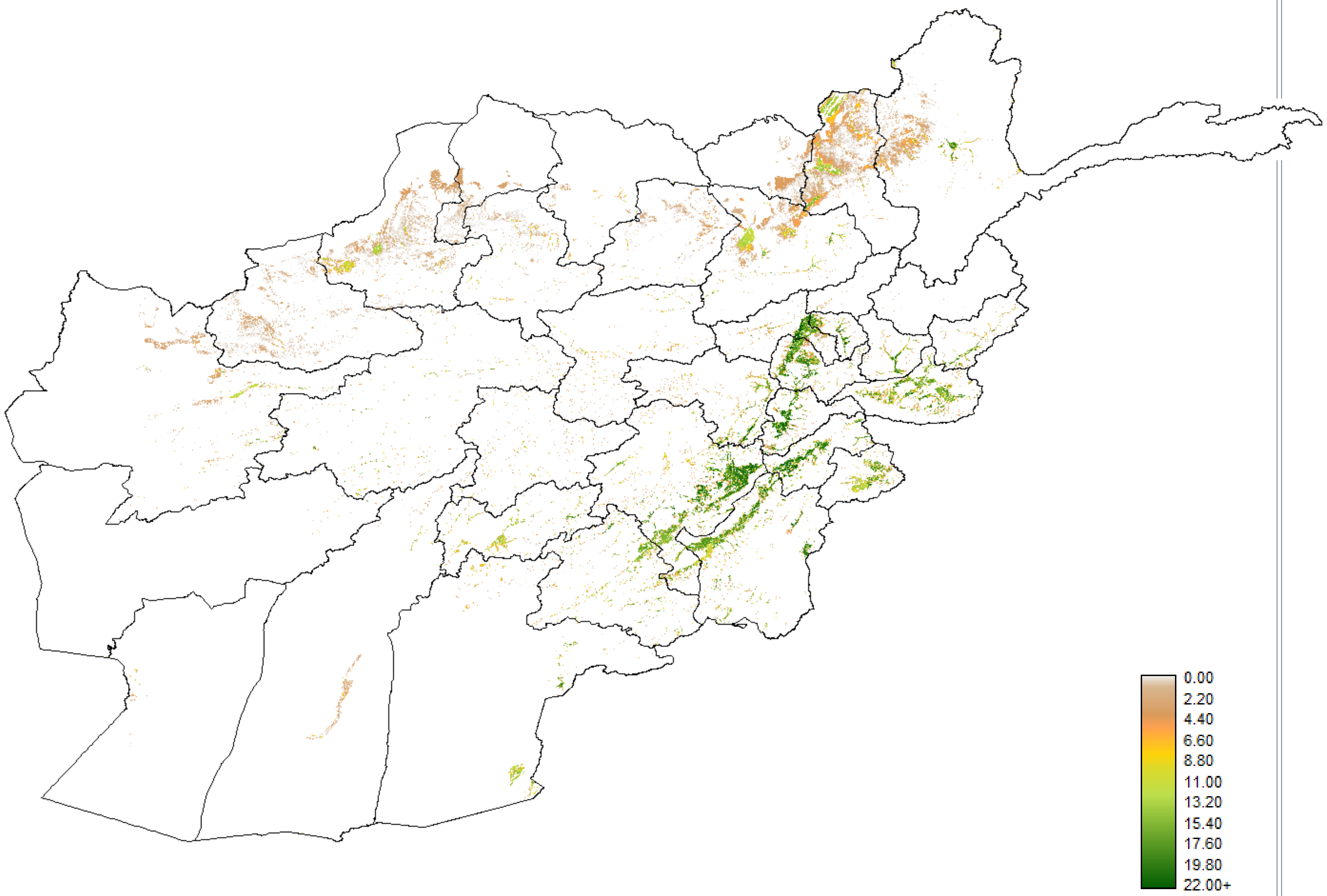


Figure 3.39b, 3.39c

Potential potato production on current cropland (tons), reference climate 1981–2010



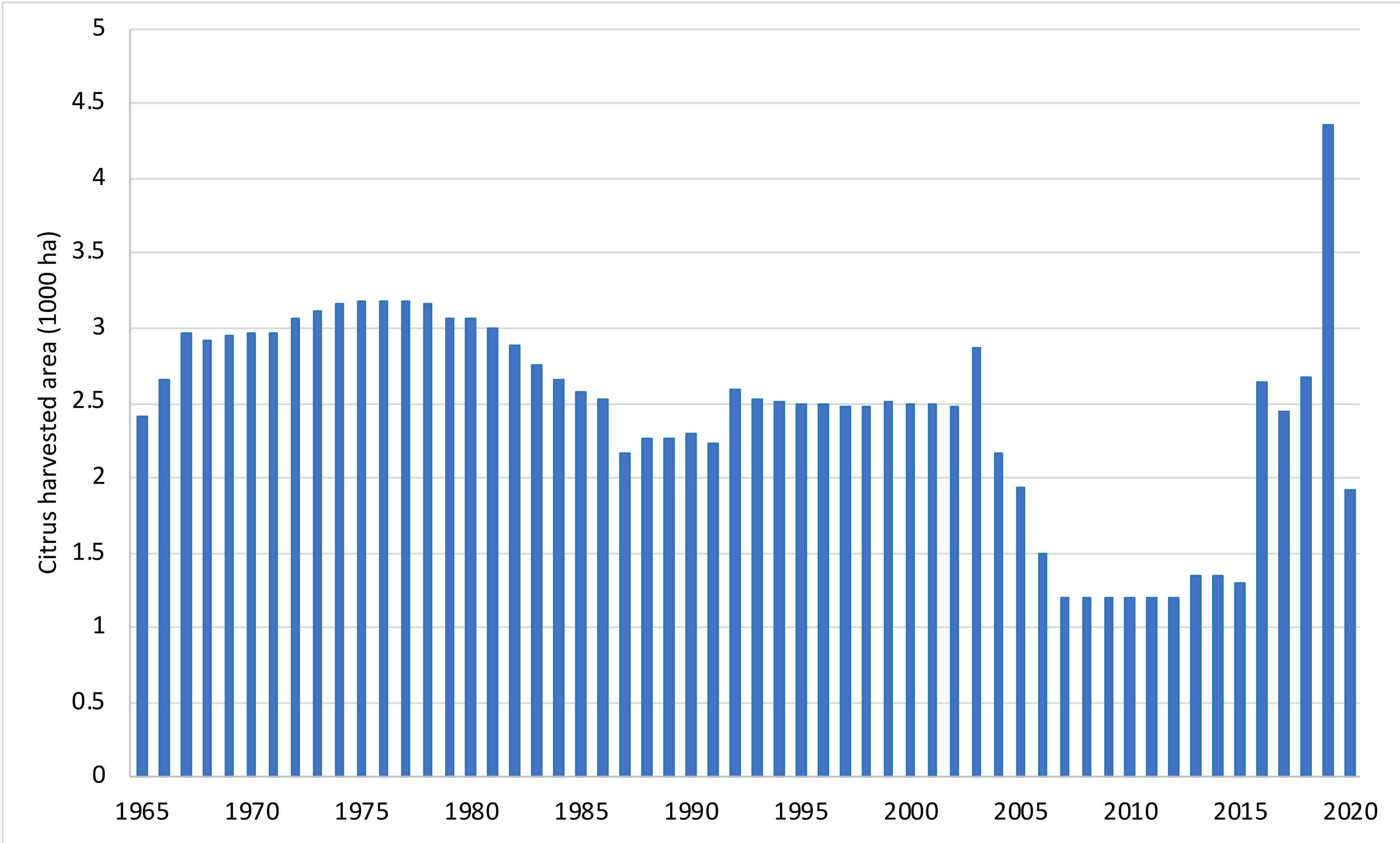
Source: Simulations using historical climate of 1981-2010. Values shown for current cropland refer to potential potato production at intermediate input level per 7.5 arc-seconds grid cell, i.e. about 5 hectares. Potential production is given as dry weight.

Figure 3.40

3.9 Climate change impacts on citrus suitability and production

According to data reported in FAOSTAT (Source: http://www.fao.org/faostat/en/#data/QC), citrus cultivation in Afghanistan occupied a harvested area in the range of 2.5 to 3 thousand hectares until about 2005 (see Figure 3.41). Then harvested citrus area dropped and after a low level of 1.2 thousand hectares in the period 2005 to 2015, citrus harvested area (reported separately in the statistics as oranges and other citrus fruit) increased after 2015 again to about 2.5 thousand hectares, reaching a peak of 4.4 thousand hectares in 2019. Thus, citrus can be regarded as a minor crop in Afghanistan, occupying only 1-2% of the total land with fruit trees and vineyards (about 200 thousand hectares according to LCDA 2010) and accounting for less than 0.1% of total irrigated land (i.e., there is about 3.8 million hectares of fruit trees, vineyards and irrigated cropland).

Citrus harvested area, Period 1965–2020



Source: FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021; Afghanistan Statistical Yearbook 2020 (NSIA, 2021).

Figure 3.41

Citrus (Citrus spec.)

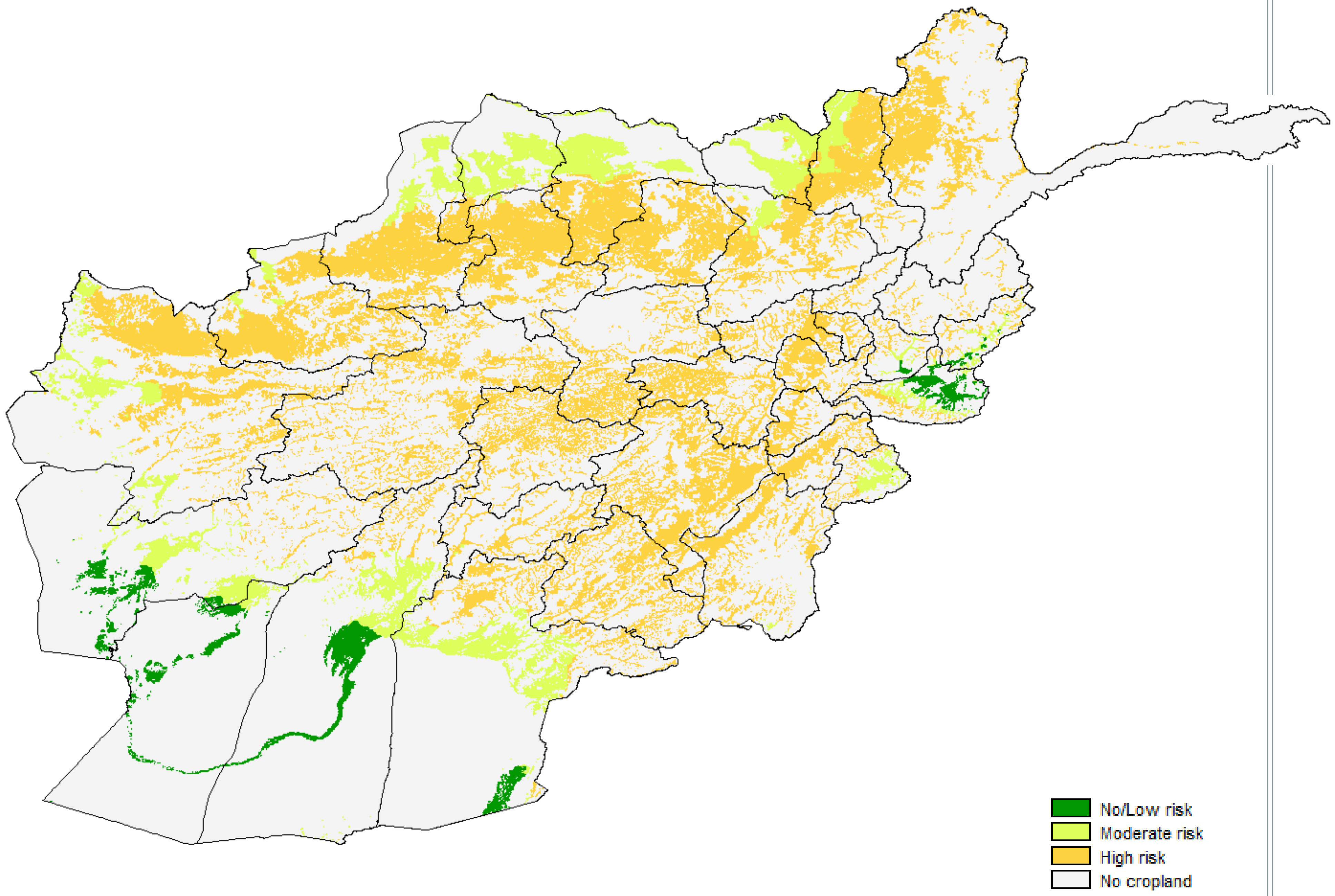
Citrus spp. are perennial fruit tree crops, mostly grown in tropical and subtropical environments with temperatures of 15-35˚C. Citrus is sensitive to frost, varying with variety, tree age and health. Frost sensitive types are lemon, lime and citron. Those may get defoliated with temperatures below 4-5°C; flowers are killed by 2-3°C, and mature fruits may be badly damaged at 2-3°C as well. Citrus tolerates high temperatures provided the trees are well supplied with soil moisture. Citrus is intolerant to high air humidity, except for mandarins tolerating wetter conditions. Citrus grows in areas with annual rainfall >600mm, but grows best in areas with annual rainfall of 1250 to 1850 mm. In arid and semi-arid areas of Afghanistan adequate irrigation water supply is required for maintaining sufficient soil moisture.

Citrus trees require a minimum of 60 cm of well-drained soil; loams and sandy loams are preferred. Sandy soils require careful water management due to low water-holding capacity and potential leaching of nutrients. Wet clay soils and poor drainage or waterlogging may cause collar and root rot leading to high tree mortality. Permissible soil pH ranges are between 5.0 and 8.2 and optimum pH between 5.5 and 7.6. Furthermore, citrus is sensitive to soil salinity and sodicity.

Citrus belongs to the C3 crop group (C3 II) consisting of tropical and subtropical cultivars characterized with optimum photosynthesis and growth at temperatures between 15°C and 30°C. Temperatures above 30°C lead to lower photosynthesis and temperatures above 35°C cause heat stress, both leading to lower yields. Citrus is well suited for cultivation in the subtropical winter rainfall areas of Afghanistan provided limited or no frost risk exists. Further, citrus is susceptible to an array of diseases linked to climatic conditions and to prevalence of insect pests.

The frost damage risk zones shown in Figure 3.42 were delineated using four agro-climatic indicators (see Part 1 of the Agro-Ecological Zoning Atlas (FAO & IIASA, 2019)), namely the number of days with average daily temperature above respectively 10°C (LGPt10), 5°C (LGPt5) and 0°C (LGPt0), and the number of days with minimum daily temperature < 0°C. In each case the average value of the 30-year period was applied. Citrus can tolerate cool temperatures and some days with light frost. For a grid cell to belong to the 'No/Low risk' class of frost damage for Citrus, we require that LGPt10 > 255 days, LGPt5 > 360 days, LGPt0 is 365 days, and the number of days with Tmin < 0°C does not exceed 30 days.

Delineation of frost damage risk zones for citrus
Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010. The frost damage risk zones shown were delineated using agro-climatic indicators generated with the NAEZ Afghanistan system (see FAO & IIASA, 2019).

Figure 3.42a

Ensemble mean, RCP8.5, 2041–2070–2099

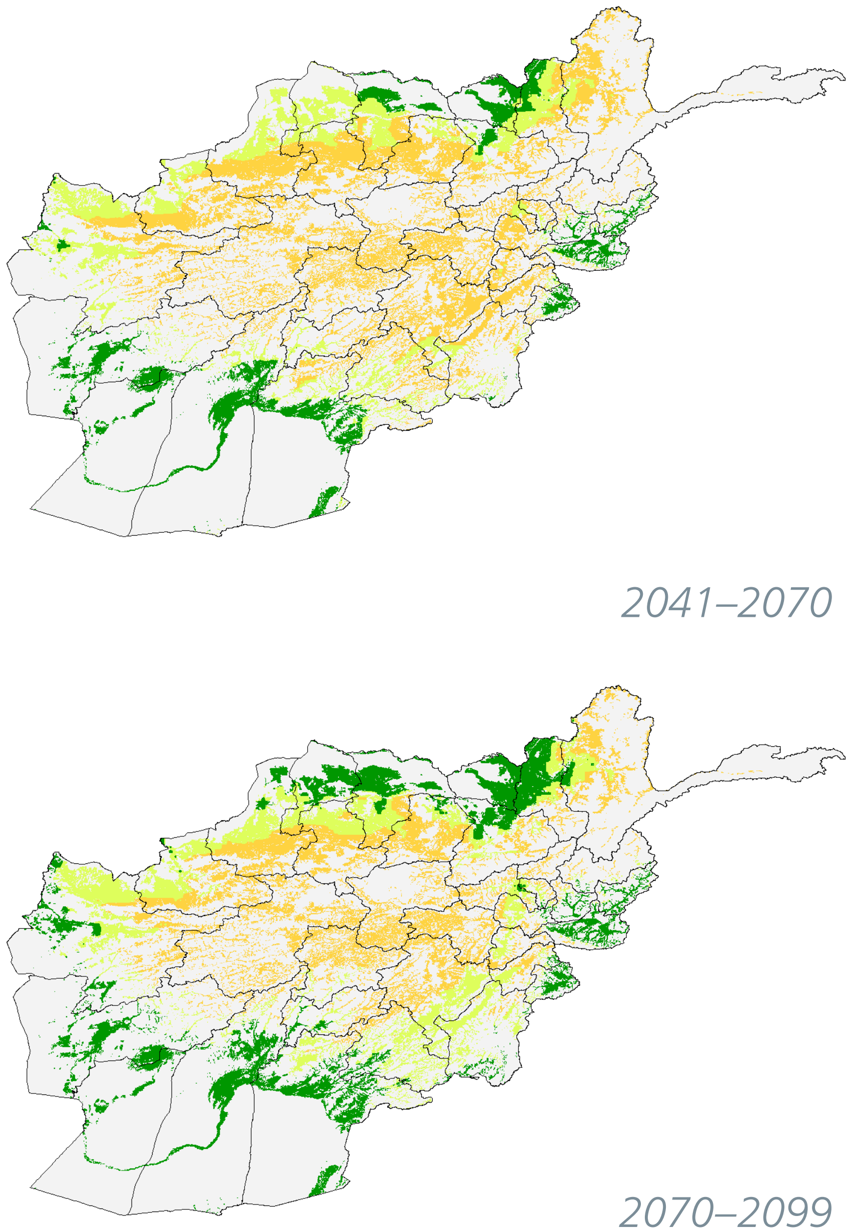


Figure 3.42b, 3.42c,

For the historical climate of 1981–2010, the No/low frost damage risk class is only found in the Eastern and Southwestern region. Large areas of moderate frost damage risk occur also in parts of the Northwestern, Western and Northeastern region (see Figure 3.42a).

With climate change, the area classified as No/low frost damage risk zone will expand greatly into the northern territory of Afghanistan where year-round cropping will become possible on irrigated land.

Table 3.30 presents citrus suitability and potential production of Afghanistan's (irrigated) land used for fruit trees and vineyards (an area of about 200 thousand hectares) and irrigated cropland (about 3.6 million hectares). Comparing the simulated land suitability and potential production of citrus for the period 1961–1990 and the period 1981–2010, the results suggest some improvement of citrus production potential mainly in northern regions and the Southwestern region.

As shown, the citrus production potential for historical climate is mainly found in the Eastern and Southwestern region, as is also indicated by the distribution of zones with No/low frost damage risk in Figure 3.42a.

Table 3.30 Suitability of citrus on irrigated land in 1961-2010, by region

Regions	Orchard & Vineyard	Suitable area and potential production			Irrigated Cropland	Suitable area and potential production		
		Area	Production	Yield		Area	Production	Yield
	1000 ha	1000 ha	1000 tons	tons/ha	1000 ha	1000 ha	1000 tons	tons/ha
Northeastern	18.3	0.2	0.7	3.53	386.9	29.1	95	3.63
Northwestern	25.6	0.06	0.1	2.82	636.4	16.1	40	2.77
Eastern	6.0	3.4	10.2	3.39	165.9	87.5	265	3.37
Central	45.4	0	0.0	0	250.5	0.0	0	0
West-central	26.6	0	0.0	0	375.7	0.0	0	0
Western	13.0	0.03	0.1	2.81	610.3	2.4	6	2.83
Southeastern	4.0	0.1	0.3	3.16	273.8	32.4	90	3.09
Southwestern	61.2	3.7	9.8	2.96	900.7	65.4	175	2.98
TOTAL	200.1	7.4	21.3	3.17	3,600.2	232.9	673	3.21

Note: The values represent suitable extents and potential production on respectively current irrigated cropland and irrigated land for fruit trees and vineyards, based on LCDA 2010 land cover. The prime (VS), good (S) and moderately (MS) suitable land for citrus is included. The assessment assumes water available and an intermediate level of inputs and management. Production and yields are shown as dry weight.

Table 3.31 presents by RCP an overview of climate change impacts on the extents suitable for citrus on current irrigated land. Results are shown for eight major regions of Afghanistan and refer to the ensemble means of crop simulation outcomes using climate projections of five climate models and for two RCPs, namely RCP4.5 and RCP8.5.

As presented, the national citrus suitable area (Table 3.31) and production potential (Table 3.32) in the 2050s is projected to increase substantially both for the land with fruit trees and vineyards as well as for current irrigated cropland. This trend is driven by warming and can be expected to continue to the 2080s. In the simulations the highest level of citrus production potential was obtained for RCP8.5 in the 2080s. The explanation in this case is simply the gradual expansion of the area with no or very minor frost risk, as can be seen in Figure 3.42 showing zones of no or low risk for citrus frost damage under historical and future climate.

Table 3.31 Climate change impacts on suitable cropland for citrus

	Suitability in land with Fruit Trees and Vineyards					Suitability in Irrigated Cropland				
Regions	Suitable Area (1000 ha)	Suitable Area, Ensemble Mean (1000 ha)				Suitable Area (1000 ha)	Suitable Area, Ensemble Mean (1000 ha)			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1961-2010	2050s	2080s	2050s	2080s	1961-2010	2050s	2080s	2050s	2080s
Northeastern	0.2	1.4	1.8	1.7	2.1	29.1	88.3	100.6	87.3	73.4
Northwestern	0.06	0.9	3.5	2.1	5.1	16.1	10.1	35.0	13.7	26.0
Eastern	3.4	3.1	2.4	1.8	1.1	87.5	85.4	74.4	67.3	32.7
Central	0	0.1	2.0	3.5	17.2	0.0	0.1	9.0	16.0	86.7
West-central	0	2.4	5.6	6.5	11.7	0.0	30.2	83.5	100.8	169.0
Western	0.03	0.3	0.8	0.5	0.7	2.4	21.7	41.3	25.3	26.4
Southeastern	0.1	0.6	1.4	1.6	2.6	32.4	86.4	124.2	137.4	164.8
Southwestern	3.7	11.5	14.5	13.9	12.8	65.4	100.3	113.7	105.4	76.6
TOTAL	7.4	20.3	32.0	31.7	53.4	232.9	423.4	581.5	553.1	655.6

Note: Suitable extents were taken to be very suitable (VS), suitable (S) and moderately suitable (MS) areas on respectively current irrigated cropland and irrigated land for fruit trees and vineyards.

Table 3.32 Climate change impacts on citrus production potential

Regions	Land with Fruit Trees and Vineyards					Land with Fruit Trees and Vineyards				
	Potential Production (1000 tons)	Potential Production, Ensemble Mean				Potential Production (1000 tons)	Potential Production, Ensemble Mean			
		RCP4.5		RCP8.5			RCP4.5		RCP8.5	
	1961-2010	2050s	2080s	2050s	2080s	1961-2010	2050s	2080s	2050s	2080s
Northeastern	0.7	4.1	5.4	4.9	5.8	95	270	309	265	210
Northwestern	0.1	2.4	9.4	5.7	14.4	40	26	98	36	72
Eastern	10.2	8.6	7.0	5.4	3.5	265	248	218	197	96
Central	0.0	0.2	5.4	9.2	49.7	0	2	24	42	248
West-central	0.0	6.7	16.0	18.5	35.0	0	83	238	287	508
Western	0.1	0.7	2.1	1.3	1.9	6	56	110	65	70
Southeastern	0.3	1.6	3.9	4.6	8.0	90	241	356	394	495
Southwestern	9.8	32.1	42.4	39.8	37.3	175	276	327	297	220
TOTAL	21.3	56.5	91.6	89.5	155.4	673	1 203	1 681	1 582	1 918

Note: Potential production was taken to be from very suitable (VS), suitable (S) and moderately suitable (MS) areas on current irrigated cropland and irrigated land for fruit trees and vineyards. The potential production is listed as dry weight.

Table 3.32 presents for irrigated land with fruit trees and vineyards (an area of about 0.2 million hectares) and for irrigated croplands (about 3.6 million hectares) the estimated citrus production potential for historical climate and for an ensemble mean of projected future climate.

The results suggest that citrus production potential will increase significantly with warming, as much as threefold for RCP 8.5 in the 2080s. Increases will occur in all regions but are most important in West-Central, Southeastern and Central region (see Figure 3.43 irrigated land with fruit trees and vineyards and Figure 3.44 for irrigated croplands).

Potential production of citrus on land for fruit trees and vineyards (1000 tons dry weight)

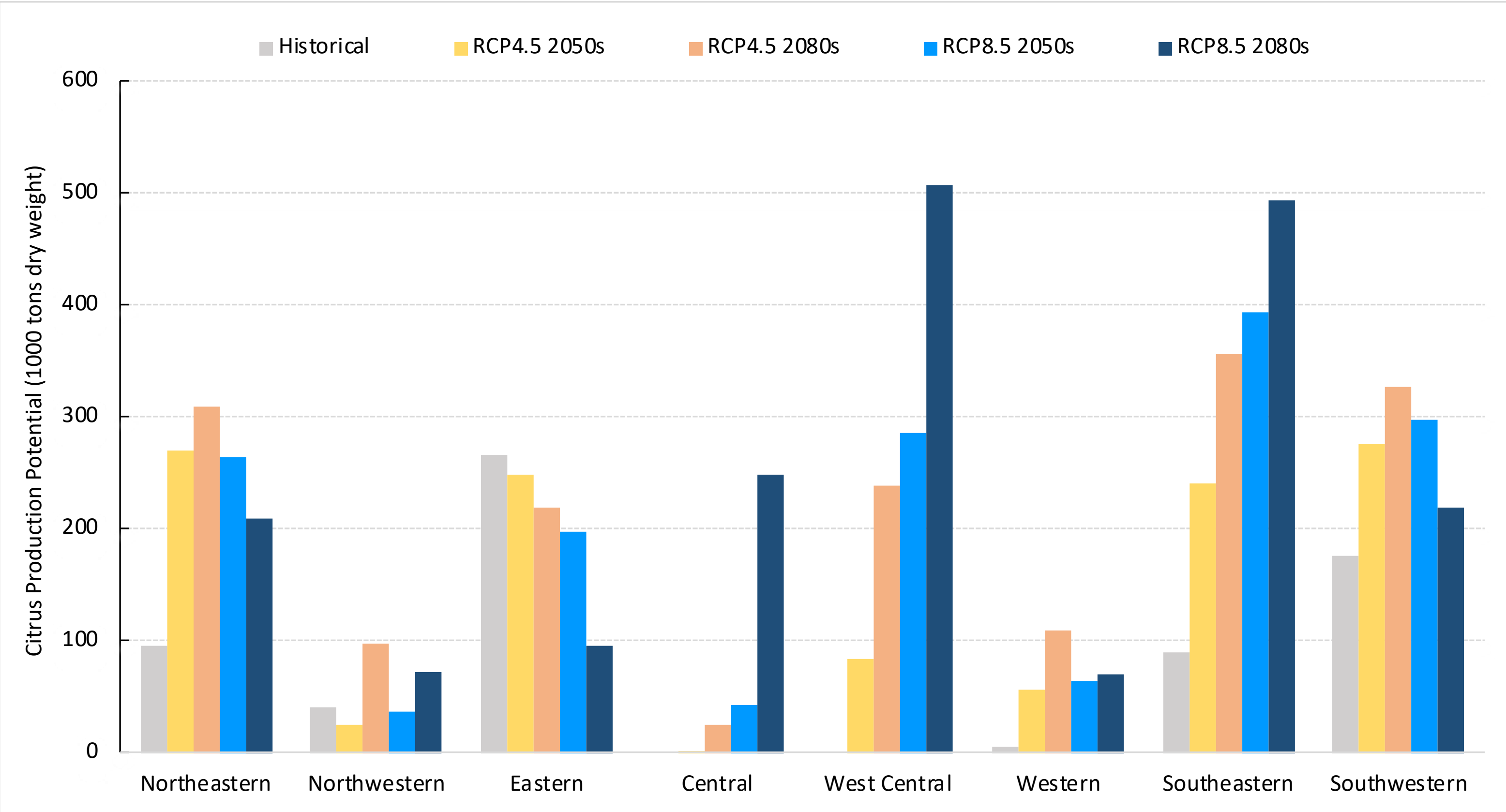


Figure 3.43

Figure 3.43 gives a graphical representation of results for land with fruit trees and vineyards by region for respectively RCP4.5 and RCP8.5, showing potential citrus production in the 2050s and the 2080s in comparison to each region's potential production during 1981–2010.

With the expansion of the frost-free area, in the long-term large increases of citrus production potential occur in Southeastern region and notably in Central and West-Central region. Note that in the latter two regions citrus production was not possible under historical climate. On the other hand, the historical hub of citrus production in the Eastern region will gradually become less suitable due to high temperatures.

Figure 3.44 shows the same information for current irrigated cropland. Note, while irrigated cropland is about 20-fold the size of land used for fruit trees and vineyards, the regional climate change impacts on citrus production potential are nevertheless qualitatively quite similar.

Figure 3.45 presents for current irrigated land the suitability for cultivation of citrus at an intermediate input level, both for historical (Figure 3.45a) and future (Figure 3.45b, 3.45c) climate conditions. The maps use a classification of the normalized suitability index SI, combining both the agro-climatic and agro-edaphic evaluation.

Potential production of citrus on irrigated cropland (1000 tons dry weight)

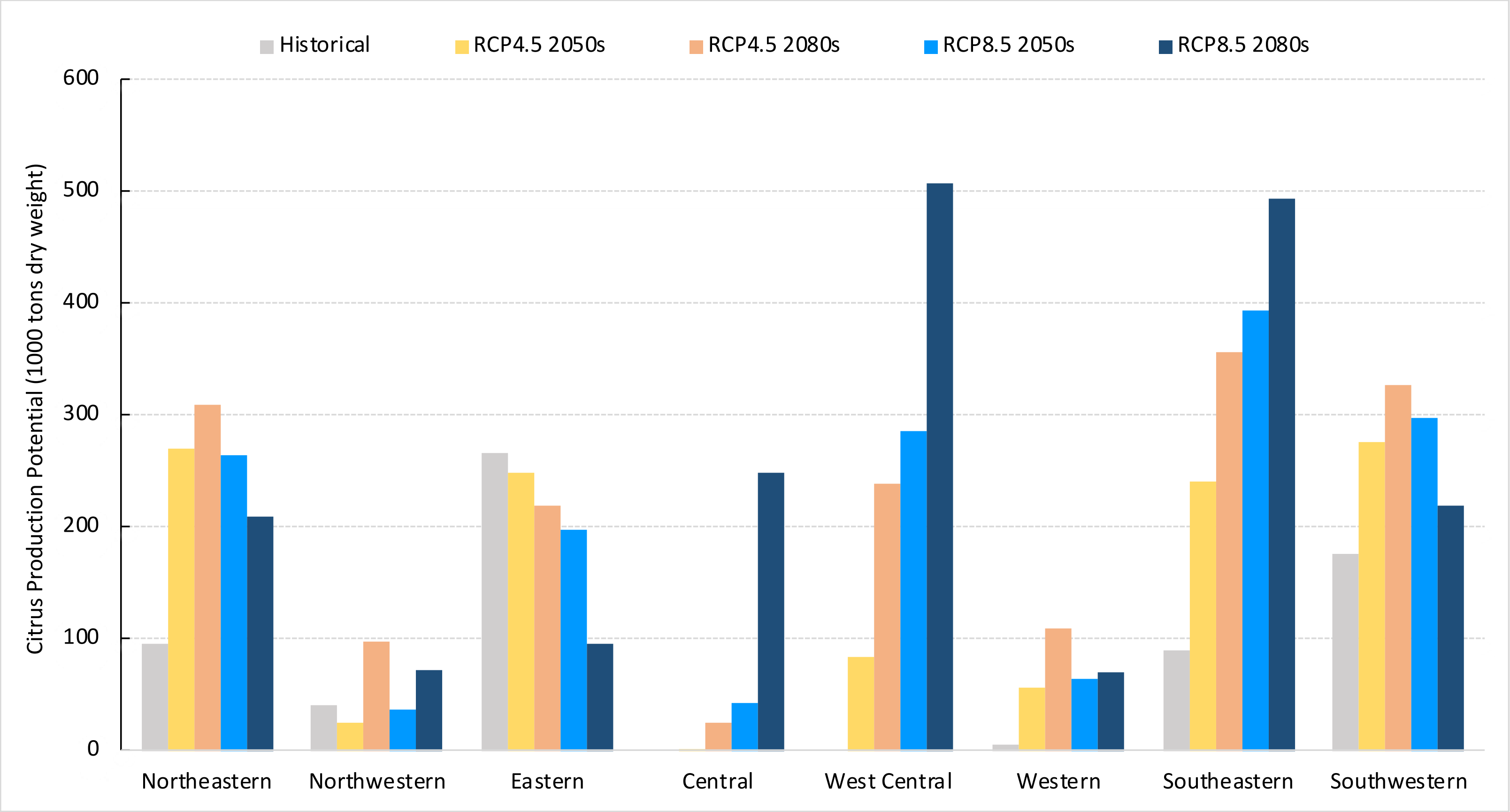
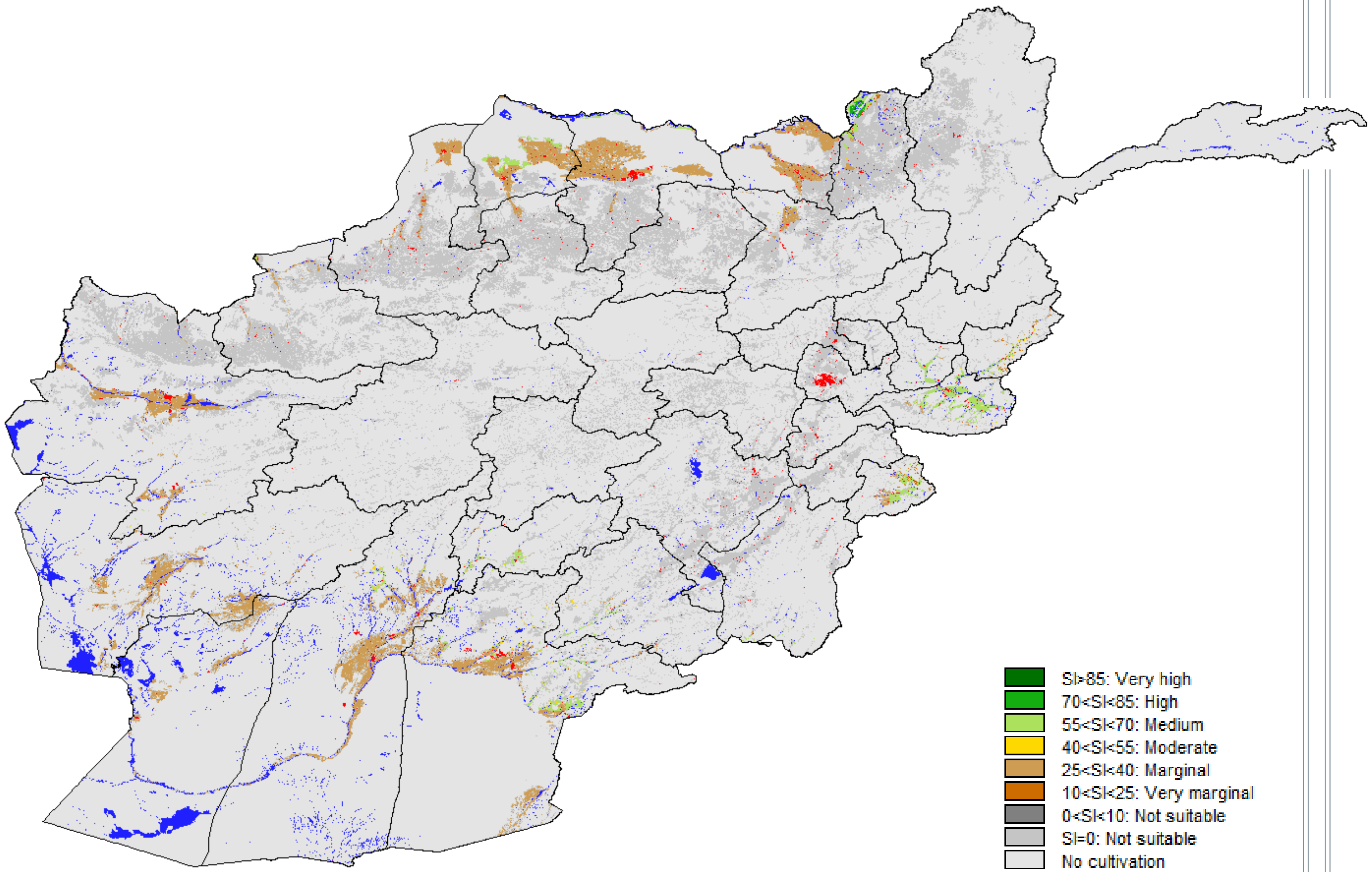
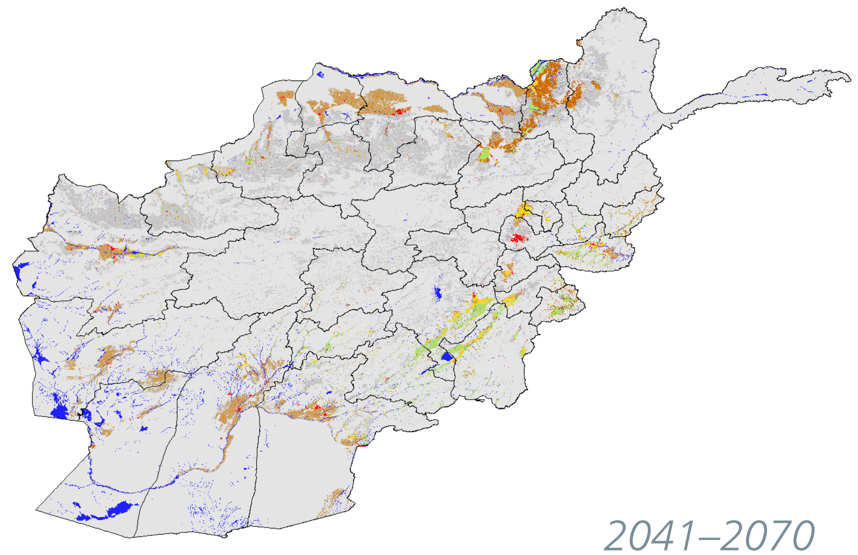


Figure 3.44

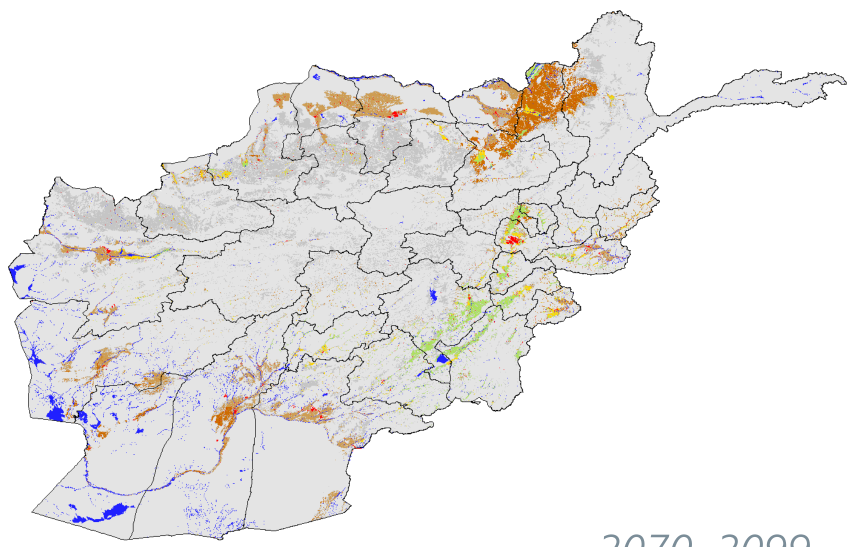
Citrus suitability index class of current cropland
Reference climate 1981–2010



Ensemble mean, RCP8.5,
2041–2070–2099



2041–2070



2070–2099

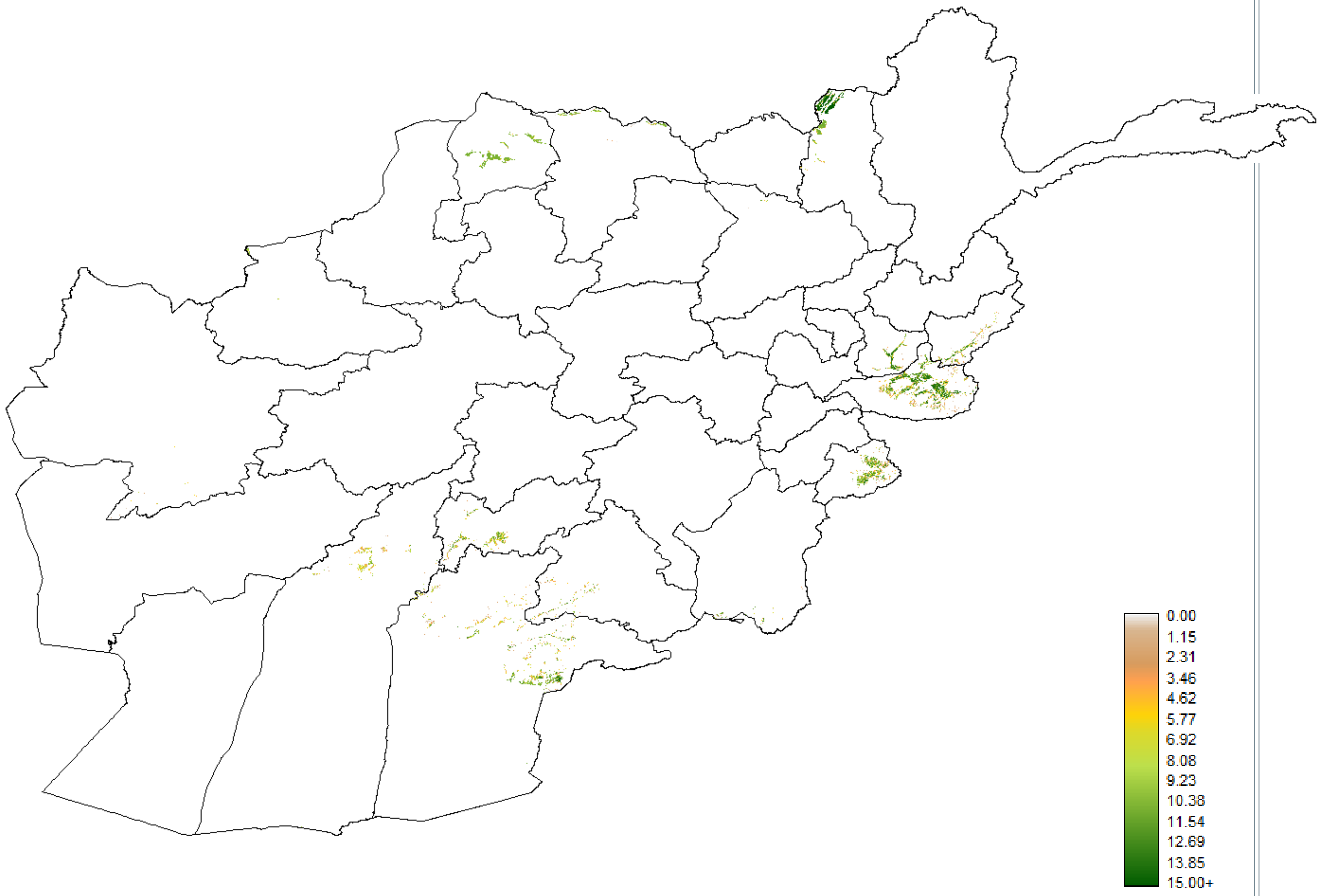
Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current cropland refer to average suitably class per 7.5 arc-seconds grid cell of the resource inventory.

Figure 3.45a **Figure 3.45b, 3.45c**

Figure 3.46 portrays the production potential of citrus in grid cells with irrigated land in the base period 1981–2010 (Figure 3.46a) and maps the results for citrus for the 2050s (Figure 3.46b) and the 2080s (Figure 3.46c) showing the production potential per grid cell under RCP8.5 (without considering CO_2 fertilization impacts). The maps illustrate that the suitable areas for citrus under historical climate were indeed extremely scarce and found only in land at low altitudes and with reliable irrigation. Under climate change the valleys with orchards and irrigated land in Central and Southeastern region will become increasingly suitable and in these regions citrus may partly substitute the current fruits adapted to cool environments, e.g., such as apples and apricots.

In summary, the NAEZ analysis concludes that suitable area and potential production of citrus will increase by a factor 1.8–2.4 above the historical level by the 2050s, and in the long-term by the 2080s may increase 2.5–3 times. Given the sensitivity of citrus to freezing events, it will be important for successful expansion of citrus production to carefully monitor and assess trends of frost risk where citrus may occur by mid-century.

Potential citrus production on current cropland (tons dry weight) Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current cropland refer to potential citrus production (dry weight) per 7.5 arc-seconds grid cell.

Figure 3.46a

Ensemble mean, RCP8.5, 2041–2070–2099

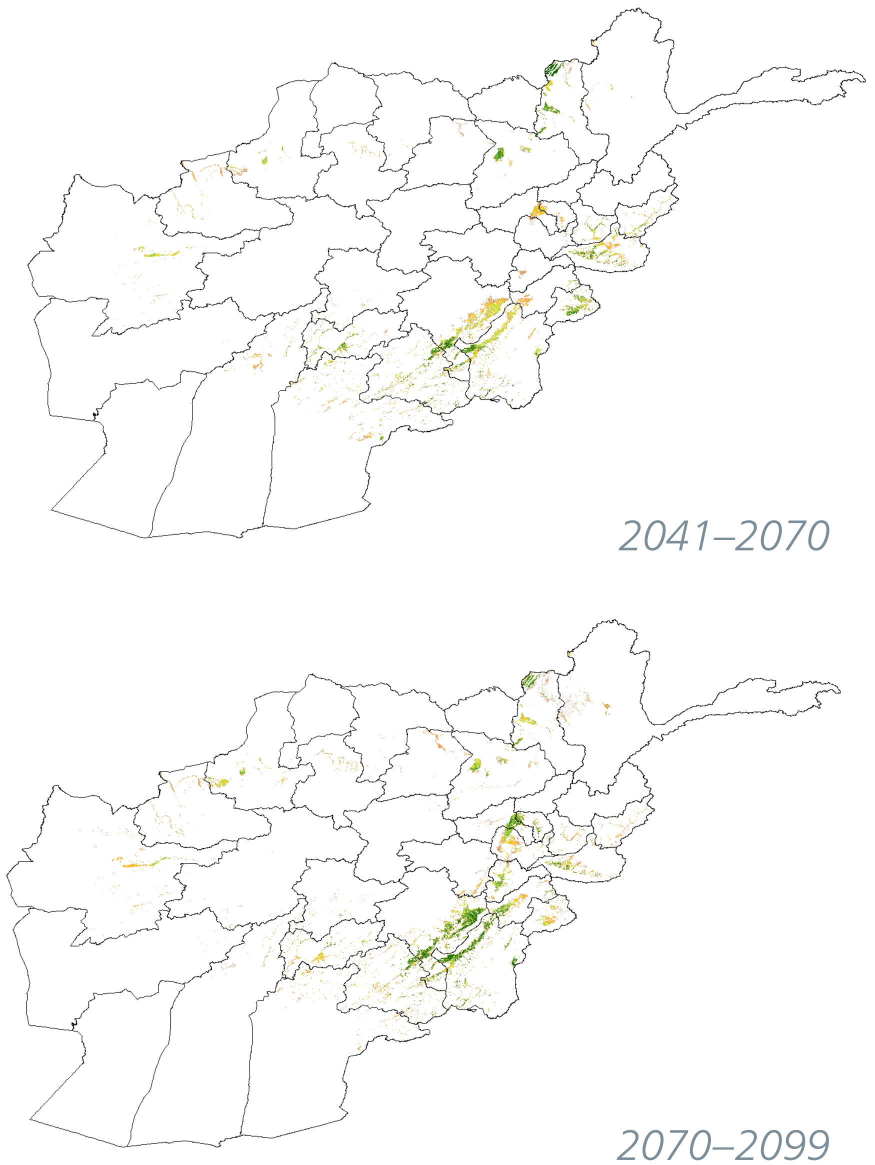


Figure 3.46b, 3.46c

3.10 Summary of climate change impacts on crop production potentials

For the current study of Afghanistan, historical and future suitability and productivity of more than 30 crops has been assessed, including major cereals like wheat (C3), barley (C3), maize (C4) and rice (C3), oil crops like soybean (C3), rapeseed (C3), sunflower (C3) and groundnut (C3), annual root and tuber crops (C3), sugar crops (C3 and C4), pulses (C3), selected perennials, and selected fodder crops. (C3/C4).

Crops were assessed for intermediate inputs and management assumptions, for rain-fed and irrigated production on current cropland. The land was evaluated in terms of area extents of prime, good, moderate and marginal quality, for baseline climate (1961–1990; 1981–2010) and climate scenario ensemble means compiled from simulations using outputs of five Earth system models and pertaining to different representative concentration pathways (RCP) in the 2020s, the 2050s and 2080s, without and with CO_2 fertilization effects.

Table 3.33 Climate change impacts on crops for current rain-fed and irrigated cropland, Afghanistan Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	4 270	11 086	↑	↔	↑	↓
Barley	4 954	13 931	↑	↔	↑	↓
Maize, grain	2 782	15 060	↑	↑	↑	↔
Maize, silage	3 253	23 783	↔	↔	↑	↔
Rice, paddy	1 543	4 290	↔	↔	↓	↓
Sorghum	4 060	14 882	↑	↑	↑	↑
Oat	3 746	5 118	↓	↓	↓	⬇
Rye	3 926	5 767	↔	↓	↓	⬇
Millet	2 740	5 701	↓	⬇	⬇	⬇
Buckwheat	1 484	928	⬇	⬇	⬇	⬇
Chickpea	1 011	1 293	↑↑	⬆	↑↑	⬆
Gram	1 621	1 696	↓	↓	↓	↓
Potato	1 531	4 463	↔	↔	↓	↓
Sweet potato	2 204	9 401	↓	↓	↔	↓
Sugar beet	849	2 798	⬇	↓↓	↓↓	↓↓
Sugarcane	653	2 947	↑↑	↑↑	↑↑	↑↑
Groundnut	1 337	1 665	↔	↔	↓	↓
Rapeseed	2 139	2 222	↑	↔	↑	↓
Sesame	2 298	3 285	↓	↓	↓	⬇
Soybean	2 506	4 637	↔	↓	↓	↓
Sunflower	2 239	4 013	⬇	⬇	↓	⬇
Cumin	1 180	614	↑	↑	↔	↓
Mustard	618	458	↑↑	↑↑	↑↑	↑↑
Cotton	1 976	946	↑	↑	↑	↑
Flax	2 881	1 057	↓	↓	⬇	⬇
Alfalfa	2 763	24 875	↑	↑	↑	↑
Citrus	267	767	↑↑	↑↑	↑↑	↑↑
Olive	2 210	2 850	↓	⬇	⬇	⬇
Cabbage	1 704	3 007	⬇	↓	↓	⬇
Onion	1 170	4 007	↓	↓	↓	⬇
Tomato	1 522	3 823	⬇	⬇	↓	⬇

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓,↑), 20%-50% (⬇,⬆) and more than 50% (↓↓,↑↑) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

Table 3.34 Climate change impacts on crops for current rain-fed and irrigated cropland, Northeastern Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	849	1 623	↑ (green)	↑ (green)	↑ (green)	↑ (green)
Barley	943	2 179	↑ (green)	↑ (green)	↑ (green)	↔
Maize, grain	442	1 856	↑ (teal)	↑ (green)	↑ (teal)	↑ (green)
Maize, silage	570	3 158	↑ (green)	↑ (green)	↑ (teal)	↑ (green)
Rice, paddy	184	527	↓ (yellow)	↓ (yellow)	↓ (red)	↓ (red)
Sorghum	752	1 974	↑ (green)	↑ (green)	↑ (teal)	↑ (green)
Oat	817	939	↑ (green)	↑ (green)	↓ (yellow)	↓ (yellow)
Rye	857	1 036	↔	↔	↓ (yellow)	↓ (yellow)
Millet	489	821	↑ (teal)	↓ (yellow)	↓ (yellow)	↓ (red)
Buckwheat	401	196	↓ (yellow)	↓ (yellow)	↓ (yellow)	↓ (yellow)
Chickpea	178	177	↑↑	↑↑	↑↑	↑↑
Gram	278	273	↑ (green)	↓ (yellow)	↔	↓ (red)
Potato	405	758	↑ (green)	↑ (teal)	↑ (green)	↑ (teal)
Sweet potato	276	1 156	↑ (green)	↓ (yellow)	↑ (green)	↓ (yellow)
Sugar beet	130	209	↑ (teal)	↓ (yellow)	↑ (teal)	↓ (red)
Sugarcane	0	0	↑↑	↑↑	↑↑	↑↑
Groundnut	232	259	↑ (green)	↓ (yellow)	↑ (teal)	↓ (red)
Rapeseed	492	335	↑ (teal)	↑ (teal)	↑ (teal)	↑ (teal)
Sesame	405	513	↑ (green)	↓ (yellow)	↔	↓ (red)
Soybean	299	560	↑ (green)	↔	↑ (teal)	↔
Sunflower	399	577	↓ (yellow)	↓ (red)	↑ (teal)	↓ (yellow)
Cumin	158	77	↑↑	↑ (teal)	↑↑	↑ (teal)
Mustard	0	0	↑↑	↑↑	↑↑	↑↑
Cotton	238	120	↑ (green)	↑ (green)	↑ (green)	↔
Flax	630	183	↑ (green)	↑ (green)	↓ (yellow)	↔
Alfalfa	292	2 705	↑ (teal)	↑ (green)	↑↑	↑ (teal)
Citrus	34	108	↑↑	↑↑	↑↑	↑↑
Olive	444	455	↑ (green)	↓ (red)	↓ (red)	↓↓
Cabbage	385	453	↓ (yellow)	↓ (yellow)	↑ (green)	↑ (green)
Onion	321	635	↓ (yellow)	↓ (yellow)	↔	↓ (yellow)
Tomato	342	562	↔	↓ (red)	↑ (teal)	↓ (yellow)

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓,↑), 20%-50% (↓,↑) and more than 50% (↓↓,↑↑) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

Table 3.33 to Table 3.41 indicate at the national and regional levels the projected changes in crop-wise suitable rain-fed and irrigated cropland and associated attainable potential production under a high-end climate change scenario for RCP8.5 in the 2050s (period 2041–2070) and the 2080s (period 2070–2099) relative to the historical period 1981–2010. Magnitude and direction of changes are represented by seven colored arrow symbols: for minor impacts of -3% to +3% (symbol ↔); for moderate impacts of -20% to -3% (symbol ↓) or +3% to +20% (symbol ↑); for considerable impacts of -50% to -20% (symbol ↓) or +20% to +50% (symbol ↑); and for very large losses exceeding -50% (symbol ↓↓) or gains greater than +50% (symbol ↑↑).

By the 2050s the analysis finds at the national level mostly minor or moderate impacts, notably some improvements for winter crops where rain-fed cultivation especially in northern regions can benefit from better soil moisture conditions due to the shift of the crop calendar made possible by the shortening of cold breaks and dormancy periods.

For long-cycle or perennial crops requiring year-round frost-free conditions, e.g., such as sugarcane and citrus, potentially suitable areas and potential production increase very strongly.

On the other hand, for various crops currently suitable in low-lying warm areas of the Southwestern, Western and Eastern region, yields begin to decline due to heat stress and shorter crop cycles, and suitable area and production, on balance across regions, tends to decrease with further warming.

There are major differences in the outcomes for different regions due to differences in climatic risks and constraints. In terms of broad characteristics we find: (i) regions at higher latitudes or altitudes with a large share of rain-fed cropland in total cropland (e.g., Northeastern and Northwestern region), (ii) the central highland regions (i.e., Central and West-Central region; parts of Southeastern region), and (iii) the low-lying areas of southern and eastern Afghanistan (i.e., Southwestern and Eastern region; parts of Souteastern region).

At higher latitudes or higher altitudes, the cold winter temperatures under historical climate limit the productive use of land during winter and early spring, a period when snowfall and winter rainfall can result in sufficient soil moisture for rain-fed cropping before soils dry up towards summer. The shift of crop calendars for winter crops is an important factor especially in the Northeastern and Northwestern region as well as parts of the Western region, where most of the rain-fed cropland Afghanistan's is located.

Table 3.35 Climate change impacts on crops for current rain-fed and irrigated cropland, Northwestern Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	886	1 665	↑	↔	↑	↔
Barley	1 154	2 479	↑	↓	↑	↓
Maize, grain	545	2 878	↔	↔	↑	↓
Maize, silage	756	4 393	↓	↓	↓	⬇
Rice, paddy	122	334	↓	↓	↓	⬇
Sorghum	881	2 825	↔	↔	⬆	↔
Oat	789	828	↓	↓	↓	↓
Rye	849	894	↔	↓	↔	↓
Millet	580	904	⬇	⬇	⬇⬇	⬇⬇
Buckwheat	128	58	⬇	⬇	↑	↓
Chickpea	40	48	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Gram	294	288	⬇	⬇	⬇⬇	⬇⬇
Potato	207	281	↓	↓	⬇	↓
Sweet potato	520	2 167	⬇⬇	⬇⬇	⬇	⬇
Sugar beet	49	136	⬇	⬇⬇	↑	⬇⬇
Sugarcane	0	0	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Groundnut	381	458	⬇⬇	⬇⬇	⬇⬇	⬇⬇
Rapeseed	341	278	↑	↔	⬆	↑
Sesame	526	808	⬇	⬇	⬇	⬇⬇
Soybean	528	953	↓	↓	↓	⬇
Sunflower	308	489	⬇⬇	⬇⬇	⬇	⬇⬇
Cumin	234	114	⬇	⬇	⬇⬇	⬇⬇
Mustard	1	1	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Cotton	354	162	↓	↓	↓	⬇
Flax	567	152	↓	↓	⬇	⬇
Alfalfa	554	4 644	↔	↔	↑	↓
Citrus	16	40	↔	↑	⬆⬆	⬆⬆
Olive	594	806	⬇	⬇⬇	⬇⬇	⬇⬇
Cabbage	324	362	⬇⬇	⬇⬇	⬇	⬇⬇
Onion	98	151	↓	↑	⬆	↑
Tomato	256	451	⬇⬇	⬇⬇	↓	⬇

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓,↑), 20%-50% (⬇,⬆) and more than 50% (⬇⬇,⬆⬆) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

Table 3.36 Climate change impacts on crops for current rain-fed and irrigated cropland, Central Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	200	936	↑	↑	↑	↓
Barley	203	961	↑	↑	↑	↓
Maize, grain	153	837	↑	⬆	↑	⬆
Maize, silage	157	1 684	↑	↑	↑	↑
Rice, paddy	109	329	↑	⬆	⬆	⬆
Sorghum	165	728	↑	⬆	⬆	⬆
Oat	191	408	↑	↔	↔	↔
Rye	191	482	↑	↔	↑	↓
Millet	132	425	⬆	⬆	⬆	⬆
Buckwheat	164	145	↑	↔	↔	↓
Chickpea	133	202	⬆	↑	⬆	↑
Gram	113	107	⬆	⬆⬆	⬆	⬆⬆
Potato	168	717	↑	↓	↔	↓
Sweet potato	54	204	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Sugar beet	158	555	⬇	↓	⬇⬇	⬇⬇
Sugarcane	0	0	↔	↔	↑	↑
Groundnut	1	2	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Rapeseed	165	243	↑	↔	↑	↓
Sesame	75	74	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Soybean	149	309	↑	↑	↑	↑
Sunflower	162	371	↑	↑	↑	↑
Cumin	91	49	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Mustard	0	0	↔	↔	↑	↑
Cotton	24	9	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Flax	176	111	↑	↓	↑	↓
Alfalfa	157	1 466	↑	⬆	↑	⬆
Citrus	0	0	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Olive	2	2	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Cabbage	163	479	↑	↓	↑	⬇
Onion	166	647	↔	⬆	↓	↑
Tomato	149	474	↑	↑	↑	↔

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓,↑), 20%-50% (⬇,⬆) and more than 50% (⬇⬇,⬆⬆) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

In the central highland regions (Central and West-Central region), with mainly irrigated cropland, current cold temperature limitations for cropping will be relaxed by climate change and potentially suitable areas and attainable yields of many crops will increase.

This will allow new crops to be grown in these areas or more productive varieties with longer crop cycle duration to be cultivated. For the central highlands the process of global warming appears initially to be beneficial from an agronomic perspective, provided water resources are not diminished and irrigation water supply can be secured and enhanced.

Nearly all crops benefit in Central and West-Central region from a moderate level of climate change, e.g., such as in the 2050s when both suitable extents and average attainable yields increase. For intense climate change, as projected under RCP8.5 in the 2080s, some important crops adapted to cooler environments begin to loose production potential.

Magnitude and direction of climate change impacts will develop quite similar in the provinces of Central and West-Central region. In both regions increasing extents of suitable irrigated land for long-cycle crops, which could not be cultivated under historical climate conditions, will emerge in the longer term, e.g., sugarcane, citrus and olive.

Table 3.37 Climate change impacts on crops for current rain-fed and irrigated cropland, West-Central Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	288	1 213	↑ (green)	↑ (green)	↑ (green)	↓ (yellow)
Barley	276	1 271	↑ (green)	↔	↑ (green)	↓ (yellow)
Maize, grain	211	1 299	↑ (green)	↑ (teal)	↑ (green)	↑ (teal)
Maize, silage	221	2 555	↑ (green)	↔	↑ (green)	↓ (yellow)
Rice, paddy	165	482	↑ (green)	↑ (green)	↑ (green)	↑ (green)
Sorghum	237	1 158	↑ (teal)	↑ (teal)	↑ (teal)	↑ (teal)
Oat	259	534	↑ (green)	↔	↔	↓ (yellow)
Rye	260	633	↑ (green)	↔	↔	↓ (yellow)
Millet	201	661	↑ (green)	↑ (green)	↑ (teal)	↔
Buckwheat	231	173	↓ (red)	↓ (yellow)	↓ (red)	↓↓
Chickpea	192	202	↑ (green)	↔	↑ (green)	↓ (yellow)
Gram	192	233	↑ (green)	↑ (green)	↑ (teal)	↑ (green)
Potato	212	845	↔	↓ (yellow)	↔	↓ (yellow)
Sweet potato	178	795	↑ (green)	↑ (teal)	↑ (teal)	↑ (teal)
Sugar beet	217	809	↓↓	↓↓	↓↓	↓↓
Sugarcane	0	0	↑ (green)	↑ (green)	↑↑	↑↑
Groundnut	125	166	↑↑	↑↑	↑↑	↑↑
Rapeseed	222	314	↑ (green)	↔	↑ (green)	↓ (yellow)
Sesame	183	229	↑ (green)	↑↑	↑ (teal)	↑↑
Soybean	205	309	↑ (green)	↑ (green)	↑ (green)	↑ (green)
Sunflower	230	509	↑ (green)	↑ (green)	↑ (green)	↓ (yellow)
Cumin	193	107	↑ (green)	↑ (green)	↑ (green)	↑ (green)
Mustard	0	0	↑ (green)	↑ (green)	↑↑	↑↑
Cotton	153	60	↑ (green)	↑↑	↑ (teal)	↑↑
Flax	234	133	↑ (green)	↓ (yellow)	↑ (green)	↓ (yellow)
Alfalfa	213	2 065	↑ (green)	↑ (teal)	↑ (green)	↑ (teal)
Citrus	0	0	↑↑	↑↑	↑↑	↑↑
Olive	80	116	↑↑	↑↑	↑↑	↑↑
Cabbage	232	557	↔	↓ (yellow)	↓ (yellow)	↓ (red)
Onion	205	909	↓ (yellow)	↔	↓ (yellow)	↓ (red)
Tomato	202	667	↑ (green)	↔	↔	↓ (red)

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓ (yellow), ↑ (green)), 20%-50% (↓ (red), ↑ (teal)) and more than 50% (↓↓, ↑↑) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

Table 3.38 Climate change impacts on crops for current rain-fed and irrigated cropland, Western Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	905	1 758	↔	↓ (yellow)	↑ (green)	↓ (yellow)
Barley	1 141	2 447	↑ (green)	↓ (yellow)	↑ (green)	↓ (yellow)
Maize, grain	427	2 299	↔	↔	↔	↓ (yellow)
Maize, silage	535	3 496	↓ (yellow)	↓ (yellow)	↑ (green)	↓ (yellow)
Rice, paddy	260	685	↓ (yellow)	↓ (yellow)	↓ (yellow)	↓ (yellow)
Sorghum	823	2 561	↔	↔	↑ (teal)	↔
Oat	743	791	↓ (yellow)	↓ (yellow)	↓ (yellow)	↓ (red)
Rye	819	902	↓ (yellow)	↓ (yellow)	↓ (yellow)	↓ (red)
Millet	433	796	↓ (red)	↓ (red)	↓↓ (red)	↓↓ (red)
Buckwheat	163	73	↓ (red)	↓ (red)	↔	↓ (red)
Chickpea	64	77	↑↑ (teal)	↑↑ (teal)	↑↑ (teal)	↑↑ (teal)
Gram	187	177	↓ (red)	↓ (red)	↓↓ (red)	↓↓ (red)
Potato	123	209	↑ (green)	↓ (yellow)	↓ (yellow)	↓ (red)
Sweet potato	339	1 389	↓ (red)	↓ (red)	↓ (yellow)	↓ (red)
Sugar beet	57	171	↓ (red)	↓↓ (red)	↓↓ (red)	↓↓ (red)
Sugarcane	147	660	↑↑ (teal)	↑↑ (teal)	↑↑ (teal)	↑↑ (teal)
Groundnut	135	163	↓ (red)	↓ (red)	↓↓ (red)	↓↓ (red)
Rapeseed	191	174	↑ (teal)	↓ (yellow)	↑ (teal)	↓ (red)
Sesame	358	519	↓ (red)	↓ (red)	↓↓ (red)	↓↓ (red)
Soybean	410	720	↓ (yellow)	↓ (yellow)	↓ (yellow)	↓ (red)
Sunflower	338	556	↓↓ (red)	↓↓ (red)	↓↓ (red)	↓↓ (red)
Cumin	66	33	↓ (yellow)	↔	↓ (yellow)	↓ (yellow)
Mustard	150	101	↑ (teal)	↑ (green)	↑ (teal)	↓ (yellow)
Cotton	362	175	↑ (green)	↔	↔	↓ (yellow)
Flax	480	134	↔	↓ (yellow)	↓ (red)	↓ (red)
Alfalfa	467	3 967	↔	↔	↔	↓ (yellow)
Citrus	2	6	↑↑ (teal)	↑↑ (teal)	↑↑ (teal)	↑↑ (teal)
Olive	368	454	↓ (red)	↓ (red)	↓↓ (red)	↓↓ (red)
Cabbage	191	216	↓↓ (red)	↓ (red)	↓ (red)	↓ (red)
Onion	58	126	↓ (red)	↓ (yellow)	↑ (green)	↓ (yellow)
Tomato	108	272	↓↓ (red)	↓↓ (red)	↑ (green)	↓↓ (red)

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓ (yellow), ↑ (green)), 20%-50% (↓ (red), ↑ (teal)) and more than 50% (↓↓ (red), ↑↑ (teal)) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

Yet another set of consequences will apply in low-lying areas with year-round temperature growing period conditions already in the reference climate, i.e., with no or only minor cold temperature limitations for cropping. Such cropland areas at low altitudes in the already warm Western, Southwestern and Eastern region may experience large negative impacts on crop production potential, at least in the longer term under projected high-end climate scenarios in the 2080s under RCP8.5. In this scenario and for these areas two negative factors combine, namely a reduction of available soil moisture in rain-fed cropland due to deteriorating annual and seasonal P/ET0 ratios, and more frequent heat stress for crops due to more extreme daily temperatures. Winter cereal crops will still be possible, but with somewhat lower attainable yields both on rain-fed and irrigated land.

Climate change produces clearly negative impacts for the majority of crops in the Eastern region. Low-lying irrigated croplands enjoyed year-round cultivation conditions already under historical climate which limits the options for adjusting crop calendars of winter crops in response to climate change. On the other hand, summer crops will more frequently and more intensely suffer from heat stress. As a consequence, production losses will likely be incurred in both seasons.

As shown in Table 3.39, the cropland at low altitudes in the Eastern region experiences a decrease of suitable areas under a high-end climate change scenario and especially so for cryophilic crops. Average attainable yields decline somewhat by the 2050s and are more severely affected by the 2080s, with only few exceptions. Notably sugarcane will improve in suitable area and potential production.

Table 3.39 Climate change impacts on crops for current rain-fed and irrigated cropland, Eastern Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	127	496	↔	↓ (yellow)	↔	↓ (red)
Barley	128	477	↔	↓ (yellow)	↔	↓ (red)
Maize, grain	112	736	↔	↔	↔	↓ (yellow)
Maize, silage	111	1 088	↔	↑ (green)	↔	↑ (green)
Rice, paddy	82	242	↔	↓ (yellow)	↓ (yellow)	↓ (yellow)
Sorghum	126	610	↔	↔	↔	↓ (yellow)
Oat	114	226	↔	↓ (yellow)	↓ (yellow)	↓ (red)
Rye	113	250	↔	↓ (red)	↓ (yellow)	↓ (red)
Millet	111	339	↓ (red)	↓↓	↓↓	↓↓
Buckwheat	93	64	↓ (yellow)	↓ (yellow)	↓ (red)	↓ (red)
Chickpea	105	145	↓ (yellow)	↓ (red)	↔	↓ (red)
Gram	105	127	↔	↓ (yellow)	↔	↓ (yellow)
Potato	104	434	↓ (yellow)	↓ (yellow)	↓↓	↓↓
Sweet potato	108	558	↔	↓ (yellow)	↔	↓ (yellow)
Sugar beet	16	58	↓↓	↓↓	↓↓	↓↓
Sugarcane	67	336	↑ (teal)	↑↑	↑↑	↑↑
Groundnut	103	141	↔	↓ (yellow)	↓ (red)	↓ (red)
Rapeseed	105	140	↔	↓ (yellow)	↔	↓ (yellow)
Sesame	106	190	↔	↓ (yellow)	↔	↓ (yellow)
Soybean	105	201	↔	↓ (yellow)	↔	↓ (yellow)
Sunflower	112	236	↔	↓ (red)	↓ (yellow)	↓ (red)
Cumin	104	58	↔	↓ (yellow)	↓ (yellow)	↓ (yellow)
Mustard	75	71	↑ (teal)	↑ (teal)	↑ (teal)	↑ (green)
Cotton	103	55	↔	↔	↔	↓ (yellow)
Flax	108	57	↔	↓ (yellow)	↑ (green)	↓ (red)
Alfalfa	114	1 178	↔	↔	↔	↓ (yellow)
Citrus	91	276	↓ (red)	↓ (red)	↓↓	↓↓
Olive	113	151	↓↓	↓↓	↓↓	↓↓
Cabbage	47	106	↑↑	↑↑	↑ (green)	↑ (teal)
Onion	87	429	↓↓	↓↓	↓↓	↓↓
Tomato	92	272	↓↓	↓↓	↓↓	↓↓

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓ (yellow), ↑ (green)), 20%-50% (↓ (red), ↑ (teal)) and more than 50% (↓↓, ↑↑) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

Table 3.40 Climate change impacts on crops for current rain-fed and irrigated cropland, Southeastern Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	253	1 178	↔	↓	↔	↓
Barley	254	1 224	↔	↓	↔	⬇
Maize, grain	220	1 389	↔	↑	↔	↑
Maize, silage	223	2 505	↔	↓	↔	↓
Rice, paddy	165	483	↑	↑	↑	↑
Sorghum	247	1 251	↔	↑	↑	↑
Oat	231	491	↔	↓	↔	↓
Rye	231	589	↔	↓	↔	↓
Millet	201	652	↓	↑	↔	↓
Buckwheat	209	155	⬇	⬇	⬇⬇	⬇⬇
Chickpea	184	248	↑	↓	↑	↓
Gram	193	227	↑	↑	↑	↑
Potato	210	856	↓	↓	↓	↓
Sweet potato	180	828	⬆	⬆	↑	⬆
Sugar beet	166	649	⬇⬇	⬇⬇	⬇⬇	⬇⬇
Sugarcane	14	56	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Groundnut	148	204	⬆	⬆	⬆	⬆
Rapeseed	215	305	↔	↓	↔	↓
Sesame	187	270	↑	⬆	↑	⬆
Soybean	217	431	↔	↔	↔	↓
Sunflower	222	505	↔	↓	↔	↓
Cumin	206	110	↔	↑	↑	↑
Mustard	20	18	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Cotton	148	67	⬆	⬆	⬆	⬆⬆
Flax	222	126	↔	↓	↔	↓
Alfalfa	229	2 262	↑	↑	↑	↑
Citrus	31	87	⬆⬆	⬆⬆	⬆⬆	⬆⬆
Olive	140	209	⬆	⬆	⬆	⬆
Cabbage	215	534	↓	↓	↓	↓
Onion	177	841	↓	↓	⬇	↓
Tomato	213	688	↓	↓	↓	⬇

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓,↑), 20%-50% (⬇,⬆) and more than 50% (⬇⬇,⬆⬆) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

The estimation of potential crop production in Southeastern region produces mixed results, a few positive and several negative outcomes (see Table 3.40).

Note that rain-fed cropland accounts for less than 5% of total cropland and as much as 50% of irrigated land is classified as 'Poorly irrigated'. The results obtained for changes of the crop production potentials should therefore in this case be regarded as quite uncertain, as it is assumed in the crop simulations that irrigation water is available now and will be available in the future when needed to fully meet crop water requirements.

The Southwestern region comprises of 5 provinces (Helmand, Kandahar, Nimroz, Urozgan and Zabul). It has the largest territory of the eight regions (29% of country total), but also the smallest cropland share of only 6%, of which 90% is irrigated land.

Mostly negative impacts result from climate change in the Southwestern region (see Table 3.41). The warmer winters and high summer temperatures projected under RCP8.5 by the 2080s would cause heat stress and yield reductions for most crops. As a consequence, the estimated production potential of most major crops in the Southwestern region declines with increasing severity of climate change.

The rain-fed cropland, located foremost in the northern part of the region, accounts for 10% of total cropland. As much as 90% of the cropland in the Southwestern region is equipped with irrigation, of which a third is classified as 'Poorly irrigated'. Thus an already fairly negative agronomic outcome may turn out to be even more difficult and challenging due to adverse impacts on water resources and likely intensified water scarcity.

Table 3.41 Climate change impacts on crops on current rain-fed and irrigated cropland, Southwestern Region

Crop	Historical, 1981-2010		RCP8.5 in 2050s		RCP8.5 in 2080s	
	Suitable Area (1000 ha)	Potential Production (1000 tons)	Change of Suitable Area	Change of Production	Change of Suitable Area	Change of Production
Wheat	771	2 218	↔	↓	↓	↓
Barley	857	2 795	↑	↓	↔	↓
Maize, grain	674	3 766	↔	↓	↓	↓
Maize, silage	681	5 331	↔	↔	↓	↔
Rice, paddy	456	1 207	↓	↓	↓	↓
Sorghum	831	3 774	↑	↔	↑	↓
Oat	602	901	↓	↓	↑	↓
Rye	607	980	↓	↓	↑	↓↓
Millet	594	1 104	↓↓	↓↓	↓↓	↓↓
Buckwheat	94	64	↓↓	↓↓	↓↓	↓↓
Chickpea	117	132	↑↑	↑↑	↑↑	↑↑
Gram	259	265	↓	↓	↓	↓
Potato	103	363	↑	↑	↑	↑
Sweet potato	549	2 305	↓	↓	↓	↓
Sugar beet	56	211	↓↓	↓↓	↓↓	↓↓
Sugarcane	425	1 895	↑	↑↑	↑↑	↑↑
Groundnut	213	272	↓	↓	↓	↓
Rapeseed	408	432	↓	↓	↓	↓↓
Sesame	456	682	↓	↓	↓	↓↓
Soybean	593	1 043	↓	↓	↓	↓
Sunflower	467	770	↓↓	↓↓	↓	↓
Cumin	130	66	↓	↓	↓	↓
Mustard	372	268	↑	↑	↓	↓
Cotton	593	297	↔	↓	↔	↓
Flax	465	161	↓	↓	↓↓	↓↓
Alfalfa	738	6 588	↔	↔	↔	↓
Citrus	77	209	↑↑	↑↑	↑	↑
Olive	470	649	↓↓	↓↓	↓↓	↓↓
Cabbage	148	299	↔	↓	↓	↓
Onion	59	269	↔	↓	↓	↓
Tomato	163	436	↓↓	↓↓	↓	↓↓

Note: Arrows show results without CO_2 fertilization effects and indicate changes of less than 3% (↔), 3%-20% (↓,↑), 20%-50% (↓,↑) and more than 50% (↓↓,↑↑) compared to baseline conditions. Suitable areas include prime (VS), good (S), moderate (MS) and marginal (mS) extents on rain-fed cropland and prime, good and moderate extents on irrigated cropland. Potential refers to maximum possible production on all suitable cropland. Potential production is given as dry weight of harvested product except for sugar crops (1000 tons sugar), cotton (1000 tons lint) and olive (1000 tons oil). For cotton, citrus, rice and sugarcane the marginally suitable extents were not included.

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3.11 Climate change impacts on rangeland production

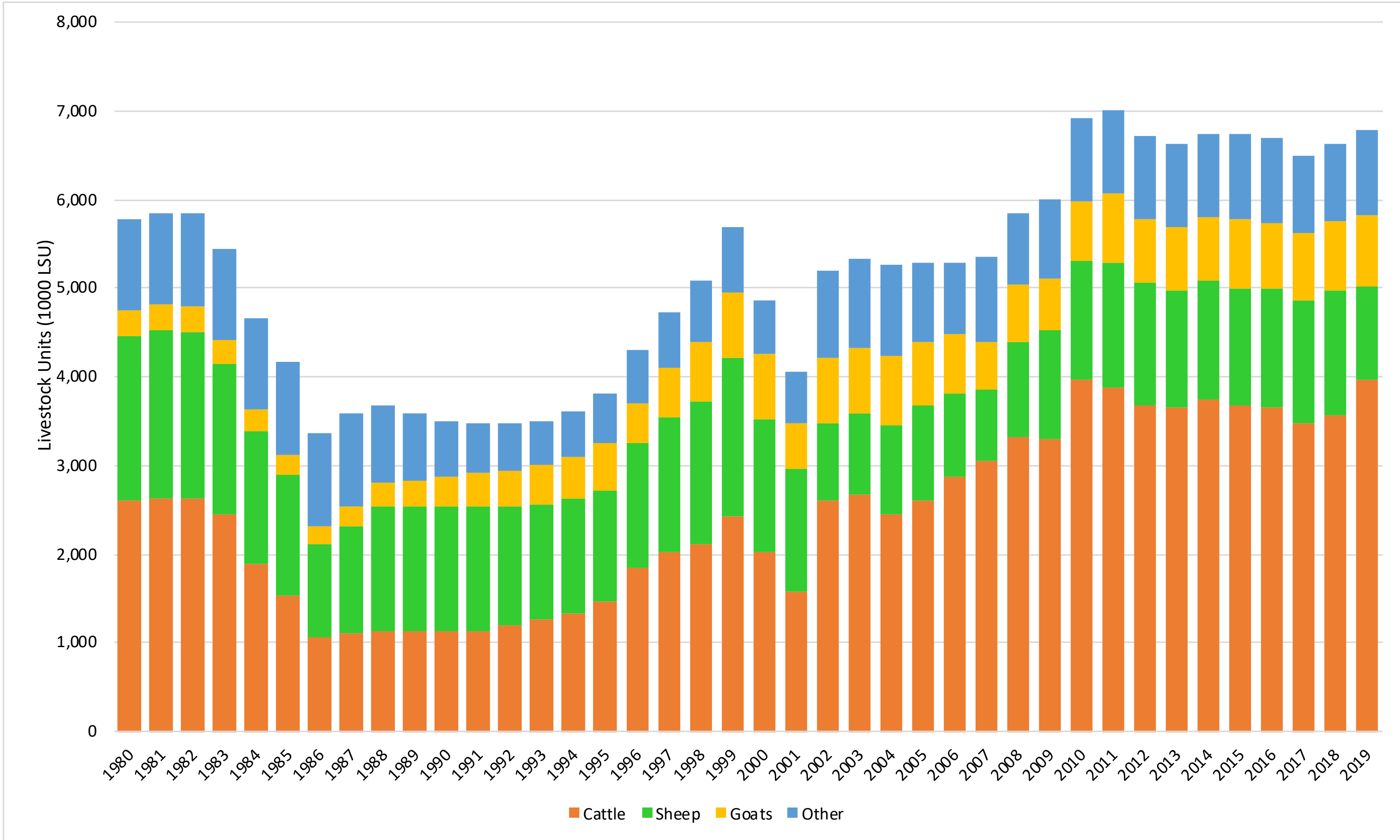
For decades, livestock raising has been a key component in the livelihood strategies of Afghanistan's rural population, providing power for field work and transport, milk and meat for household consumption, income from market sales, and manure as a fertilizer for cropping as well as an important local fuel for cooking and heating. In the crop-based sedentary system farmers usually rear some sheep and goats and sedentary farming accounts for almost all cattle in Afghanistan. A nomadic system is practiced by an estimated 1.5 million pastoralists (Afghanistan Statistical Yearbook 2020 (NSIA, 2021)) and relies on the vast but low-productive rangelands, with seasonal movement of the herds between low-lying winter pastures and exploiting the mountainous grassland at higher altitudes in summer.

According to data reported in FAOSTAT (Source: http://www.fao.org/faostat/en/#data/QC), the livestock (excluding chicken) in Afghanistan during the last decade counted between 6 to 7 million livestock units (LSU)[1] of which cattle, sheep and goat accounted for about 85% (see Figure 3.47). For 2016 the Afghanistan Statistics Organization reported 5.2 million cattle, 13.3 million sheep and 7.4 million goats, together amounting to 5.7 million LSU. The remaining 0.95 million LSU comprise of horses, asses, mules and camels. Estimates reported by FAO Afghanistan for 1995 and 1997/98 indicate that traditional pastoralists managed about 1.3 million LSU (around 30% of the livestock excluding chicken), including nearly half of the national sheep herd, 30-45% of goats and around 70% of camels.

The land cover database of Afghanistan, LCDA 2010, classifies 30.2 million hectares as rangeland. Rangeland is the most widespread land cover class in Afghanistan covering as much as 47% of the territory. Most rangeland is of only low productivity due to insufficient rainfall, recurrent droughts and occurrence at high altitudes.

[1] Livestock Unit (LSU) is a reference unit which facilitates the aggregation of livestock from various animal cohorts and species, via the use of specific coefficients, established initially on the basis of feed requirements of each species and category. The reference unit used for the calculation of livestock units (=1 LSU) is the grazing equivalent of one adult dairy cow producing 3000 kg of milk annually, fed without additional concentrated foodstuffs.

Livestock numbers (1000 LSU), period 1980–2019



Source: FAOSTAT (available at http://www.fao.org/faostat/en/#data/QC), download on 5 May 2021. Note: Coefficients for conversion from livestock type to LSU: cattle 0.7, sheep 0.1, goats, 0.1, horses 0.4, asses 0.5, mules 0.6, camels 0.75.

Figure 3.47

Rangeland species

AEZ assumes a mixture of different annual and perennial pasture grasses and pasture legumes adapted to cool and warm temperatures. In each environment/ecology the best adapted pasture type (in terms of expected biomass production) is selected for suitability assessment and above-ground consumable biomass estimation.

The simulated pasture species in AEZ cover a wide spectrum of temperatures conducive to growth of cryophilic pasture species including legumes (C3 I), thermophilic grass species and pasture legumes (C3 II), and pasture grasses adapted to warm and hot temperatures (C4 I) or adapted to cool and moderately cool temperatures (C4 II). Rainfed productivity depends on the period during the year when both soil moisture and temperature regimes are suitable for growth and development of particular pasture species.

This broad range of pasture species also covers a wide span of adaptability to different soil limitations including soil salinity and sodicity.

Table 3.42 shows the distribution of rangeland and the respective suitable areas for grazing (of at least marginal suitability) across regions and broad altitude ranges. It indicates that about 10% of the LCDA rangeland class is located below 1000 m, 24% at an altitude of 1000-2000 m, 41% at 2000- 3000m, and the remaining 25% are found above 3000 m.

Also shown are the extents assessed as suitable for grasses and pasture legumes (assuming rain-fed at low inputs and management), amounting to 24.1 million hectares. Among the 34 provinces of Afghanistan, in five provinces rangeland accounts for more than 80% of land cover: Ghor (89%), Bamyan (86%), Panjsher (86%), Daykundi (84%) and Wardak (82%). Eight of 34 provinces contribute more than half (51%) of all rangeland (Ghor, Badakhshan, Herat, Kandahar, Ghazni, Bamyan, Badghis and Daykundi).

The land suitable for rain-fed low input pasture shown in Table 3.42 was assessed for the historical climate of 1981-2010 and was taken to be all rangeland except for very steep terrain and land with unsuitable miscellaneous soil units (e.g., rock outcrops). Note, the share of rangeland judged as not suitable due to soil and steep terrain limitations increases with altitude. It is 9% for rangeland below 1000 m, nearly 20% for the rangeland at 2000-3000 m, and amounts to one third for the rangeland in mountainous areas above 3000 m.

Table 3.42 Land suitable for grazing in current rangeland

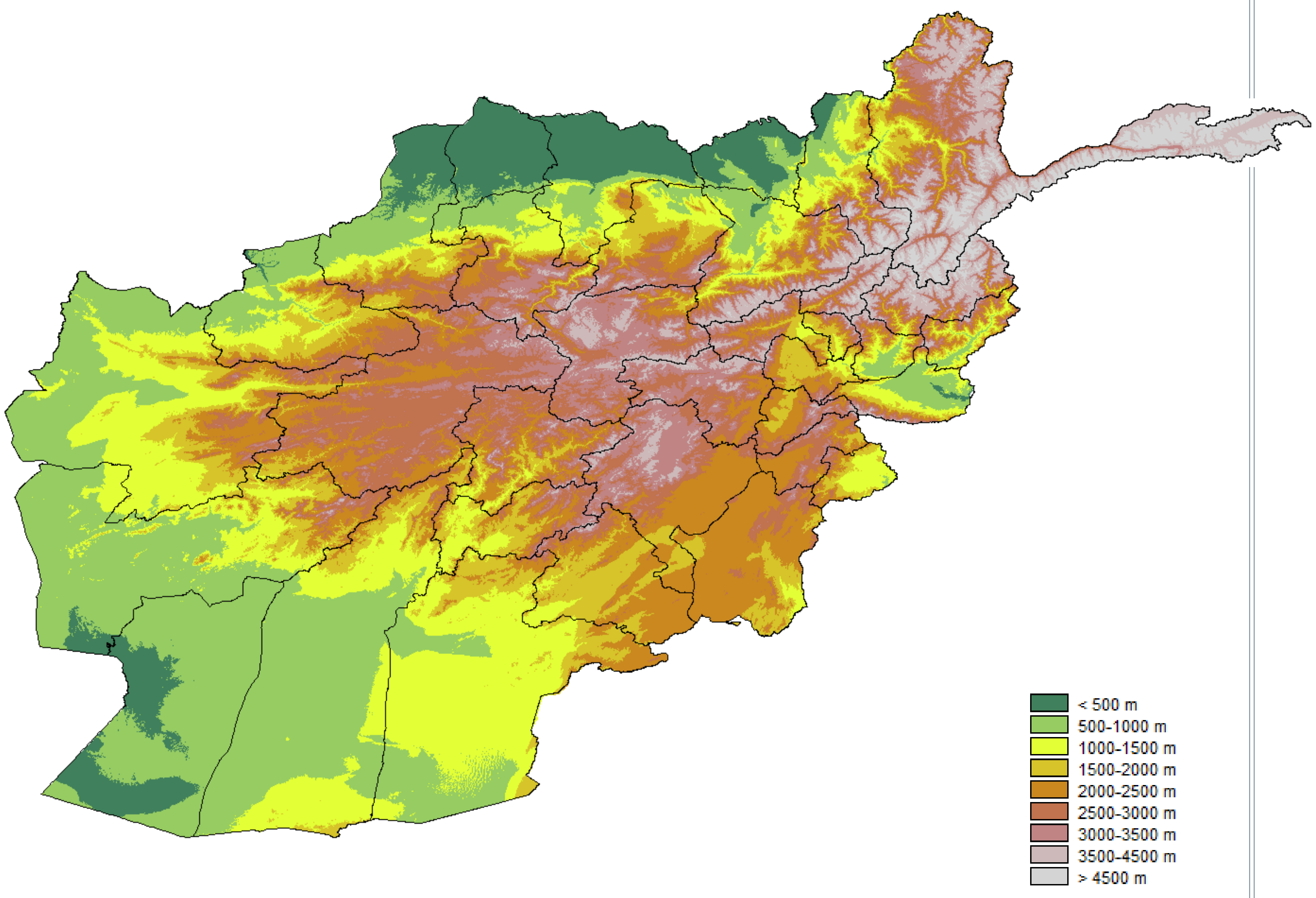
	Classified as Rangeland (1000 ha)					Suitable Area (1000 ha)				
Regions	TOTAL	<1000m	1000-2000m	2000-3000m	>3000m	TOTAL	<1000m	1000-2000m	2000-3000m	>3000m
Northeastern	4 613	394	739	1 132	2 348	2 859	365	543	701	1 250
Northwestern	3 814	1 194	963	1 114	542	3 240	1 094	817	895	434
Eastern	1 151	84	295	149	623	755	77	233	87	356
Central	2 291	1	234	996	1 060	1 713	0	205	791	716
West-central	4 409	0	243	2 056	2 110	3 499	0	201	1 628	1 670
Western	7 681	842	1 901	4 225	713	6 663	779	1 730	3 589	565
Southeastern	1 715	2	392	1 231	90	1 358	2	305	986	65
Southwestern	4 571	346	2 523	1 555	147	4 063	316	2 333	1 307	107
TOTAL	30 244	2 863	7 289	12 458	7 633	24 148	2 632	6 367	9 985	5 164

Note: Land suitable for rain-fed low input pasture was calculated for the historical climate of 1981–2010 and was taken to be all rangeland except for very steep terrain and land with unsuitable miscellaneous soil units (e.g., rock outcrops).

Figure 3.48 presents a delineation of broad altitude ranges used in the tabulation of results. Besides precipitation, average seasonal temperature and hence altitude is an important determinant of potential biomass production in rangelands.

Two-thirds of rangeland in Afghanistan occur at an altitude above 2000 m. Less than 10% is located below 1000 m and as much as one quarter lies above 3000 m. The share of rangeland above 2000 m is especially high in the provinces of West-Central (94%) and Central (90%) region. In contrast, the highest shares of rangeland below 2000 m occur in Southwestern (63%) and Northwestern (57%) region.

Spatial distribution of land by altitude



Source: Altitude zones were delineated based on SRTM data at 1 arc-second (about 30m) resolution.

Figure 3.48

Table 3.43 provides estimates of potential biomass production and yield of the areas classified in LCDA as rangeland, simulated under rain-fed conditions and low input assumptions for average climate of period 1981–2010.

As shown, average attainable rain-fed pasture yields generally decrease with altitude, at national level from average 2.4 tons dry matter (DM) per hectare for rangeland located below 1000 m to only 0.2 tons DM per hectare for rangeland above 3000 m. Such relationship, which is caused by decreasing length of the vegetation period with altitude and lower intensity of plant photosynthesis due to temperature, is found for all regions, but absolute values can vary across regions due to differences in precipitation received.

Under the assumption of rain-fed low input conditions, the potential production of all suitable rangeland in Afghanistan for historical climate of 1981–2010 is estimated in AEZ at 19.2 million tons DM. For comparison, assuming a feed requirement per livestock unit (LSU) of 12.5 kg DM per day and a fodder utilization rate of 50% suggests that the rangeland could support 2.1 million LSU, equivalent to about one-third of the national livestock herd.

Table 3.43 Potential biomass production and yield of current rangeland, reference climate 1981-2010

	Potential biomass production (1000 tons DM)					Average potential yield (tons DM/ha)				
Regions	**TOTAL**	**<1000m**	**1000-2000m**	**2000-3000m**	**>3000m**	**TOTAL**	**<1000m**	**1000-2000m**	**2000-3000m**	**>3000m**
Northeastern	2 568	881	1 016	452	219	0.90	2.42	1.87	0.65	0.17
Northwestern	3 238	1 780	939	441	78	1.00	1.63	1.15	0.49	0.18
Eastern	1 254	250	731	121	152	1.66	3.22	3.13	1.39	0.43
Central	1 454	1	472	804	177	0.85	2.49	2.31	1.02	0.25
West-central	1 550	0	210	923	418	0.44	n.a.	1.05	0.57	0.25
Western	3 947	1 110	1 630	1 117	91	0.59	1.43	0.94	0.31	0.16
Southeastern	2 011	11	723	1 194	82	1.48	6.14	2.37	1.21	1.27
Southwestern	3 131	180	2 039	900	12	0.79	1.60	1.22	0.60	0.24
TOTAL	19 153	4 213	7 760	5 951	1 228	0.90	2.42	1.87	0.65	0.17

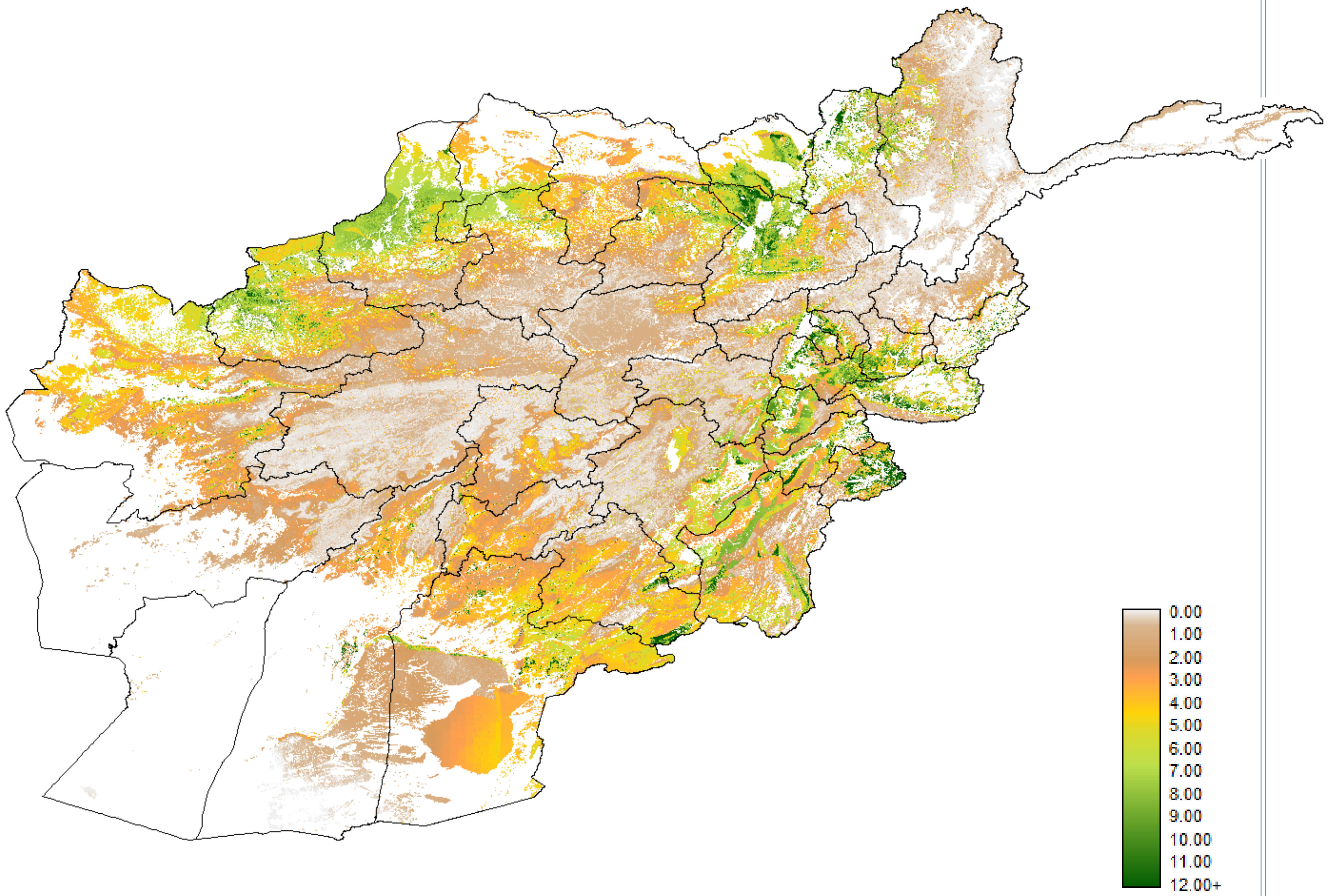
Table 3.43 provides estimates of potential biomass production and yield of the areas classified in LCDA as rangeland, simulated under rain-fed conditions and low input assumptions for average climate of period 1981-2010.

Note: Values refer to land suitable for rain-fed low input pasture simulated under the historical climate of 1981–2010.

Figure 3.48 shows the production potential of current rangeland in the reference period 1981–2010 (Figure 3.48a) and maps the results under RCP8.5 for the 2050s (Figure 3.48b) and the 2080s (Figure 3.48c). The maps illustrate the large differences in rangeland productivity due to prevailing differences in altitude, precipitation and soils across regions.

Important grazing resources stretch across northern Afghanistan including parts of Northeastern, Northwestern and Western region. Some productive rangeland is also found in Southeastern, Central and Eastern region. In the Southwestern region only Zabul and the northern parts of Kandahar and Helmand province can support seasonal rain-fed livestock grazing.

Potential pasture production on current rangeland (tons dry weight) Reference climate 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current rangeland refer to potential pasture production (dry weight) per 7.5 arc-seconds grid cell (i.e., about 5 hectares).

Figure 3.48a

Ensemble mean, RCP8.5, 2041–2070–2099

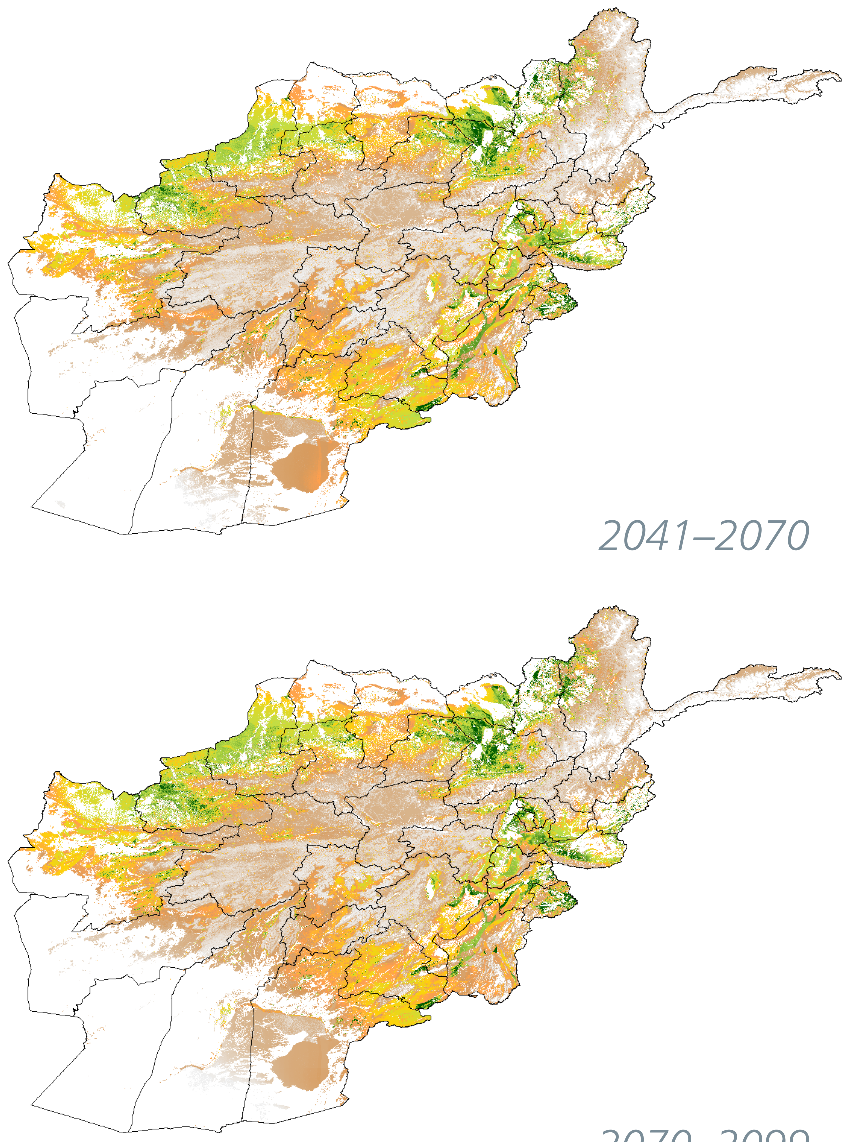
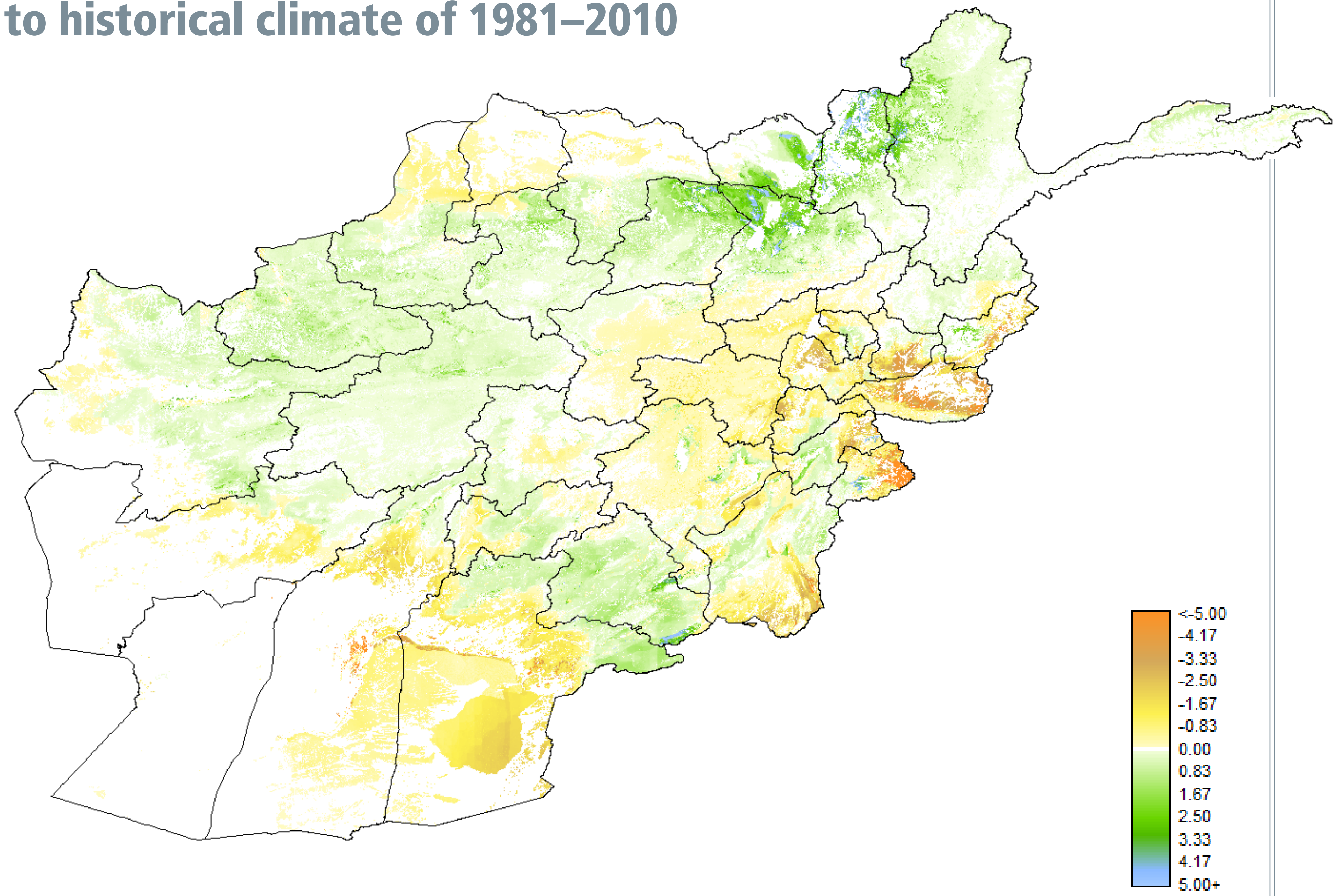


Figure 3.48b, 3.48c

Figure 3.49 displays the spatial pattern of changes in pasture productivity by comparing for each 7.5 arc-second grid cell of the resource inventory the estimated potential production for a future climate with the results obtained under reference climate conditions.

As pasture production in Afghanistan is limited by lack of precipitation as well as low temperature at higher altitudes, the results obtained for future climate vis-à-vis historical climate critically depend on whether the potentially longer vegetation period due to warming can materialize and is supported by adequate soil moisture conditions during the vegetation period. Water requirements of plants increase more than linearly with temperature and if not matched by increasing precipitation and/or temporal shifts of the active vegetation period, warming will result in negative impacts on production potential as is visible in Figure 3.49 especially for low-lying arid and semi-arid areas. A positive impact on pasture productivity is mainly found in the Northeastern region and at higher altitudes due to an improving temperature regime with a potentially longer vegetation period and improved access to winter rainfall.

Change of potential pasture production on current rangeland (tons dry weight), Ensemble mean, RCP4.5, 2070–2099 relative to historical climate of 1981–2010



Source: Simulations using historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current rangeland refer to the difference of potential pasture production (dry weight) per 7.5 arc-seconds grid cell relative to the potential in period 1981-2010.

Figure 3.49a

Ensemble mean, RCP8.5, 2041–2070–2099 relative to historical climate

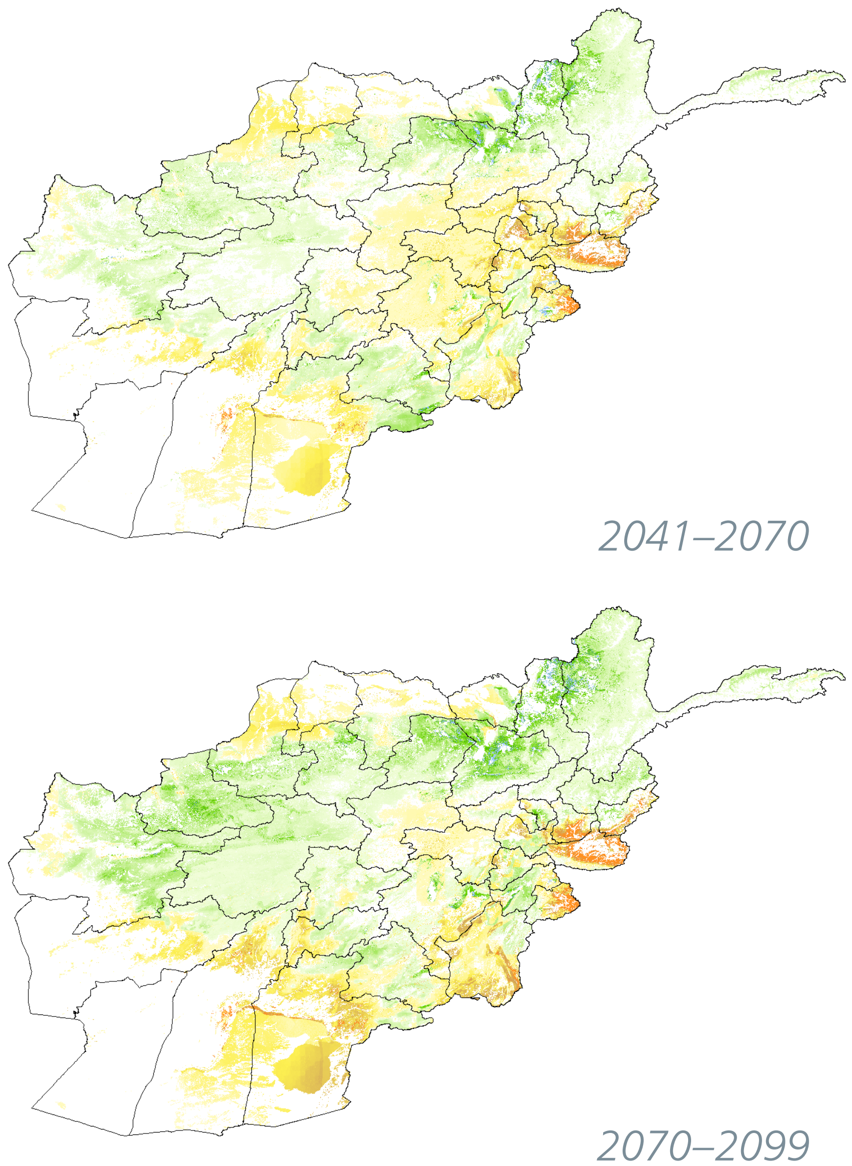


Figure 3.49b, 3.49c

Table 3.44 summarizes for the simulation results of rangeland potential production the direction of distortions due to climate change by region and for broad ranges of altitude. On balance, at the national level the potential productivity of rangelands appears stable or may slightly improve with climate change, albeit with large differences across regions and different altitudes. Positive changes are most likely to occur in Northeastern, Northwestern and Western region and frequently for altitudes above 2000 m. Most low-lying areas below 1000 m, hence much of Southwestern, Southeastern and Eastern region, are expected to experience a decline of rangeland productivity. West-central and Central region are severely water limited and rain-fed rangeland production potential changes little despite of warming at high altitudes.

Table 3.44 Climate change impacts on potential pasture production relative to period 1981-2010

	Change of Potential biomass production					Change of Average potential yield				
Regions	TOTAL	<1000m	1000-2000m	2000-3000m	>3000m	TOTAL	<1000m	1000-2000m	2000-3000m	>3000m
Northeastern	↑ (teal)	↑ (teal)	↑ (teal)	↑ (teal)	↑ (teal)	↑↑ (teal)	↑ (teal)	↑↑ (teal)	↑↑ (teal)	↑↑ (teal)
Northwestern	↑ (green)	↔	↑ (teal)	↑ (teal)	↑ (green)	↑ (green)	↓ (yellow)	↑ (teal)	↑ (teal)	↑ (teal)
Eastern	↓ (yellow)	↓ (red)	↓ (yellow)	↓ (yellow)	↔	↓ (red)	↓↓ (red)	↓ (red)	↔	↑↑ (teal)
Central	↓ (yellow)	↓ (yellow)	↓ (yellow)	↓ (yellow)	↓ (red)	↔	↓ (red)	↓ (yellow)	↔	↓ (yellow)
West-central	↓ (yellow)	n.a.	↔	↔	↓ (yellow)	↔	n.a.	↓ (yellow)	↔	↔
Western	↑ (green)	↑ (green)	↑ (green)	↑ (teal)	↑ (teal)	↑ (teal)	↑ (green)	↑ (teal)	↑↑ (teal)	↑ (teal)
Southeastern	↓ (yellow)	↓↓ (red)	↓ (red)	↓ (yellow)	↓ (yellow)	↓ (red)	↓↓ (red)	↓↓ (red)	↓ (yellow)	↑ (green)
Southwestern	↓ (yellow)	↓↓ (red)	↓ (yellow)	↑ (teal)	↓ (yellow)	↓ (red)	↓↓ (red)	↓ (red)	↑ (green)	↑ (green)
TOTAL	↔	↑ (green)	↔	↑ (green)	↔	↑ (green)	↔	↔	↑ (green)	↑ (teal)

Table 3.44 provides estimates of potential biomass production and yield of the areas classified in LCDA as rangeland, simulated under rain-fed conditions and low input assumptions for average climate of period 1981-2010.

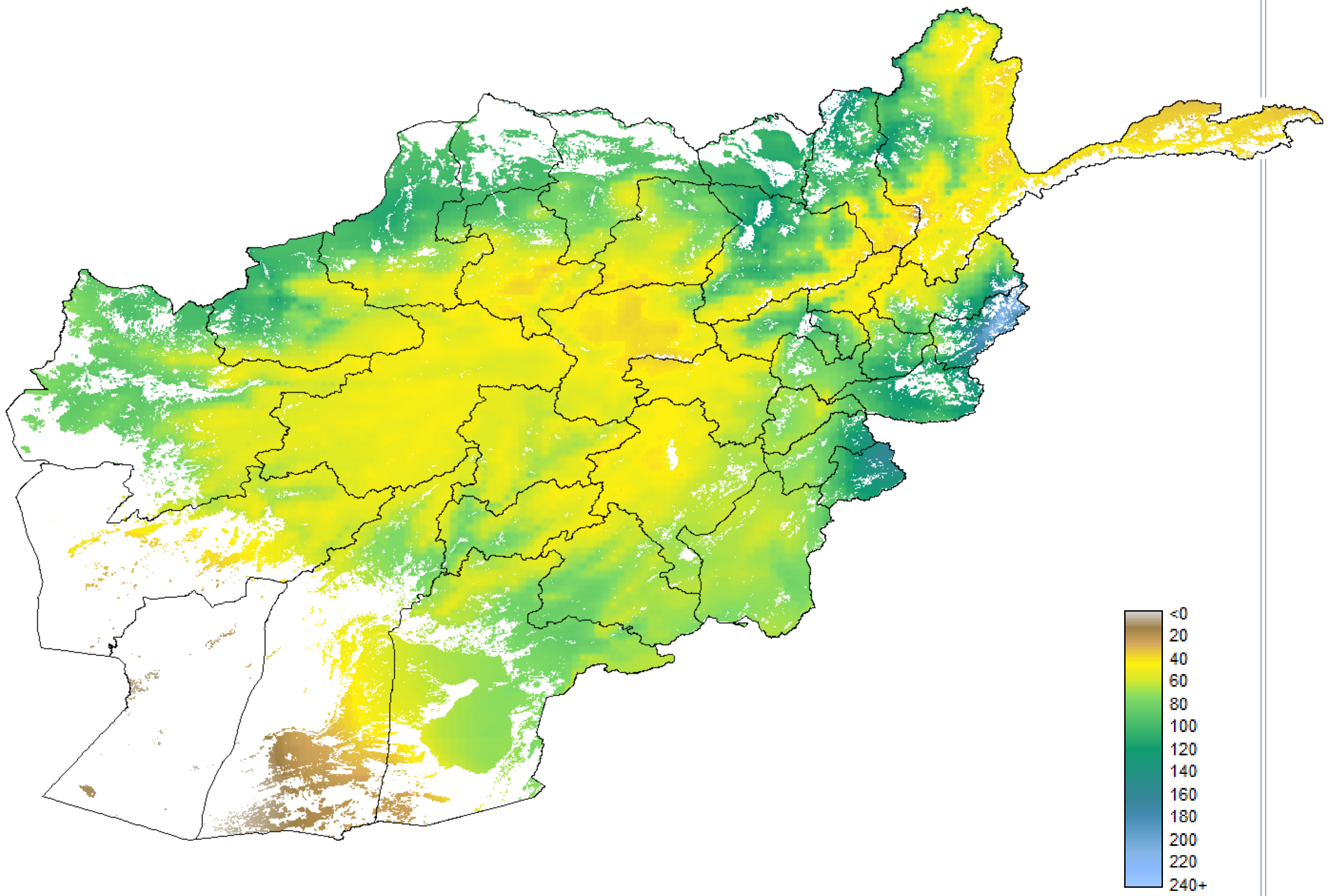
Note: Arrows indicate changes of simulated potential grass biomass production of less than 3% (↔), 3%-15% (↓ (yellow), ↑ (green)), 15%-30% (↓ (red), ↑ (teal)) and more than 30% (↓↓ (red), ↑↑ (teal)) compared to baseline conditions.

These spatially distinct impacts of climate change on rangeland productivity may significantly affect the complex traditional migration patterns of nomadic pastoralists. On one hand, due to warming additional areas will in the future be able to host winter grazing; on the other hand, pasture productivity at low altitudes is expected to decrease. Pastures at higher altitudes will become more accessible and for a longer period of time during the year, but may suffer from extended dry periods in summer.

The coincidence of the periods when temperature is conducive to biomass accumulation and when available soil moisture can (at least partly) meet the crop water demand of pasture species is well captured by an AEZ agro-climatic indicator, the annual number of reference growing period days (LGP days). LGP is based on a daily reference water balance and denotes the number of days in a year when temperature and available soil moisture exceed minimum requirements for plant growth.

The number of reference growing period days on rangeland for the historical climate of 1981–2010 is mapped in Figure 3.50. Changes in the number of annual growing period days due to climate change are presented for an ensemble mean of RCP8.5 in the 2050s (period 2041-2070 in Figure 3.51a) and in the 2080s (period 2070–2099 in Figure 3.51b).

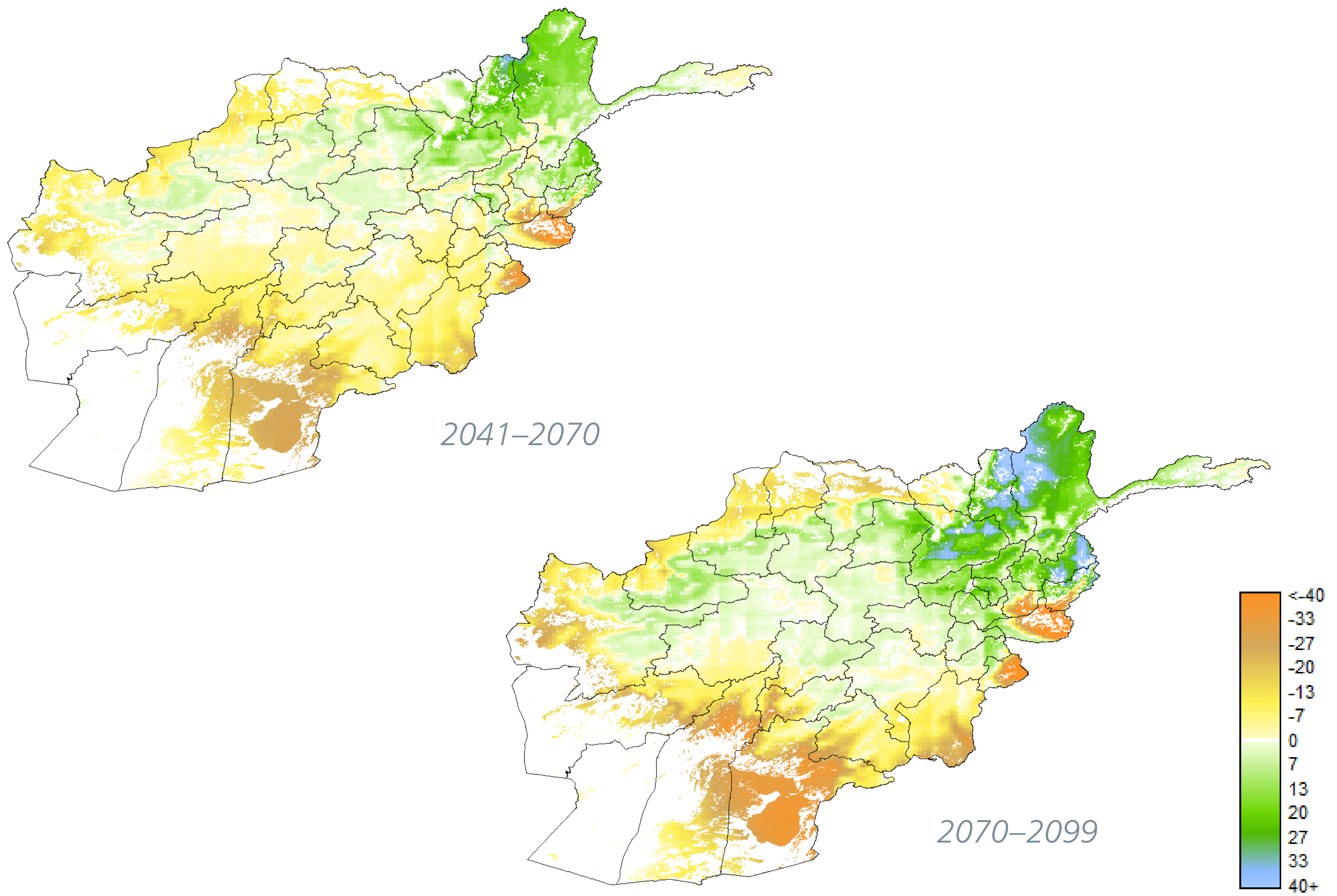
Number of growing period days on rangeland (days), Reference climate 1981–2010



Source: Simulations for historical climate of 1981-2010 with NAEZ-Afghanistan.

Figure 3.50

Change in number of growing period days (days), Ensemble mean, RCP8.5, 2041–2070–2099 relative to historical climate of 1981–2010



Source: Simulations of historical climate of 1981-2010 and ensemble mean of simulations with the NAEZ-Afghanistan system using climate projections of five climate models. Values shown for current rangeland refer to the difference of the number of reference growing period days relative to LGP days in period 1981-2010.

Figure 3.51a, 3.51b

Note, the spatial pattern of LGP changes portrayed in Figure 3.51 matches well the respective patterns of changes in potential rangeland biomass production provided in Figure 3.49. Hence, the future growing period dynamics observed in the AEZ simulations are an important indicator for explaining future rangeland productivity. In addition, the intensity of biomass accumulation (i.e., rate of photosynthesis) can be described by an inverted U-shaped function of average temperature. At locations with low average temperature under historical climate, e.g., rangelands at high altitude, warming will result in an increased rate of photosynthesis. At locations with an average temperature beyond the optimal level for different pasture species (e.g., in hot lowland areas) the intensity of plant photosynthesis will decrease with further warming.

Both, the increased flexibility of finding periods during the year with adequate temperature and moisture conditions for pasture species, facilitated by fewer freezing days under future climate, as well as likely increased intensity of photosynthesis contribute to the beneficial outcomes for rangelands especially in the Northeastern region, for areas above 1000-1500 m in northern Afghanistan and for pastures above 2000 m in southern and eastern parts of the country.

4. Conclusions

Agro-ecology

The NAEZ-Afghanistan system has been implemented in this project and used to assess potential crop production on current rain-fed and irrigated cropland for more than 30 annual and perennial crops. Climate change impacts were evaluated on the basis of climate projections obtained from five global climate models and for two representative concentration pathways, RCP4.5 and RCP8.5 to assess likely spatial shifts of agro-climatic characteristics of land due to projected climate change in the period 2041–2070 (the 2050s) and 2070–2099 (the 2080s). The analysis indicates that climate change will impact agriculture in all regions, requiring shifts of crop calendars, the use of adapted cultivars, and in some areas adjustment of the primary crops to mitigate heat stress and exploit emerging opportunities.

- Year-round climatic conditions in Afghanistan will become warmer and mostly dryer in the future. Due to the shortening of cold breaks and where natural soil moisture limitations can be overcome with irrigation, the multiple cropping potential of the land is expected to increase with climate change in the currently temperature-limited Northeastern and Central region.
- Climate change will create new limitations and increased risks for cropping in some areas (mainly southern low-lying areas) and provide new openings for farmers in other parts of the territory. Success will depend on timely preparedness to mitigate damages and to benefit from new opportunities.
- Climate change will result in higher seasonal and annual temperatures everywhere in Afghanistan. Precipitation changes are somewhat less uniform, remaining approximately at historical levels or even decreasing slightly, which results in a deteriorating annual balance of precipitation to potential evapotranspiration. The combined impact of these changes on a farmer's field can range from severely negative to fairly positive depending on the climate point of departure, i.e., altitude, prevailing temperature and rainfall in the historical period, the availability or possible development of reliable irrigation, as well as soil and terrain conditions.

Rain-fed and irrigated cropland

- Impacts of climate change on crop suitability and yields vary between C3 and C4 crops, between annual crops and perennials, and between individual crop-specific tolerances for high temperatures and moisture stress as well as climate related agro-climatic constraints. C3 crops are generally less heat tolerant than C4 crops but can benefit substantially more from CO_2 fertilization. Perennial crops (and grasses) are dependent on favorable temperature and rainfall distributions, or irrigation, throughout the year. This is in contrast to annual crops, which may allow crop calendar shifts and cultivar changes to optimize growth cycle temperature and soil moisture conditions.

- Winter grain crops, mostly wheat and barley, will continue to be the backbone of national food security in Afghanistan. At the national level, the potential production of winter grain crops appears to be stable or may initially even increase with climate change, regardless of accounting for enhanced photosynthesis due to increased atmospheric CO_2 concentration.
- Growing conditions for winter crops will be enhanced in some important growing areas, notably in northern and central regions, but higher temperatures will likely cause lower yields in the low-lying southern and eastern regions.
- Warming will shorten or eliminate the dormancy period in winter (taken to be the period when average daily temperature is below 5°C). This will alter the crop calendar of winter and spring crops and shift the crop growth cycle to the part of the year when better soil moisture conditions prevail, as is typically the case in winter rainfall areas.
- Simulations indicate that growing conditions of winter crops will likely improve mainly due to reducing the length of dormancy periods and associated shifts of crop calendars, which will give access to more growing period days and better soil moisture conditions in winter rainfall areas. For irrigated winter crops the changed crop calendars result in a reduction of net irrigation requirements.
- Warming is seen as an opportunity especially in the provinces of the Northeastern, Central and West-Central regions where cold and cool temperatures have been limiting the number of days in a year suitable for cropping. In contrast, in low-lying southern parts of the country high growing period temperatures in the future may negatively affect the crop production potential, even under irrigation conditions.
- For summer crops, especially in regions where projected production potentials increase, the simulations find increases in irrigation demand, both in terms of average demand per unit of suitable area and in terms of total irrigation water volume required to attain the potential production in the regions where suitable areas expand due to warming.
- At the national level the analysis of total suitable areas, when adding up over all suitability classes and jointly considering all cereal crops, finds moderate increases in all scenarios, with best outcomes when climate change progresses in the long term only moderately, e.g. as in RCP4.5. The net gain is primarily achieved because of improvements on rain-fed land, due to better use of soil moisture in the winter months and gains of temperature growing period days at higher altitudes mainly in the Northeastern region and central highlands. Under high-end climate change scenarios the mostly irrigated cropland in southern regions experiences considerable losses.
- Results suggest that the total suitable area for cereals in Afghanistan can be nearly maintained or even increased in scenarios of moderate climate change, such as RCP8.5 in the 2050s or RCP4.5 in the 2080s. With rapid and intense warming, as projected under RCP8.5 for the 2080s, some losses are expected to occur in most regions. Safeguarding the cereal production potential will require effective adaptation of crop calendars, changes of primary cereal crop types where possible and necessary, and provision of adequate and timely volumes of irrigation water.
- Available data put actually irrigated land at about 2.2 million hectares, i.e., only some 60% of land classified as irrigated land in the land cover database LCDA 2010. For rain-fed cultivation in the last decades the cropped rain-fed area has been between 1.3-1.5 million hectares, which represents 35-40% of the land classified as rain-fed cropland. These factors should be taken into account when interpreting the potential production estimates elaborated in this study, to avoid overly optimistic conclusions especially for irrigated land where it is assumed that crop water demand can be fully met from irrigation when required.
- There may be uncertain and unreliable water supply in 1.1 million hectares of 'Poorly irrigated' cropland. For these areas the irrigated production potential was quantified and included in the national estimates (according to advice given by experts consulted on this question by FAO-Afghanistan).
- Soil moisture conditions throughout the year, besides temperature the second pillar of crop cultivation, will be negatively affected by climate change in most regions, including the large Northwestern and Western regions where 60-70% of the cropland is cultivated with rain-fed practices. Rising temperatures and stable or declining precipitation will cause a growing water deficit of 'green' water in the annual soil water balance. It may also imply reduced runoff and negative impacts on water resources with unfavorable consequences for the availability of adequate and reliable irrigation. Note, despite of negative impacts on year-round soil moisture balance, seasonal results for rain-fed winter crops can still improve due to crop calendar shifts.
- The results presented in this report do not consider the possible beneficial effects of increased future atmospheric CO_2 concentrations. This was adopted for three reasons: (i) to focus on and reveal the direct impacts of changes in climatic variables; (ii) to avoid too optimistic and uncertain estimates; and (iii) to account for the fact that the magnitude of actual impacts in farmer's fields will also depend on the presence/absence of other environmental limiting factors (e.g., climate, soil, water, nutrients) and is in the scientific literature regarded as quite uncertain.

Rangeland

- Rangeland is the most widespread land cover class in Afghanistan covering 30.2 million hectares, i.e., as much as 47% of the territory. Most rangeland is of only low productivity due to insufficient rainfall, recurrent droughts and occurrence at high altitudes.
- On balance, at the national level the production potential of rangelands appears stable or may slightly improve with climate change, yet with large differences across regions and at different altitudes. Positive changes are most likely to occur in Northeastern, Northwestern and Western region and frequently for altitudes above 2000 m. Most low-lying areas below 1000 m, hence much of Southwestern, Southeastern and Eastern region, are expected to experience a decline of rangeland productivity. Rangelands in West-central and Central region are severely water limited and the production potential changes little despite of warming at high altitudes.
- The spatially distinct impacts of climate change on rangeland productivity may significantly affect the complex traditional migration patterns of nomadic pastoralists. On one hand, due to warming additional areas will in the future be able to host winter grazing; on the other hand, pasture productivity at low altitudes will likely decrease. Pastures at higher altitudes will become more accessible and for a longer period of time during the year, but may suffer from extended dry periods in summer.

Limitations

- The results presented in this report have assessed the impacts and outcomes of projected gradual changes in climate. The possible increase of the occurrence of extreme weather events, such as more frequent years of drought, extreme precipitation events, or late frosts, could not be evaluated in the NAEZ simulations because information available from current global earth system models and regional climate models cannot provide reliable estimates of future climate variability.
- The NAEZ analysis in this study has assessed crop suitability and production potential for changing climatic conditions but did not quantify climate change impacts on water resources and water availability for agriculture. The annual and seasonal water balance is expected to deteriorate in the regions of Afghanistan as indicated by falling annual P/ET_0 ratios. The hydrographs will also be affected by the retreating of glaciers and the changes in snow cover and melting. These changes may increase water scarcity in drought-prone areas and irrigation water will likely be in short supply in some areas under rapidly evolving climate change.

1.

Appendix

Overview of the NAEZ-Afghanistan System

Introduction

The quality and availability of land and water resources, in combination with socio-economic conditions and institutional factors, are essential to assure sustainable food security. In order to optimize the wise use of the land and water resources it is important to determine their agronomic potential. The crop cultivation potential describes the possible upper limit of producing different crops under given agro-climatic, soil and terrain conditions for specific levels of agricultural inputs and management conditions.

The Agro-Ecological Zones (AEZ) approach determines for each location the cultivation potentials for about 50 crops, modelled by more than 300 generic production systems, and is based on the fundamental principles of land evaluation (e.g., FAO, 1976, 1993, 2007). These generic production systems used in the analysis are referred to as Land Utilization Types (LUT). The AEZ concept was originally developed by the Food and Agriculture organization of the United Nations (FAO) and over time, the International Institute for Applied System Analysis (IIASA) and FAO have together further developed and applied the AEZ methodology and the supporting databases and computer programs.

The national agro-ecological zoning system for Afghanistan (NAEZ-Afghanistan) includes 2010 baseline data of land cover, soil type and terrain; and climatic conditions for a time series of historical data and a selection of future climate simulations using IPCC AR5 Earth System Model (ESM) outputs for four Representative Concentration Pathways (RCPs).

Climatic data comprises precipitation, temperature, wind speed, sunshine duration and relative humidity. These parameters are used to compile an agronomically meaningful climate resources inventory including quantified thermal and moisture regimes in space and time. The land resources database has been assembled on the basis of national data and global grids, with a resolution of 7.5 arc-seconds (about 0.21 km by 0.21 km at latitude of central Afghanistan) for land cover, soil and terrain data and 30 arc-seconds (about 0.85 km by 0.85 km) for climate attributes.

Matching procedures to identify crop-specific limitations of prevailing climate, soil and terrain resources and evaluation with simple and robust crop models, under assumed levels of inputs and management conditions, provide maximum potential and attainable crop yields for basic land resources units. Attributes specific to each LUT include crop information such as crop parameters (crop growth cycle duration, harvest index, maximum leaf area index, maximum rate of photosynthesis, etc.), cultivation practices and input requirements, and utilization of main produce, crop residues and by-products. NAEZ-Afghanistan has generated large spatial databases of (i) natural resources endowments relevant for agricultural uses, and (ii) assessments of suitability and attainable yields of main food and fiber commodities for rain-fed and irrigated cultivated land areas.

Structure and overview of NAEZ procedures

The suitability of land for the cultivation of a given crop/LUT depends on specific crop requirements as compared to the prevailing agro-climatic and agro-edaphic conditions at a location. AEZ combines these two components systematically by successively modifying grid-cell specific agro-climatic potential yields according to assessed soil limitations and terrain constraints (Fischer et al., 2021). This structure allows stepwise review of results. An overview of the overall model structure and data integration used in NAEZ-Afghanistan is shown in Figure A1.1.

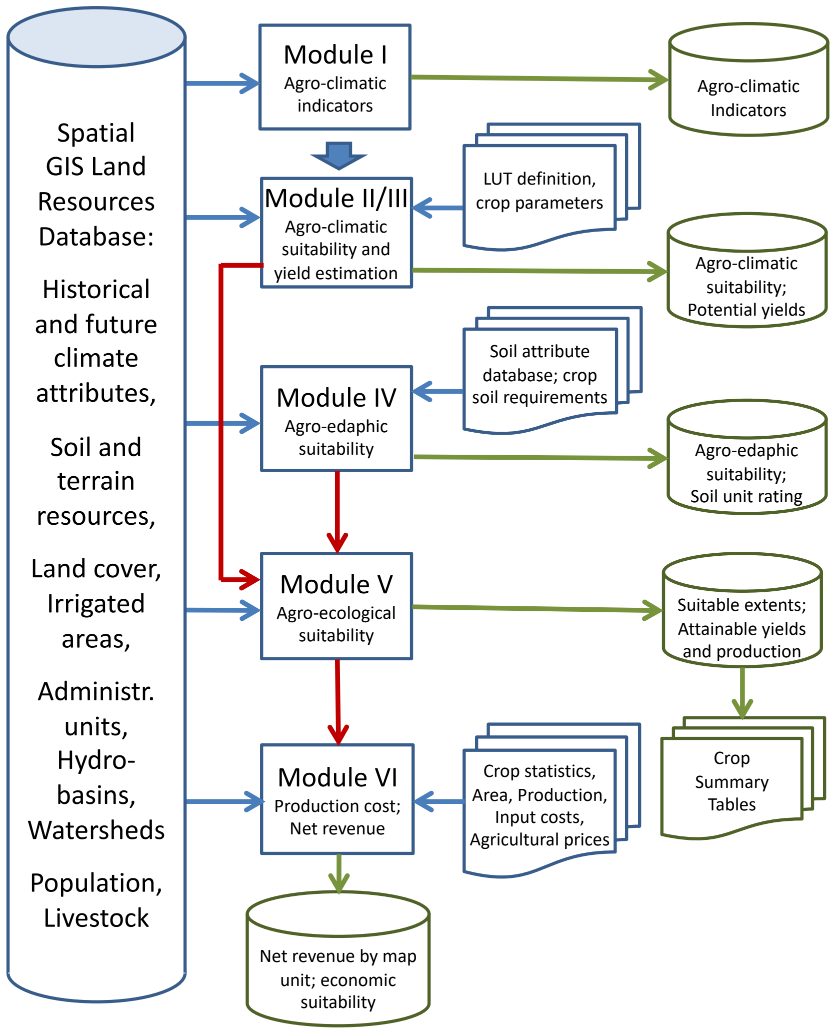


Figure A1.1 Overall structure and data integration in NAEZ-Afghanistan

Calculation procedures for establishing crop suitability estimates include five main steps of data processing, namely:

(i) Module I: Climate data analysis and compilation of general agro-climatic indicators for historical, baseline and future climates.

(ii) Module II: Crop-specific agro-climatic assessment and water-limited biomass/yield calculation.

(iii) Module III: Yield-reductions due to the impacts of agro-climatic risks and constraints of workability, pests and diseases.

(iv) Module IV: Crop specific edaphic assessment and yield reductions due to soil and terrain limitations.

(v) Module V: Integration of results from Modules I-IV into crop-specific grid-cell databases. These are used to map by crop, input level and time period the agro-ecological suitability and attainable yields and production.

In addition to estimating crop potentials, i.e., sequential execution of Module I to Module V, the national AEZ applications collect agro-economic information on crop prices, input use and crop-wise production costs to produce estimates of economic suitability and comparative advantage of major crops, evaluated in each grid cell at simulated attainable yields:

(vi) Module VI: Quantification of production cost and value of output for attainable crop yields, examination of economic suitability and comparison of major crops by expected net revenue.

Module I: Agro-climatic data analysis

The main purpose of Module I is the compilation of a geo-referenced climatic resources inventory offering a variety of relevant agro-climatic indicators. These agro-climatic indicators provide a general characterization of land resources and suitability for agricultural uses. Several agro-climatic layers are used as input during the estimation of crop yields and production in Module II, quantification of agro-climatic constraints in Module III, and for estimating agro-ecological suitability and attainable yields in Module V.

NAEZ-Afghanistan makes use in the water balance calculations of daily input data for temperature and precipitation and of monthly data for other required climate attributes. The use of observed daily data improves the capability of AEZ to represent extreme weather events such as occurrence of frost days, heat waves and periods of excessive or no rainfall. For future years, daily precipitation and temperature are derived from daily outputs of five major ESMs and for four different RCPs (alternative representative greenhouse gas concentration pathways).

NAEZ-Afghanistan includes the compilation of three 30-year historical reference periods, namely the period 1961–1990, the period 1971–2000 and 1981–2010. In addition to simulations for these three reference periods, annual time series results of agro-climatic indicators were computed for fifty years, from 1961 to 2010. For projections of future climate, the analysis considers three future reference periods: years 2011–2040, 2041–2070 and 2070–2099, referred to respectively as the '2020s', the '2050s' and '2080s'. Year-by-year simulations and time series analysis with NAEZ Module I were performed for 1960 to 2099, providing in addition to period averages also information on the distribution and variability of agro-climatic indicators within each 30-year period.

The results of Module I are used to generate tabulations by administrative or watershed territorial units and a variety of GIS raster maps of the agro-climatic analysis results for visualization and download.

Module II: Biomass and yield calculation

The main purpose of Module II is the estimation of agro-climatic potential biomass and yield for a wide range of LUTs under different input/management assumptions and separately for rain-fed and irrigated conditions. Biomass and yield calculations and the procedures used for the computation of daily crop water balances are based on the eco-physiological model developed by various FAO technical reports (Allen et al., 1998; Doorenbos and Kassam, 1979; Kassam, 1977; Smith, 1992).

Module II consists of two main steps:

(i) Calculation of maximum crop biomass and yield potentials considering only prevailing radiation and temperature conditions, and

(ii) Computation of yield losses due to water stress during the crop growth cycle. The estimation is based on rain-fed crop water water balances for a range of eight different levels of soil water holding capacity. Yield estimation for irrigation conditions assumes that crop water requirements are fully met, i.e., that irrigation will be scheduled such that no yield-reducing crop water deficits occur during the crop growth cycle.

The results of the biomass and yield calculation depend on the timing of the crop growth cycle (crop calendar). Maximum biomass and yields are separately calculated for irrigated and rain-fed conditions. Under rain-fed conditions, water stress may occur during different stages of the crop development reducing biomass production and the yields achieved. In NAEZ-Afghanistan, water requirements of each LUT are calculated daily and are considered in the calculation of LUT-specific water balance and actual evapotranspiration in a grid-cell. The crop calendar (i.e., sowing and harvesting dates) for a given LUT and grid cell is determined by identifying within the permissible window of time the sowing date that leads to the highest attainable yield.

Results of Module II include LUT-specific temperature/radiation defined maximum yields, yield reduction factors accounting for sub-optimum thermal conditions, for yield impacts due to crop water deficits, estimated amounts of net irrigation requirements, potential and actual LUT evapotranspiration, the accumulated temperature sums during each LUT crop cycle, and the simulated optimum crop calendars.

Module III: Agro-climatic constraints

Agro-climatic constraints cause direct or indirect losses in the yield and quality of produce. The relationships between these constraints with general agro-climatic conditions such as moisture stress and excess air humidity, and risk of early or late frost are varying by location, between agricultural activities as well as using control measures as assumed for different input levels.

Module III computes for each grid cell LUT-specific multipliers corresponding to different types of agro-climatic risks and constraints which are applied to further reduce previously calculated agro-climatic potential yields (i.e., the results of Module II).

This step is carried out in a separate module, termed Module III, to make explicit the climatic effect of limitations due to pests and diseases, and workability constraints and to permit time-effective reprocessing in case new or additional information becomes available. Four groups of agro-climatic constraints are applied, including:

- Yield losses because of pests, diseases and weed damage on plant growth
- Yield losses due to pests, diseases and weed damage on quality of produce
- Yield losses due to climatic factors affecting the efficiency of farming operations (e.g., excessive wetness causing difficulties for harvesting and handling of produce)
- Yield losses due to occurrence of early or late frosts.

These agro-climatic constraints are expressed as yield reduction factors according to the different constraints and their severity for each crop/LUT and by level of inputs. Due to paucity of available empirical data, the estimates of constraint ratings have been mostly obtained through expert opinion.

Module IV: Agro-edaphic constraints

Module IV estimates yield reductions due to the constraints induced by soil limitations and prevailing terrain-slope conditions. Crop yield impacts resulting from sub-optimum soil and terrain conditions are quantified separately for soils and terrain-slopes. Soil suitability is assessed through crop specific evaluations of seven major relevant for agriculture. It is estimated from soil attributes available in the Afghanistan Harmonized Soil Database, AFGHSD v1 (see Appendix 3). Soil qualities include soil nutrient availability, soil nutrient retention capacity, soil rooting conditions, soil oxygen availability, presence of lime and gypsum, presence of soil salinity and sodicity conditions, and soil management/workability constraints. These limitations are estimated on a crop-by-crop basis and are combined into a crop and input specific edaphic suitability rating.

The growing period for most crops continues beyond the rainy season and, to a greater or lesser extent, crops mature on moisture stored in the soil profile. However, the amount of soil moisture stored and available to a crop, varies, e.g., with depth of the soil, physical characteristics, and the rooting pattern of the crop. Depletion of soil moisture reserves causes the actual evapotranspiration to fall short of the potential rate. Available soil water capacity (AWC), an important parameter in the crop water balance, is assessed considering soil depth, soil volume and salinity.

Chemical and physical soil profile characteristics considered for both top-soil (0-30 cm) and sub-soil (30-100cm), include: the soil textural class; organic carbon content; pH, cation exchange capacity of soil and clay fraction; base saturation; total exchangeable bases; calcium carbonate contents; gypsum content; sodicity and salinity.

Suitability ratings of soil characteristics are empirical coefficients that reflect the effect the value of the soil characteristic has on the yield potential of a specific crop. The rating system is adapted from Sys et al. (1993). The individual ratings themselves draw on extensive compilation of results of research farm experiments and empirical knowledge among others summarized by Sys et al. (1993), Nachtergaele (1988) and Nachtergaele and Bruggeman (1986).

The output of Module IV comprises of result tables by crop and water source (rain-fed, gravity irrigation, sprinkler irrigation, drip irrigation), which list for each component soil of the soil map units recorded in AFGHSD v1, about 2400 soil map units, the calculated soil quality indicators and soil unit ratings.

Module V: Integration of climatic and edaphic evaluation

Module V executes the final step in the AEZ crop suitability and land productivity assessment. It incorporates the LUT specific results of the agro-climatic evaluation for biomass and yield calculated in Module II/III for different soil AWC classes and it uses the edaphic ratings produced for each crop/soil/slope combination assessed in Module IV to estimate agro-ecological attainable yields and related variables.

The inventories of soil resources and terrain-slope conditions are integrated by ranking all soil types in each soil map unit regarding their occurrence in different slope classes. Considering simultaneously the slope class distribution of all the grid cells belonging to a particular soil map unit, the characteristics of soil types and the shares of a soil map unit assigned to different soil types, a data pre-processing step of Module V results in an overall consistent distribution of soil-terrain slope combinations by individual soil association map units and 7.5 arc-sec grid cells (i.e., approximately 0.21 km by 0.21 km for latitude at center of Afghanistan).

The algorithm in Module V steps through the grid cells of the spatial soil association layer of the AFGHSD v1 and determines for each grid cell the respective make-up of land units in terms of soil types and slope classes. Each of these component land units is separately assessed and assigned a suitability rating and simulated attainable yield. The grid cell results are accumulated over all component land units in a grid cell. Processing of soil and slope distribution information takes place at 7.5 arc-second grid cells, the resolution used for storing NAEZ-Afghanistan results.

AEZ applies in Module V a terrain-slope suitability rating procedure to account for important factors that influence production sustainability. This is achieved through: (i) defining permissible slope ranges for cultivation of various crop/LUTs and setting maximum slope limits; (ii) for slopes within the permissible limits, accounting for likely yield reduction due to loss of fertilizer and topsoil, and (iii) distinguishing among a range of farming practices, from manual cultivation to fully mechanized cultivation. In addition, the terrain-slope suitability rating is varied according to amount and distribution of rainfall, which is quantified by means of the modified Fournier index (calculated in Module I). The calculations are crop/LUT specific and are separately performed for different input/management levels and water supply systems.

Application of the procedures in modules I to V produces an expected yield and suitability distribution under rain-fed and irrigation conditions by 7.5 arc-seconds grid cell, for each crop/LUT and input level. Land suitability results for each crop are stored as six classes: very suitable (VS), suitable (S), moderately suitable (MS), marginally suitable (mS), very marginally suitable (vmS), and not suitable (NS). These detailed crop databases are used to derive additional characterizations and aggregations of the land. Examples include the calculation of land extents with cultivation potential by land cover type and AEZ class, quantification of climatic production risks by using historical time series of suitability results, impacts of climate change on crop production potentials, and irrigation water requirements under current and future climates.

Various utility programs have been developed to aggregate and tabulate results by administrative or hydro-region units, or to map the contents of Module V crop databases in terms of a suitability index, suitable area shares, potential grid-cell production and related water balance variables.

Module VI: Economic evaluation and comparative advantage of major crops

Module VI builds on the results of the NAEZ-Afghanistan crop suitability and land productivity assessment. First, LUT specific production cost functions, where fixed and variable cost components are expressed as (linear) functions of yield, were applied with respect to current and projected agro-ecological attainable crop yields to estimate for major crops the grid-cell specific production costs. Cost functions and prices are based on information provided by experts at FAO-Afghanistan and are representative for conditions in recent years. Average farm gate prices of 2014–2016 were then used to determine the output value and respective attainable net revenues per unit area.

The various crop-specific results were then used to construct a spatial database showing a surface of best attainable net revenues by choosing in each grid cell the best performing crop. Each of the crops was then compared to this best-outcome surface in order to indicate and map the comparative advantage in terms of its attainable net revenue relative to the best available option in each grid cell.

Limitations

The agronomic data, such as the information on environmental requirements for some crops, contain generalizations necessary for global and national applications. In particular, assumptions on occurrence and severity of some agro-climate related constraints to crop production (used in Module III) are uncertain and could certainly benefit from additional systematic data collection and verification.

Land degradation in its multiple aspects, including crucial elements such as soil degradation (soil erosion, contamination, sealing, compaction, nutrient depletion, and biodiversity loss), vegetation degradation, and water resources decline in quality and quantity, are not or only partially taken into account. These factors will obviously put pressure on sustainable yield and production capacities.

Agriculture covers, by definition, apart from cropping a wide range of other activities and land uses include agro-forestry, livestock rearing and inland fisheries. The NAEZ-Afghanistan assessment does not encompass all these sectors and focuses mostly on the potential for growing crops (for food, fodder and fiber). Nonetheless, the outputs of the model can be used as spatial agronomic backbone to support various other applications in agricultural development planning, targeting of food security, scenario studies of climate change impacts and adaptation, or for assessing livestock sector development options.

Land has many important functions. AEZ outputs emphasize the suitability of land for crop production. The need to plan for more and better food supplies, from less resources and with less environmental impacts, will have to continue with high priority in Afghanistan in the next decades.

The results presented in this report have assessed the impacts and outcomes of projected gradual future changes in climate. The possible increase of the occurrence of extreme weather events, such as more frequent years of drought, extreme precipitation events, or late frosts, could not be evaluated in the NAEZ simulations because information available from AR5 earth system models and regional climate models cannot provide reliable estimates of future climate variability.

The NAEZ analysis in this study has assessed crop suitability and production potential for changing climatic conditions but did not quantify climate change impacts on water resources and water availability for agriculture. The annual and seasonal water balance is expected to deteriorate in most regions of Afghanistan as indicated by falling annual P/ET0 ratios. The hydrographs will also be affected by the retreating of glaciers and the changes in snow cover and melting. These changes may increase water scarcity in drought-prone areas and irrigation water will likely be in short supply in some areas under rapidly evolving climate change.

2.

Appendix

Agro-ecological zoning soil moisture regime

In Module I, AEZ calculates a daily reference soil-water balance for each grid-cell and estimates actual evapotranspiration for a reference crop. In the Module II, soil moisture balance calculations are performed considering specific crop/LUTs.

Soil moisture balance

Daily soil moisture balance calculation procedures follow the methodologies outlined in *CROPWAT (Smith 1992)* and the paper: *"Crop Evapotranspiration" (Allen et al., 1998)*. The quantification of a crop-specific water balance determines crop "actual" evapotranspiration (ETa) used for water-constrained crop yield estimation.

The volume of water available for plant uptake is calculated by means of a daily soil water balance (Wb). The Wb accounts for accumulated daily water inflow from precipitation (P) or snowmelt (Sm) and outflow from actual evapotranspiration (ETa), and excess water lost due to runoff and deep percolation.

$$Wb_j = \min(Wb_{j-1} + Sm_j + P_j - ETa_j,\ Wx)$$

where j is the day of the year; Wx is the maximum water available to plants. The snowmelt (Sm) is accounted within the snow balance calculation procedures and water in excess of Wx is booked as lost from soil moisture due to runoff and deep percolation.

The upper limit Wx of the water available to plants depends on the soil's physical and chemical characteristics that influence total soil water holding capacity (Sa). By definition, Wx is the product of total soil water holding capacity (Sa) and rooting depth (D).

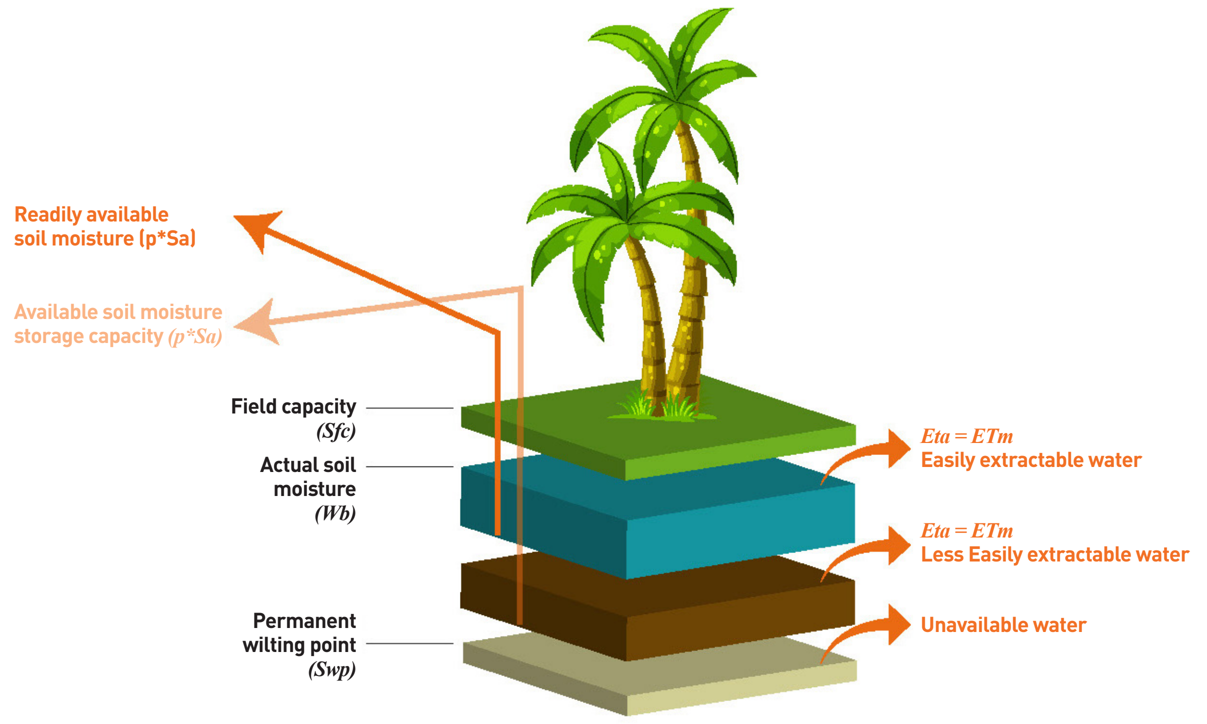
$$Wx = Sa \times D$$

The Sa value is a soil-specific attribute defined as the difference between soil moisture content at field capacity (Sfc) and permanent wilting point (Swp) over the rooting zone. For reference soil moisture balance calculations, a total water holding capacity of 100 mm is assumed. On any given day, actual soil water content (Wb) will be available to plants if $Swp < Wb < Sfc$ (Figure below).

However, water extraction becomes more difficult as soil water content (Wb) is less than a critical threshold (Wr) defined by p, the "soil water depletion factor", and the soil water holding capacity (Sa). When sufficient easily extractable water is available in the soil, actual evapotranspiration ETa will match maximum potential evapotranspiration ETm. In the reference water balance of AEZ Module I, maximum potential evapotranspiration ETm is taken to be the Penman-Monteith reference evapotranspiration ETo. In crop water balance calculations of specific crops/LUTs, crop-stage specific parameters are applied to ETo to estimate respective ETm values.

For actual soil moisture falling below the threshold of easily extractable water, the value of ETa will be less than ETm and a crop water deficit $WDe = ETm - ETa$ occurs.

Schematic representation of water balance calculations.



3.

Appendix

Compilation of Afghanistan Harmonized Soil Database

Introduction

Agro-ecological zoning requires a spatially detailed evaluation of soil qualities and edaphic suitability for a variety of possible cropping options. NAEZ-Afghanistan applies a newly compiled soil database to represent on a detailed spatial grid the soil resources of each region. This national harmonized soil database (AFGHSDv1) contains general soil information such as soil depth, soil drainage and occurrence of soil phases relevant for agricultural land use, plus some 17 soil profile attributes each for topsoil (0-30 cm) and subsoil (30 -100 cm soil depth).

Detailed terrain and land use/cover data were used in database compilation for guiding soil correlations and defining soil association units. Terrain data was extracted from SRTM digital elevation data (resolution of 1 arc-second) and processed to derive a national terrain slope inventory for use in NAEZ-Afghanistan. Classification of land use/cover was obtained from the Land Cover Database of the Islamic Republic of Afghanistan (LCDA 2010).

Afghanistan Harmonized Soil Database

Various available national soil resources maps and data sets, varying in detail and quality, were used for the compilation of AFGHSD v1. This includes three different soil resources maps or spatial databases: (i) the USDA Soil Map of Afghanistan; (ii) the USGS Soil Map of Afghanistan; and (iii) the global SoilGrids250m database.

The USDA soil map, the USGS soil map, land use/cover data and a layer of province administrative units were combined to define soil association mapping units. The SoilGrids250m database, SRTM derived terrain slope data, land use/cover classification and selected available nationwide interpolated soil profile attributes (e.g., pH, salinity, soil depth) were used to guide and review correlations of 'great group' soil taxonomy classes and WRB classifications with the FAO'90 soil unit level classification.

The soil association mapping units of the national harmonized soil database were parameterized with soil attributes derived from (i) selected attributes of available national level interpolated soil profile data, (ii) 1:1,000,000 USDA soil map, (iii) USGS soil map, and (iv) World Inventory of Soil Emissions Database (AEZ–WISE II) available for FAO'90 soil classification.

In summary, data sources used for the national soil data base include:

- USDA Soil Map of Afghanistan
- USGS Soil Map of Afghanistan
- Land Cover Database of the Islamic Republic of Afghanistan (LCDA 2010)
- SRTM Digital Elevation Data (at 1 arc-second resolution)
- SoilGrids250m Digital Data
- World Inventory of Soil Emission Potentials Database (AEZ-WISE II)
- Afghanistan national soil profile data by location
- Interpolated national level soil profile attributes (e.g., soil pH, salinity class).

The national harmonized soil database of Afghanistan (AFGHSDv1) developed in this study is covering Afghanistan in terms of 2398 soil associations mapping units. The soil classification used in the edaphic soil suitability assessment module in NAEZ is the revised legend of the FAO/Unesco Soil Map of the World (FAO'90).

Main data sources

USDA Soil Map

The USDA Soil Map of Afghanistan (USDA-NRCS, 2005) at a scale of 1:1,000,000 contains 153 mapping units classified according to the USDA soil taxonomy at soil great group level. The USDA soil map legend provides map associations, soil moisture regimes, soil temperature regimes and physiographic information. Some details of the 153 USDA mapping units are shown in Table A3.1. The digital USDA soil map was provided by FAO-Afghanistan and for its use in NAEZ-Afghanistan the great group USDA soil taxonomy classes of the map legend were correlated to FAO'90 and WRB soil groups and associated soil phases.

USGS Soil Map

The USGS Soil Map of Afghanistan compiled by United States Geological Survey contains 86 map units, coded in 11 classes, with information on soil depth, soil layer stratification, topsoil and subsoil textures and soil phase information (Table A3.2). The USGS digital map and attribute file was provided by FAO-Afghanistan.

Land Cover Atlas of the Islamic Republic of Afghanistan

Land use/cover of the LCDA 2010 database, taken from the Land Cover Atlas of the Islamic Republic of Afghanistan (FAO, 2016), was used to structure and refine the distribution of soil units and soil attributes. For this purpose, four aggregate land use/land cover classes were compiled from the LCDA 2010 database: (i) Irrigated cropland, orchards and vineyards; (ii) Rain-fed cropland; (iii) Forest, shrub land and rangeland, and (iv) Other land use/cover including bare land, wetland, water bodies, glaciers and snow covered land, and built-up land.

SRTM Digital Elevation Data

Terrain data were derived from 1 arc-second (about 21 m by 21 m at the latitude of central Afghanistan) SRTM data (Farr et al, 2007), provided by FAO-Afghanistan, and were classified in terms of median elevation and distributions of terrain slope classes per 7.5 arc-second grid cell for use in NAEZ as follows:

1. Median elevation (m) of 1 arc-second grid-cells

2. Distributions (%) of calculated 1 arc-second terrain slopes in terms of eight slope gradient classes: 0–0.5%, 0.5–2%, 2–5%, 5–8%, 8–16%, 16–30%, 30–45%, and > 45%.

SoilGrids25m Data

SoilGrids250m data (Hengl et al., 2017), a gridded global soil database at a resolution of 7.5 arc-seconds latitude/longitude provides estimated WRB and USDA soil classifications and standard soil properties and classes for: soil organic carbon; soil pH H_2O and KCl; sand, silt and clay fractions; bulk density; cation exchange capacity (clay); coarse fragments; and depth to bedrock. The attributes are mapped at 7 standard depths, namely 0 cm, 5 cm, 15 cm, 30 cm, 60 cm, 100 cm and 200 cm.

World Inventory of Soil Emission Potentials Database (AEZ-WISE II)

The AEZ-WISE II database (Batjes et al., 2002), comprising 9607 profiles, has been used to derive soil attributes using uniform taxonomy-based pedotransfer (taxotransfer) rules. The attributes were compiled by topsoil (0-30 cm) and subsoil (30-100 cm) separately by FAO'90 soil units and topsoil textures. Attributes include: gravel content; sand, silt, clay fractions; USDA texture class; reference and measured bulk density; organic carbon content; pH; cation exchange capacity (CEC_{clay} and CEC_{soil}); base saturation (BS); total exchangeable bases (TEB); calcium carbonate ($CaCO_3$), gypsum ($CaSO_4$), sodicity (ESP), and salinity (EC_e).

Soil Profile Data

The Afghanistan Soil Research Institute supported by FAO-TCP assistance has completed and made available soil profile databases for nine provinces of Afghanistan (FAO-AFG, undated). The databases comprise location-specific soil profiles classified according to WRB and include various gridded soil attributes obtained by digital soil mapping, i.e., sand, silt, and clay fractions, texture classes, soil depth, salinity, pH, bulk density, CEC, calcium carbonate, organic carbon and total nutrients.

Table A3.1 USDA soil map legend and correlations with FAO'90 classification

USDA SOIL MAPPING UNITS				Equivalent FAO'90 DOMINANT UNIT			Equivalent FAO'90 ASSOCIATED UNIT		
MAP UNIT CODES	SOIL TAXONOMY	SOIL MOISTURE REGIME	SOIL TEMPERATURE REGIME	FAO 90 Soil Unit	FAO 90 SYMBOL	PHASE	FAO 90 Soil Unit	FAO 90 SYMBOL	PHASE
137	Aquisalids withTorrifluvents	Aridic	Hyperthermic	Solonchaks	SC	—	Fluvisols	FL	-
23, 34, 47	Calcixeralfs with Xerochrepts	Xeric	Thermic	Luvisols	LV	—	Cambisols	CM	-
123, 133, 134, 139, 154	Dunes	Aridic	Hyperthermic	Dunes	DS	—	-	-	-
44, 46, 48, 54, 67, 69, 89, 103, 109, 120	Haplocalcids with Torriorthents	Aridic	Thermic	Calcisols	CL	—	Regosols	RG	-
27, 29, 35, 43, 45, 53, 61, 84, 85, 90, 97, 100, 112, 114	Haplocambids with Torriorthents	Aridic	Mesic	Cambisols	CM	—	Regosols	RG	-
56	Haplocambids with Torripsamments	Aridic	Hyperthermic	Cambisols	CM	—	Arenosols	AR	-
66, 72, 88, 91, 95, 104, 118, 121, 125, 132	Haplocambids with Torripsamments	Aridic	Thermic	Cambisols	CM	—	Arenosols	AR	-
142, 144	Haplocambids with Torripsamments	Aridic	Hyperthermic	Cambisols	CM	—	Arenosols	AR	-
75, 115, 119, 147	Haplosalids	Aridic	Thermic	Solonchaks	SC	—	-	-	-
7, 8, 12	Natrixeralfs with Halaquepts	Xeric	Thermic	Solonetz	SN	—	Solonchaks	SC	-
2, 3, 4, 9, 14, 15, 16, 17, 20, 24, 25, 30, 32	Rocky land with ice-capped bare rock	Aridic	Cryic/Frigid	Rocks	RK	—	Glaciers	GG	-
1, 5, 11, 36, 38, 41, 42, 49, 51, 59, 78	Rocky land with Lithic Cryorthents	Aridic	Cryic/Frigid	Rocks	RK	—	Regosols	RG	Lithic
6, 57, 63, 65, 73	Rocky land with Lithic Haplocambids	Aridic	Mesic	Rocks	RK	—	Cambisols	CM	Lithic
79	Rocky land with Lithic Haplocambids	Aridic	Cryic/Frigid	Rocks	RK	—	Cambisols	CM	Lithic
81, 92, 93	Rocky land with Lithic Haplocambids	Aridic	Mesic	Rocks	RK	—	Cambisols	CM	Lithic
99, 101, 102, 106	Rocky land with Lithic Haplocambids	Aridic	Cryic/Frigid	Rocks	RK	—	Cambisols	CM	Lithic
113, 116	Rocky land with Lithic Haplocambids	Aridic	Mesic	Rocks	RK	—	Cambisols	CM	Lithic
37, 50, 70, 74, 96, 98	Rocky land with Lithic Haplocryids	Aridic	Cryic/Frigid	Rocks	RK	—	Cambisols	CM	Lithic
22, 68, 107, 110, 149	Rocky land with Torriorthents	Aridic	Thermic	Rocks	RK	—	Regosols	RG	-
52, 76, 105, 141, 152, 153, 155	Salt Flats	Aridic	Thermic/Hyperthermic	Salt flats	ST	—	-	-	-
58, 60, 62, 108, 117, 124,	Torrifluvents	Aridic	Thermic	Fluvisols	FL	—	-	-	-
127, 128, 131	Torrifluvents with Haplogypsids	Aridic	Hyperthermic	Fluvisols	FL	—	Gypsisols	GY	-
122, 126, 143, 151	Torrifluvents with Haplosalids	Aridic	Hyperthermic	Fluvisols	FL	—	Solonchaks	SC	-
28	Torrifluvents with Torripsamments	Aridic	Mesic	Fluvisols	FL	—	Arenosols	AR	-
77	Torrifluvents with Torripsamments	Aridic	Cryic/Frigid	Fluvisols	FL	—	Arenosols	AR	-
80, 86, 111, 146	Torrifluvents with Torripsamments	Aridic	Mesic	Fluvisols	FL	—	Arenosols	AR	-
33, 71	Torriorthents with Torrifluvents	Aridic	Mesic	Regosols	RG	—	Fluvisols	FL	-
71, 82, 83, 94, 148, 150	Torriorthents with Torrifluvents	Aridic	Mesic	Regosols	RG	—	Fluvisols	FL	-
19, 26, 130, 136,	Torripsamments with Dunes	Aridic	Thermic	Arenosols	AR	—	Dunes	DS	-
129, 135, 138, 140, 145	Torripsamments with Torriorthents	Aridic	Hyperthermic	Arenosols	AR	—	Regosols	RG	-
21, 31, 40, 64, 87	Xerochrepts with Xerorthents	Xeric	Thermic	Cambisols	CM	—	Regosols	RG	-
10, 13, 18, 39, 55	Xerorthents with Xeropsamments	Xeric	Thermic	Regosols	RG	—	Arenosols	AR	-

Soil correlations

The NAEZ edaphic crop suitability assessment (Module IV) uses FAO soil classification systems and a standard set of soil profile attributes. Soil correlations are based on: (i) the USDA map unit descriptions including soil taxonomy classifications, soil moisture regimes and soil temperature regimes data; (ii) the USGS map unit descriptions including soil depth, topsoil and subsoil textures and soil phase information, and (iii) aggregate classes of land use/ cover data consisting of: irrigated cropland, orchards and vineyards (L1); rain-fed cropland (L2); forest land, shrub land, rangeland (L3); and other land cover including bare areas, wetlands, water bodies, glaciers and snow covered land, and built-up land (L4).

Terrain slopes were used to adjust shares of soil types in soil associations to account for obvious associations of soil types with terrain slopes, as listed in Table A3.3. Map units characterized with land use L1 (irrigated cropland and orchards) and L2 (rain-fed cropland) were specified separately assuming that the soils in these units are suitable for crop production and therefore have at least a minimum soil depth and are void of extreme soil salinity, very steep terrain slopes and soil phases hampering crop production and field management.

Available gridded national level pH and soil salinity class layers were used to refine pH attribute data and for adjustment of correlations of saline soils, occurrence of salic soil phases, and topsoil and subsoil soil salinity attribute values.

Table A3.2 USGS soil map legend and interpretations

USGS (original legend)		
Soil Mapping Unit		
Code	USGS Soil description	Soil Depth
1	coarse grained: gravel overlain by silty sand and clayey sand	very deep
2	coarse grained soils: gravel overlain by caliche and silty sand	very deep
3	coarse grained soils: poorly graded sand	very deep
4	fine grained soils: sandy silt	very deep
5	fine grained soils: clay underlain by gravel and silty sand	very deep
6	fine grained & coarse grained soils: clay & silty sand (shallow), silt & clay (moderately deep to deep)	shallow/moderately deep to deep
7	fine grained & coarse grained soils: gravel overlain by clay	very deep
8	fine grained & coarse grained soils: silt & clay underlain by silty sand	very deep
9	fine grained & coarse grained soils: silt & clay underlain by silty sand	moderately deep to deep
10	fine grained & coarse grained soils: clay, silt, & sand	very deep
11	fine grained & coarse grained soils: clay & silty sand with rock fragments and exposed bedrock	shallow

USGS (legend interpretation)									
Soil Mapping Unit		Dominant Unit				Associated Unit			
Code	Description	depth	topsoil texture	subsoil texture	phse	depth 2	topsoil texture	subsoil texture	phse
1	very deep, coarse to medium textured soils with petric phase	>150	4	2	petric	-	-	-	-
2	very deep, coarse textured soils with petric phase	>150	1	1	petric	-	-	-	-
3	very deep, coarse textured soils (no phase)	>150	1	1	-	-	-	-	-
4	very deep, medium textured soils (no phase)	>150	2	2	-	-	-	-	-
5	very deep, fine textured top soils and medium to coarse textured subsoils (petric phase)	>150	1	4	-	-	-	-	-
6	partly shallow, fine to coarse textured soils and partly moderately deep to deep, medium to fine textured soils (no phase)	25-50	5	5	-	50-150	6	6	-
7	very deep, medium to fine textured soils with petric phase	>150	6	6	petric	-	-	-	-
8	very deep, fine textured topsoil with medium to coarse textured subsoil (no phase)	>150	3	6	-	-	-	-	-
9	moderately deep to deep, fine textured topsoil with medium to coarse textured subsoil (no phase)	50-100	3	4	-	-	-	-	-
10	very deep, fine, medium and coarse textured soils (no phase)	>150	5	5	-	-	-	-	-
11	partly shallow, fine, medium and coarse textured soils with stony phase and partly rockland	25-50	5	5	stony	0	-	-	RK

Texture		Soil Depth (cm)		
1	Coarse	1	0	Rockland
2	Medium	2	<25	Very shallow
3	Fine	3	25-50	Shallow
4	Medium-coarse	4	50-100	Moderately deep
5	Fine-coarse	5	100-150	Deep
6	Fine-medium	6	>150	Very deep

Table A3.3 Soil unit/miscellaneous units - Terrain slope relationships

Soil units /Miscellaneous units		Maximum terrain slope	Priority
FLc	Calcaric Fluvisols	5 %	1
FLs	Salic Fluvisols	5 %	1
ARc	Calcaric Arenosols	All slopes	4
CLh	Haplic Calcisols	30 %	6
CMc	Calcaric Cambisols	16 %	4
GYh	Haplic Gypsisols	30 %	4
GYk	Calcic Gypsisols	30 %	4
KSk	Calcic Kastanozems	30 %	4
LPk	Rendzic Leptosols	All slopes	5
LPq	Lithic Leptosols	All slopes	7
LVk	Calcic Luvisols	8 %	3
RGc	Calcaric Regosols	All slopes	5
SCh	Haplic Solonchaks	5 %	2
SCk	Calcic Solonchaks	5 %	2
SCn	Sodic Solonchaks	5 %	2
SNh	Haplic Solonetz	5 %	2
SNk	Calcic Solonetz	5 %	2
DS	Dunes	All slopes	5
ST	Salt Flats	All slopes	1
RK	Rocky Land	All slopes	7
WR	Water	All slopes	1
GG	Rocky land with glaciers	All slopes	7
UR	Built-up/Urban areas	All slopes	1
MA	Marshes	All slopes	1

Soil associations

Both, USDA taxonomy descriptions and USGS map legends indicate map unit specific soil associations. For AFGHSD these soil associations were used to define soil unit compositions. Soil unit area shares (%) within soil association units were assigned based on soil unit-terrain slope relationships (Table A3.3) and information on prevailing land use/cover such that soil and terrain slope distributions when aggregated over all grid-cells in each soil association map unit are consistently assigned and integrated.

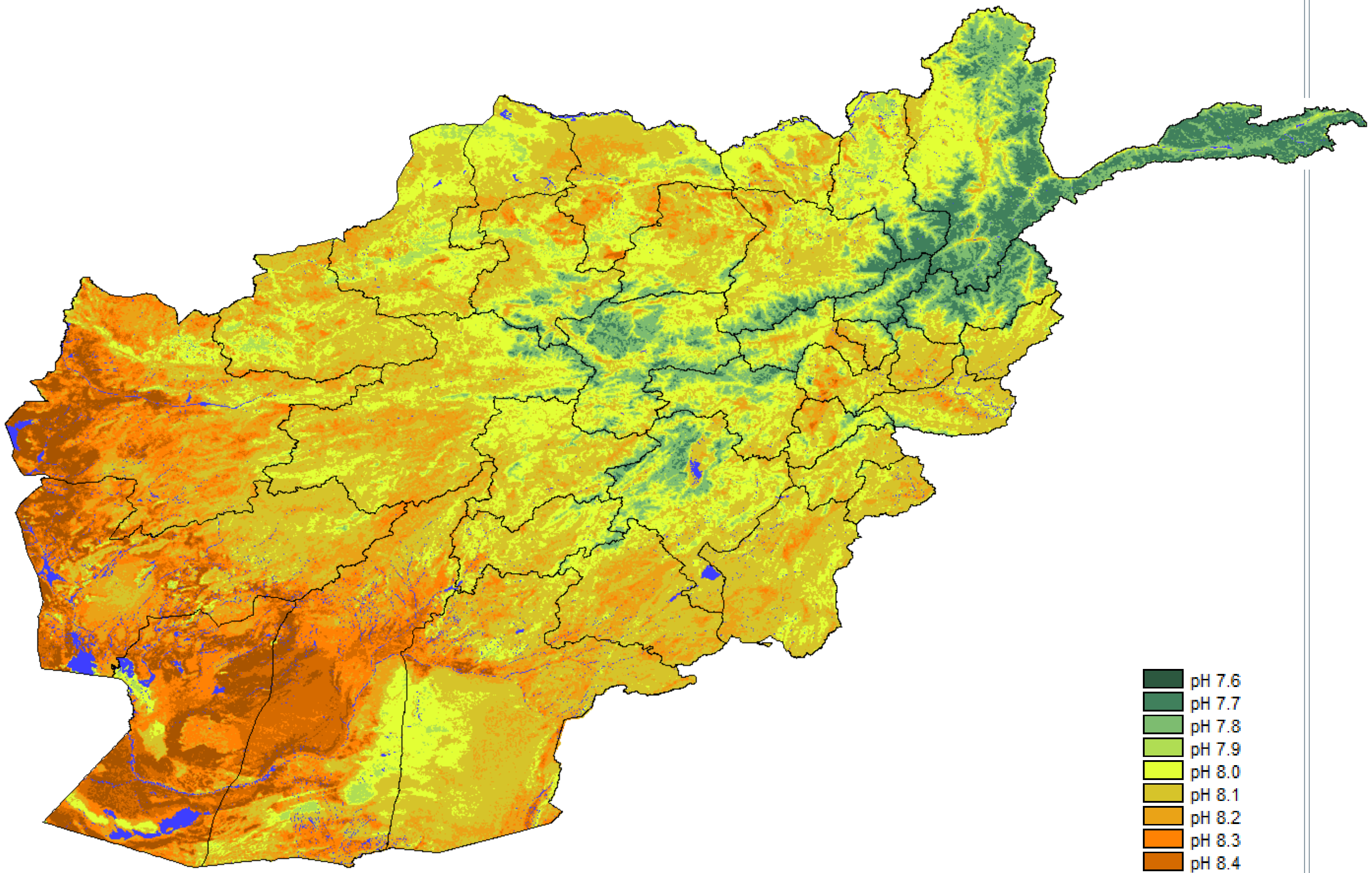
Resulting soil associations of FAO'90 soil units with broad FAO topsoil texture classes allow linkage with the AEZ-WISE II soil attribute database which provides access to reference soil attributes, which were used when information from Afghanistan sources was unavailable. Apart from selected mapped soil profile attributes, soil properties such as soil depth, soil texture and soil phases can directly be derived from USDA and USGS descriptions and have been reviewed/ adjusted vis-a-vis land use and terrain slope conditions.

Table A3.4 lists calculated extents of individual soil units/ miscellaneous units occurring in the soil associations mapping units of AFGHSD v1. Accordingly, the largest soil unit extents are listed for Calcaric Regosols (29.7%), Lithic Leptosols (18.2%) and Calcaric Cambisols (11.6%), together accounting for nearly 60% of all soil units and miscellaneous units represented in AFGHSD v1.

Table A3.4 Occurrence of soil units and miscellaneous units in AFGHSD

	Soil units /Miscellaneous units	Total occurrence (km^2)	% of Total
FLc	Calcaric Fluvisols	22 471.3	3.5
FLs	Salic Fluvisols	253.9	0.0
ARc	Calcaric Arenosols	61 959.8	9.6
CLh	Haplic Calcisols	45 524.4	7.1
CMc	Calcaric Cambisols	74 465.4	11.6
GYh	Haplic Gypsisols	319.6	0.0
GYk	Calcic Gypsisols	45 084.5	7.0
KSk	Calcic Kastanozems	0.1	0.0
LPk	Rendzic Leptosols	1 584.1	0.2
LPq	Lithic Leptosols	116 809.4	18.2
LVk	Calcic Luvisols	2 863.7	0.4
RGc	Calcaric Regosols	190 950.3	29.7
SCh	Haplic Solonchaks	479.6	0.1
SCk	Calcic Solonchaks	17 478.9	2.7
SCn	Sodic Solonchaks	389.1	0.1
SNh	Haplic Solonetz	251.2	0.0
SNk	Calcic Solonetz	38.4	0.0
DS	Dunes	18 928.3	2.9
ST	Salt Flats	2 102.7	0.3
RK	Rocky Land	14 000.4	2.2
WR	Water	14 364.4	2.2
GG	Rocky land with glaciers	4 966.9	0.8
UR	Built-up/Urban areas	3 036.6	0.5
MA	Marches	3 980.5	0.6
	TOTAL	**642 303.5**	**100.0**

Generalized map of topsoil pH



Source: The Afghanistan Soil Research Institute supported by FAO-TCP assistance has compiled soil profile databases for nine provinces of Afghanistan (FAO-AFG, undated). The database includes various gridded top-soil attributes obtained by digital soil mapping, i.e., sand, silt, and clay fractions, texture classes, soil depth, salinity, pH, bulk density, CEC, calcium carbonate, organic carbon and total nutrients.

Figure A3.1

Figure A3.1 illustrates the content of the harmonized soil database AFGHSD v1, showing the distribution of topsoil (0-30 cm) pH values, falling in Afghanistan mostly in the range of 7.6-8.5 with a median value of about 8.0. The pH, measured in a soil-water solution, is an indicator for the acidity (pH < 7) and alkalinity (pH > 7) of the soil, which affects the availability of nutrients to the plant.

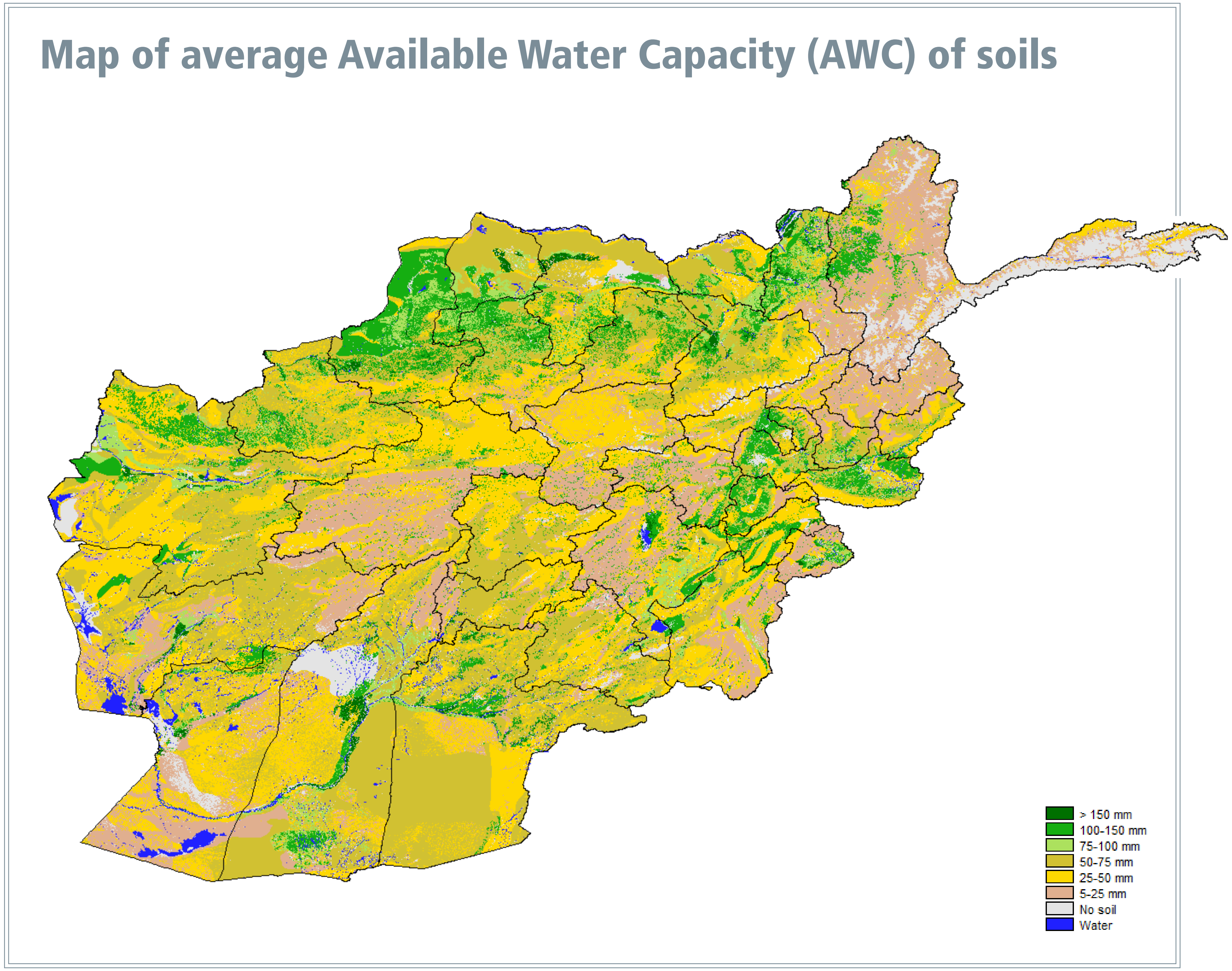
Crops vary in their tolerance to high and low soil pH. For instance, the range of soil pH causing no or only minor limitations for wheat cultivation is set in NAEZ-Afghanistan to pH 6.0 to 8.2. For cotton this range is set to pH 5.5 to 7.6, and tobacco is even much less tolerant to alkalinity. Comparing the pH requirements of crops to prevailing soil pH levels is just one step of the edaphic suitability evaluations in AEZ.

For the application of the edaphic suitability assessment (NAEZ Module IV), soil attribute data and database structure were defined following the formats of the Harmonized World Soil Database (Nachtergaele et al., 2012). Table A3.5 lists the soil attributes contained in the national harmonized soil database AFGHSD v1.

Table A3.5 Content of soil attribute database in AFGHSD v1

Soil Attribute	Unit	Soil Attribute	Unit
ID	number	**Topsoil CEC clay**	cmol/kg
Mapping unit code	number	**Topsoil CEC soil**	cmol/kg
Mapping unit symbol	text	**Topsoil base saturation**	%
SMU sequence number	number	**Topsoil TEB**	cmol/kg
Province	number	**Topsoil $CaCO_3$**	% weight
USDA soil unit code	number	**Topsoil $CaSO_4$**	% weight
USGS soil unit code	number	**Topsoil ESP**	%
Land use/cover class	text	**Topsoil ECe**	dS/m
Share of soil unit in mapping unit	%	**Sub-soil gravel content**	%
Soil Unit	FAO'90 class	**Sub-soil sand fraction**	%
Topsoil texture class (FAO)	class	**Sub-soil silt fraction**	%
Drainage class	class	**Sub-soil clay fraction**	%
Soil depth	cm	**Sub-soil texture class (USDA)**	class
Available soil moisture capacity	mm	**Sub-soil reference bulk density**	kg/dm^3
Soil phase 1	class	**Sub-soil bulk density**	kg/dm^3
Soil phase 2	class	**Sub-soil organic carbon**	% weight
Vertic/petric properties	code	**Sub-soil pH H_2O**	- log H^+
Topsoil gravel content	%	**Sub-soil CEC clay**	cmol/kg
Topsoil sand fraction	%	**Sub-soil CEC soil**	cmol/kg
Topsoil silt fraction	%	**Sub-soil base saturation**	%
Topsoil clay fraction	%	**Sub-soil TEB**	cmol/kg
Topsoil texture class (USDA)	class	**Sub-soil $CaCO_3$**	% weight
Topsoil reference bulk density	kg/dm^3	**Sub-soil $CaSO_4$**	% weight
Topsoil bulk density	kg/dm^3	**Sub-soil ESP**	%
Topsoil organic carbon	% weight	**Sub-soil ECe**	dS/m
Topsoil pH H_2O	-log H^+		

Note: Topsoil refers to 0-30 cm soil depth; Sub-soil refers to 30-100 cm soil depth.



Source: NAEZ soil evaluation based on soil attribute information (texture class, gravel content, soil depth, soil salinity) available in AFGHSD v1. The values represent maximum soil water available to plants (in mm) in the top 100 cm of the soil profile, or for the available effective soil depth where this is less than 100 cm.

Figure A3.2

The growing period for most crops continues beyond the rainy season and, to a greater or lesser extent, crops mature on moisture stored in the soil profile. However, the amount of soil moisture stored and available to a crop, varies, e.g., with depth of the soil, physical characteristics, and the rooting pattern of the crop. Depletion of soil moisture reserves causes the actual evapotranspiration to fall short of the potential rate.

The upper limit of the water available to plants depends on the soil's physical and chemical characteristics that influence total soil water holding capacity. Available soil Water Capacity (AWC), an important parameter in the crop water balance, is estimated from physical and chemical soil characteristics, effective soil depth and rooting depth of individual crops.

Gravel, stones, boulders, and rock fragments when present in the profile reduce considerably the capacity of a soil to store moisture. The FAO74 legend accounts for such conditions by defining the Stony soil phase reflecting the presence of coarse fragments in the surface layers or at the surface to an extent that it reduces effective soil volume and therefore AWC significantly. Other soil volume limiting soil phases include Lithic, Petric, Petrocalcic, Petrogypsic, Petroferric, Duripan, Skeletic, as also Gravelly and Concretionary soil phases which may occur anywhere between soil surface and 100 cm depth.

Apart from soil volume reducing soil phases, effective soil volume and hence AWC may significantly be affected by coarse fragment occurrences. Coarse fragments contents in topsoil and subsoil has been systematically parameterized in the soil attribute database of AFGHSD v1, which has been used to adjust reference soil AWC. The AWC adjustment follows procedures recommended by USDA and NCRS (1967). The same USDA source provides adjustments to AWC as a function of soil electrical conductivity. Salinity affects crops through inhibiting the uptake of water. The adjustments of AWC for coarse fragments and for salinity have been established by USDA soil texture classes.

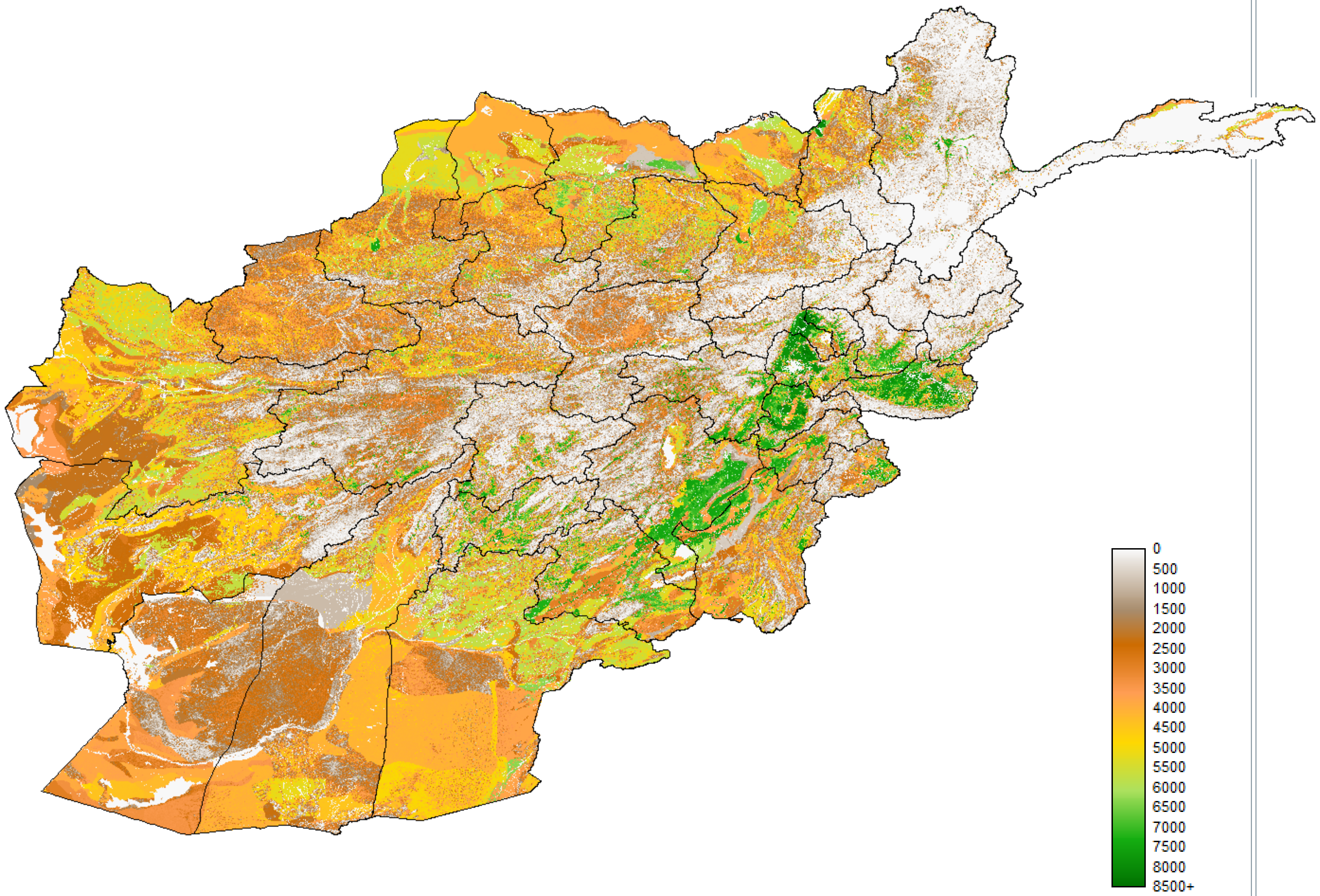
Figure A3.2 shows average soil AWC values, weighted by component soil unit shares within a grid cell, based on soil attribute information available in AFGHSD v1. The values represent maximum soil water available to plants (in mm) in the top 100 cm of the soil profile, or for the available effective soil depth where this is less than 100 cm.

NAEZ Module IV estimates yield reductions due to the constraints induced by prevailing soil and terrain-slope conditions. The soil suitability assessment follows a two-step approach. First, crop responses to individual soil attribute conditions are combined into seven soil quality ratings. Then soil qualities are combined into crop specific soil suitability ratings, by input/management level and by water supply system. The soil qualities influencing crop performance considered in the assessment include: nutrient availability (SQ1); nutrient retention capacity (SQ2); rooting conditions (SQ3); oxygen availability to roots (SQ4); presence of salinity and sodicity (SQ5); presence of lime and gypsum (SQ6), and workability (SQ7).

Figure A3.3 shows the spatially detailed results of an edaphic evaluation of soil and terrain suitability for wheat cultivation under low input/management assumptions and using soil attribute data from AFGHSD v1. The suitability rating used to represent edaphic evaluation outcomes covers a value range of 0 to 10,000 (note: range on map shown here is from 0 to 8,500), i.e., from 0 when all land in a grid cell is entirely unsuitable (shown as light grey color) to 10,000 meaning that all land in a grid cell is very suitable (shown as dark green color) for wheat.

As shown, highly suitable soils for wheat under low input/management conditions are mainly found in the provinces of Central, West-Central and Eastern region.

Soil/terrain suitability rating for wheat, low input/ management



Source: NAEZ soil evaluation module. Calculation of soil and terrain suitability index for wheat cultivation under low input/management assumptions and using soil attribute data from AFGHSD v1.

Figure 3.3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