Water Rennovation in Ukraine
Project no. 22320101

Data-Driven Insights for Crop-Soil-Water Systems in Era of Climate change

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The project is co-financed by the Governments of the Czechia, Hungary, Poland and Slovakia through Visegrad Grants from International Visegrad Fund. The mission of the fund is to advance ideas for sustainable regional cooperation in Central Europe.

Ice-Breaking Activity

1. **Receive Your Sheet**.
2. **Find Matching Students:** if the statement is "I have a pet," find someone who has a pet.
3. **Collect Signatures:** Each person can only sign your sheet TWICE.
4. **Complete the Sheet:** The goal is to fill up your sheet with as many different signatures as possible.
5. **Time Limit:** You have 10-12 min to complete this activity.

- **Remember:**
- Enjoy the process of getting to know each other!

- **Good luck and have fun!**

Gool

- The main goal of this training is to provide an overview of the concept of climate change, crop modeling and evaluate its impact on agricultural drought.
- Participants will gain the ability to analyze agricultural data and understand its relationship to climate change.

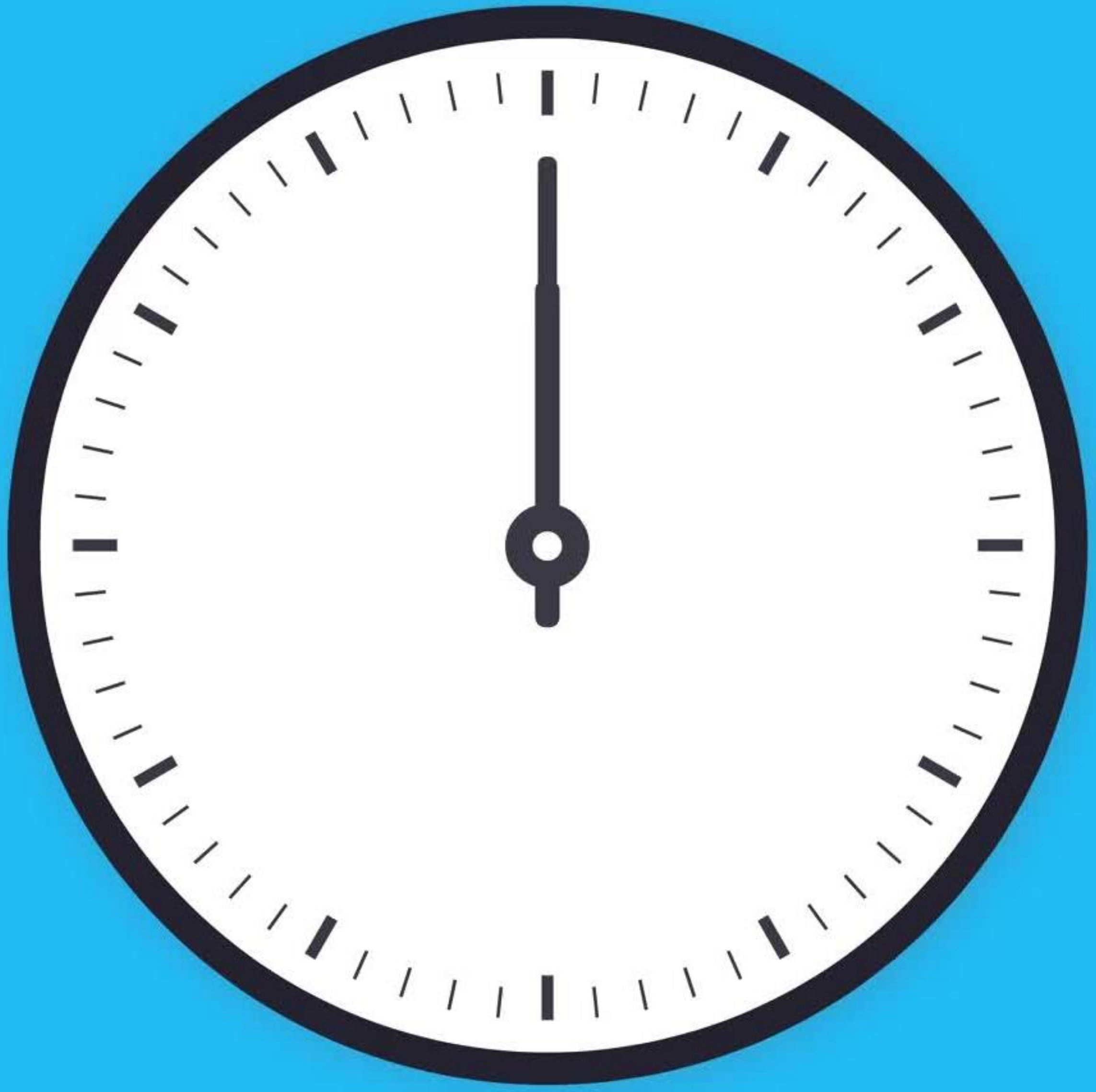
Agenda

- Climate Change and Agriculture
- Crop modeling
- Analyzing Data Related to Agricultural Drought
- Data-Driven Machine Learning for Predicting Agricultural Drought

Training Roles:

- Engage in Group Work
- Participate Effectively in Discussions
- Ask Questions
- Keep Mobile Phones on Silent Mode

- Let's start by dividing everyone into groups.



It's time for group work.

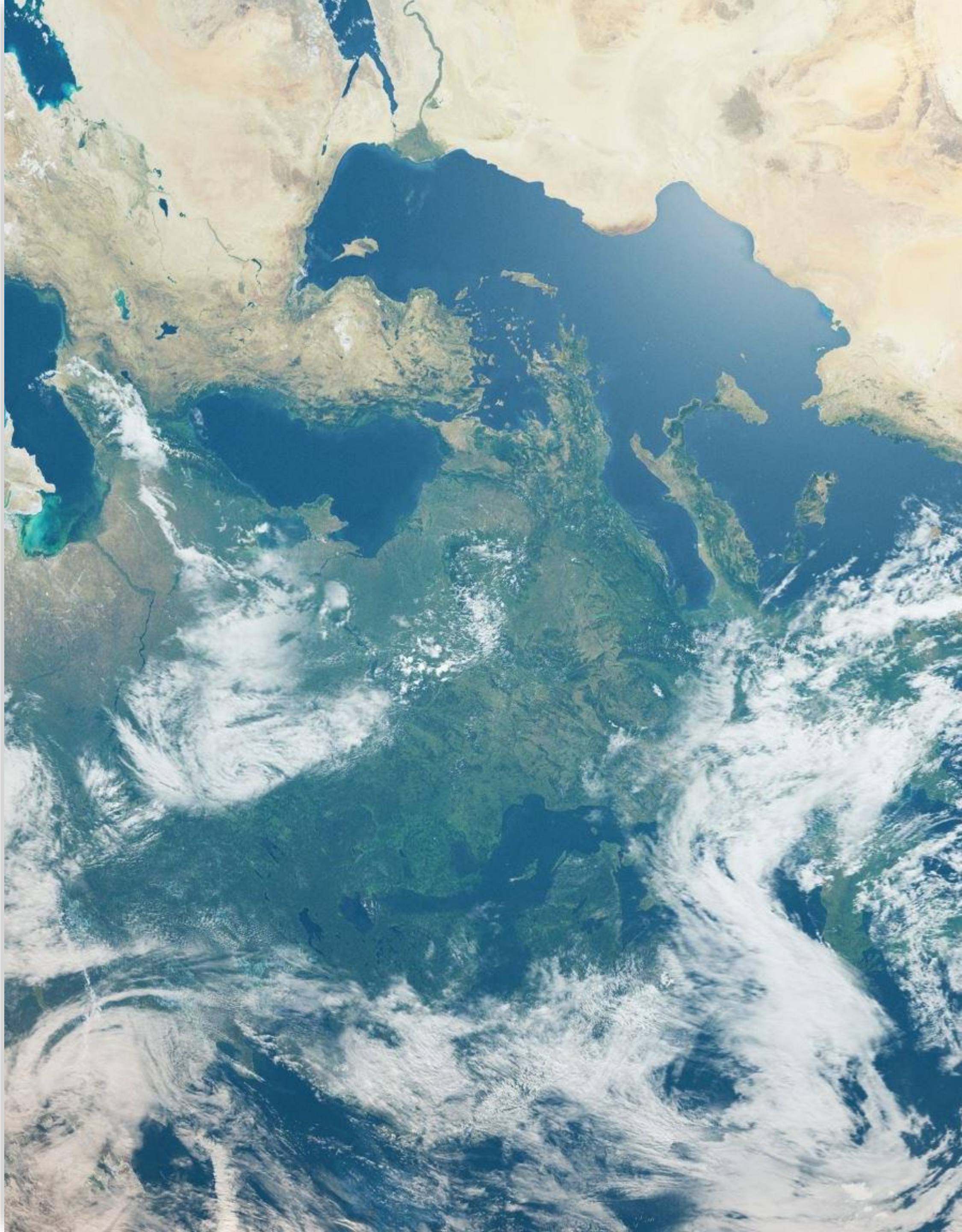
Introduction

- In recent years, the world’s population has increased rapidly, and is expected to increase from 7.2 billion people to 9.6-12.3 billion in 2100 (*Gerland* et al. 2014).
- Thus, the United Nations launched the Sustainable Development Goals (SDGs), which include an ambitious goal for zero hunger globally (SDG2) by 2030 (*Mason-D'Croz et al*. 2019).

- Nonetheless, climate change (CC) has rapidly affected many ecosystems earlier than predicted.
- Even though GHGs exist naturally, human activities have released huge amounts of it, leading to more trapping of the sun's heat, which exceeds the needs of the earth, and which is known as "global warming - GW". This global warming has directly affected weather patterns on a global scale, causing "climate change - CC".
- In this context, the **United Nations Framework Convention on Climate Change (UNFCCC)** defined CC as a "**change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods**".

- GHGs are predominantly made out of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which are quickly expanding in the air, causing global climate change.
- Unfortunately, the current GHGs projection reveal that the CO_2 concentration will reach 590 ppm by the end of the 21st century.
- The GHG emanations can be highlighted as follows: 31.6% from industrial activities, 12.2% from changes of land use, 24.9% from power sector, 14.3% from transportation, 13.8% from the agricultural sector, and 3.2% from waste industry.

- In a global scale, and after 25 years of work based on the ***United Nations Framework Convention on Climate Change (UNFCCC-1992)*** (Earth Summit in Rio de Janeiro); finally, the world leaders signed the ***Paris Agreement (PA)*** (April 2017).
- The PA which is designed at COP 21 (Paris, December 2015) was a hybrid approach combining two previous framework the first one was ***Kyoto protocol*** (2002) “top-down” and ***Copenhagen agreement*** “bottom-up” (*Asadnabizadeh* 2019). Where the main issue was to minimize the world emissions of GHGs to keep GW below 2 °C.



Climate change

- The Earth's atmosphere is full of gases, some of which are greenhouse gases (GHGs); these gases trap the sun's heat and keep earth warm for life. However, accelerated civilizational development and industrialization increased the concentration of GHGs in the earth's atmosphere. In this sense, CO_2 reached 410.6 ppm in 2019, compered with 280 ppm in the 1760s. This increase led to rapid climate change (CC).
- *Reddy* (2015) summarized the main indicators of CC as follows: **1) an increase in temperature, 2) an increase in ocean heat content, 3) an increase in sea level and surface temperatures, 4) an increase in continentality, 5) tropospheric temperature, 6) a decrease in sea ice, 7) a decrease in snow cover, and 8) a decrease in sea ice glaciers**.

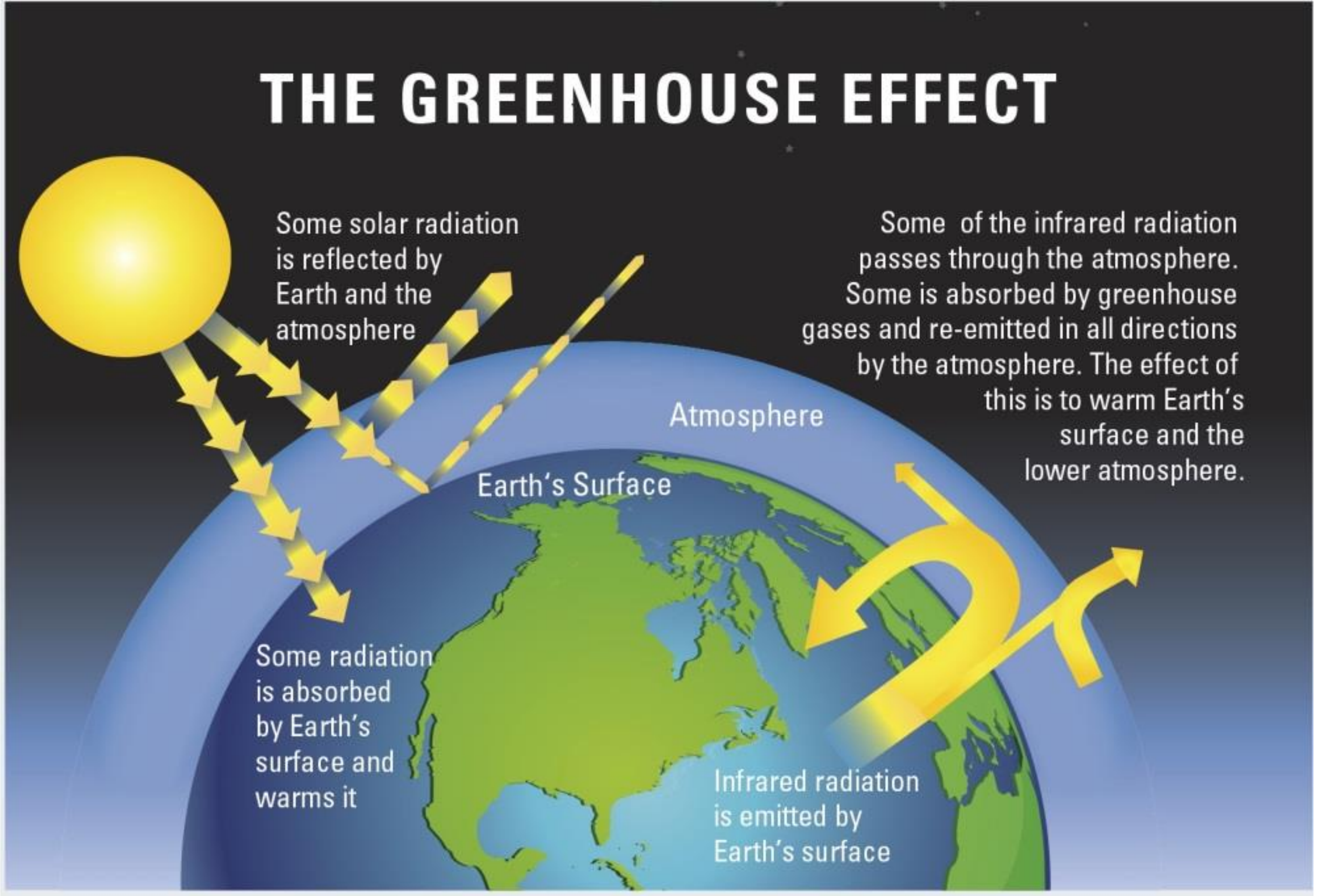


Figure 1 Schematic overview of GHGs effects **(I1)**

- **Sources and impacts of greenhouses gases:**
- **Carbon dioxide (CO_2)**
- Before the industrial revolution CO_2 did not **exceed 300 ppm.**
- Since then, different activities have led to a rapid increase in CO_2 emissions due to coal use (*Boden et al*. 2017), which increased fossil fuel emissions by 100% (from 1.5% to 3%) between 1980 and 2000 and 2000-2012 (*Hansen et al*. 2013) (Figure3), and by 29% from 2000 to 2008 (*Le Quéré et al*. 2009).

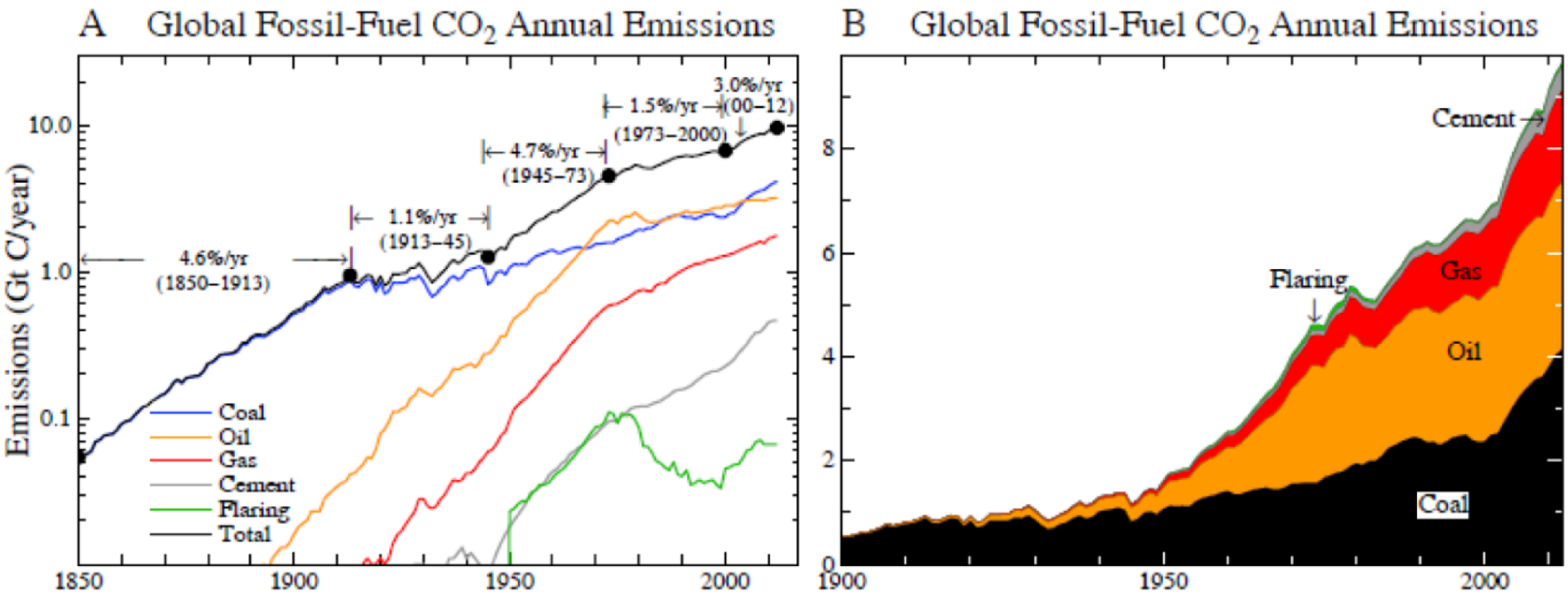


Figure 3. Emissions of CO_2 (Gt C/year) from different sources between 1850 and 2012 on a global scale (*Hansen et al.* 2013)

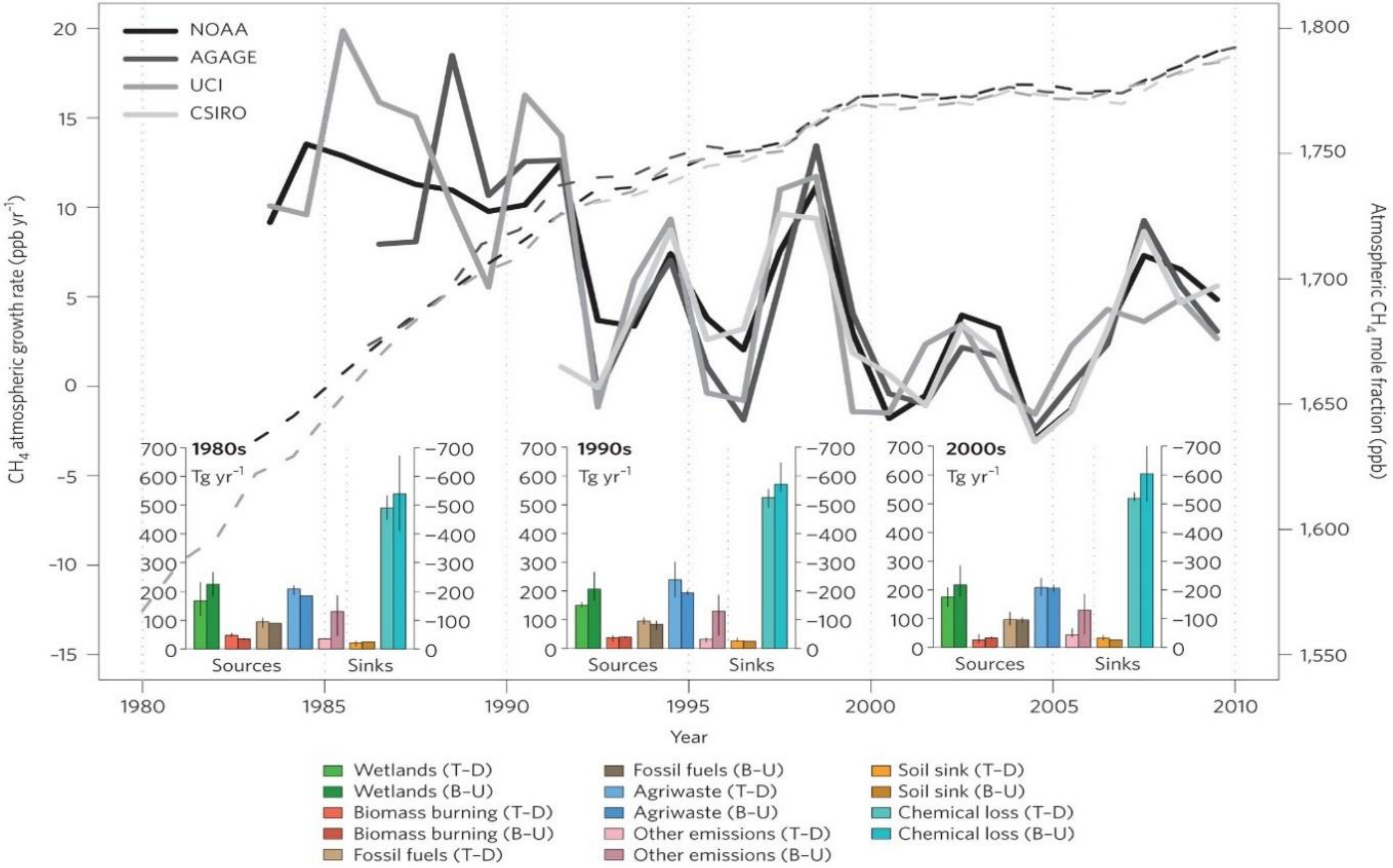


Figure 4. Sources, concentration and sinks of CH_4 from different world databases (NOAA, AGAGE, UCI and CSIRO) published by Nature (*Kirschke et al.* 2013).

The highest N_2O emissions were recorded in Brazil, China and India, due to economic development.

Interestingly, the current global N_2O emissions values exceed the highest projected scenarios

reached 331 ppb in 2018, compared to 270 ppb in 1750

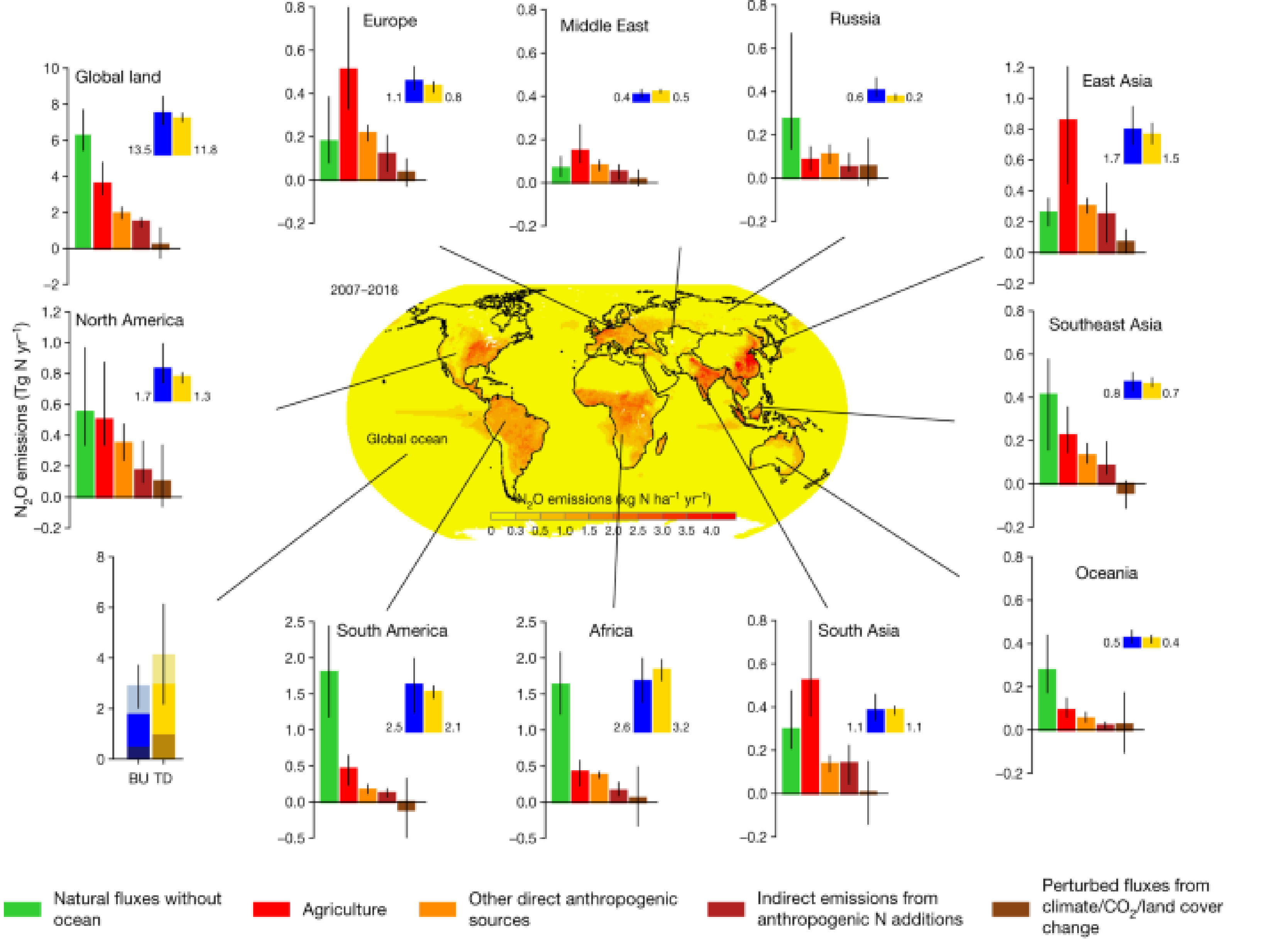


Figure 5. Sources and concentrations of N_2O from different sectors around the world, published by Nature (*Tian et al.* 2020).

Greenhouse Gas Emissions from Soil

- Soil serves as **a source and sink** for GHGs (*Oertel et al*. 2016).
- By 2030, the IPCC (2007) projected an increase in N_2O and CH_4 from the agricultural sector of 30-60% and 60%, respectively, due to an increase in world population and food demand.
- **The GHGs budget reveals that 35% of CO_2, 47% of CH_4, 53% of N_2O, and 21% of NO is emitted from soil** (IPCC, 2007).

GHG emissions from soil are related to many processes and affected by many driving factors, which can be summarized as follows :

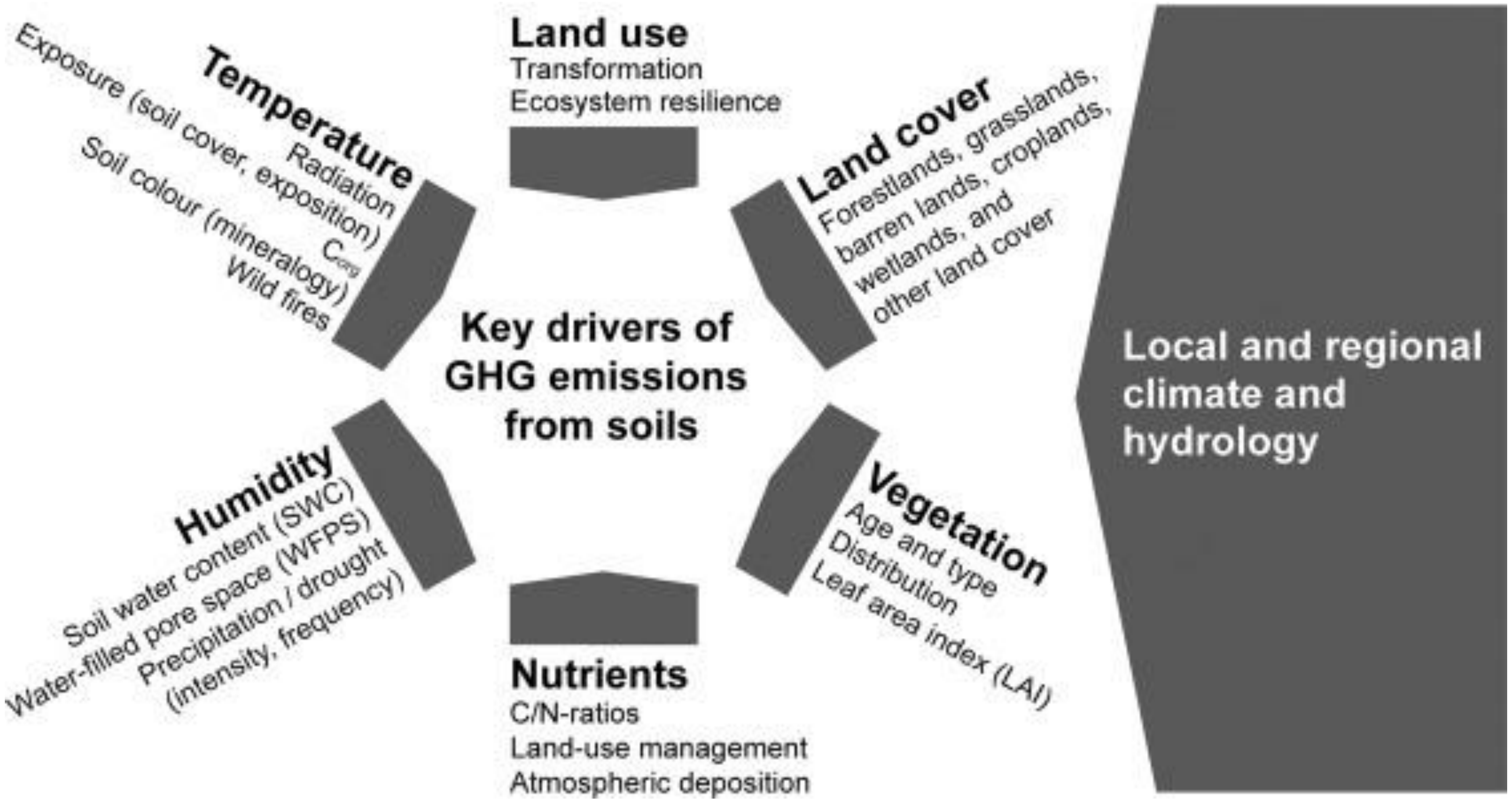


Figure 7. Schematic illustration of driving factors controlling soil GHG emissions, as proposed by *Oertel et al. (2016)*

1. **Soil moisture ($\boldsymbol{M_{soil}}$)**: M_{soil} is one of the leading factors that controls soil emissions, due to the fact that M_{soil} controls both **the C-cycle and the N-cycle**.

For instance, when M_{soil} is less than 10%, the NO emissions decrease significantly (*Brümmer et al.*, 2008). Similarly, an increase of M_{soil} soil above 30% accelerates N_2O emissions, with an optimum situation in which 60% of the soil pores are filled by water (*Gao et al.* 2014).

In a similar context, CO_2 emissions are reported to be higher when 20-60% of the soil pores are filled by water (*Wang et al.* 2011). On the contrary, CH_4 sinks into the soil when aerobic conditions are dominant (*Dutaur, and Verchot* 2007); however, rice production areas and wetlands are the main sources of CH_4 (*Wang et al.* 1996, *Hwang et al.* 2020).

2- Soil temperature (*T_{soil}*): an increase in T_{soil} leads to an increase in soil emissions due to the enhancement of microbial metabolism (*Oertel et al.* 2016).

Many researchers have noticed an exponential relation between an increase in T_{soil} and NO and CO_2 emissions (*Tang et al.* 2003).

Similarly, an increase in T_{soil} results in an exponential increase in N_2O emissions, while the consumption of CH_4 increases linearly (*Mosier et al.* 1996).

Also, an increase by 5°C of T_{soil} accelerates CO_2 emissions by 25–40% (*Rustad and Fernandez* 1998).

Field research studies have shown that seasonal changes in T_{soil} and M_{soil} lead to seasonal changes in soil GHG emissions (*Schaufler et al.* 2010), whereas the highest emissions recorded in summer.

However, M_{soil} along with T_{soil} explains 86% of the total variance of N_2O emissions, and 74% of the total variance of N_2O emissions (*Schindlbacher et al.* 2004).

Site specific criteria (S_p): *Sp* extends to include location, topography, elevation, and cover, which all together affect M_{soil} and T_{soil}. For instance, N_2O emissions are higher in lowlands or mountain foothills than on slopes and hills, due to the accumulation of soil moisture, which is higher than in other landscapes (*Oertel et al.* 2016).

Exposure to fires: fires in any ecosystem can affect the GHG budget, where burning areas show lower flows of carbon dioxide and nitrous oxide compared to unburned areas one month after fire (*Kim*, 2013).

Soil pH: this factor affects **microbial activity**; thus, it influences total GHG emissions from soil. Low emissions have been reported in acidic soil (*Oertel et al.* 2016). Scientifically, moderate pH (pH neutral) is optimal for GHG emissions. CO_2 emissions are higher in neutral pH than other pH-values (*Čuhel et al.* 2010), however CH_4 production needs pH values between 4 and 7 (*Dalal and Allen* 2008).

Interestingly, *Pilegaard et al.* (2006) reveals an absence of a correlation between NO and N_2O and pH.

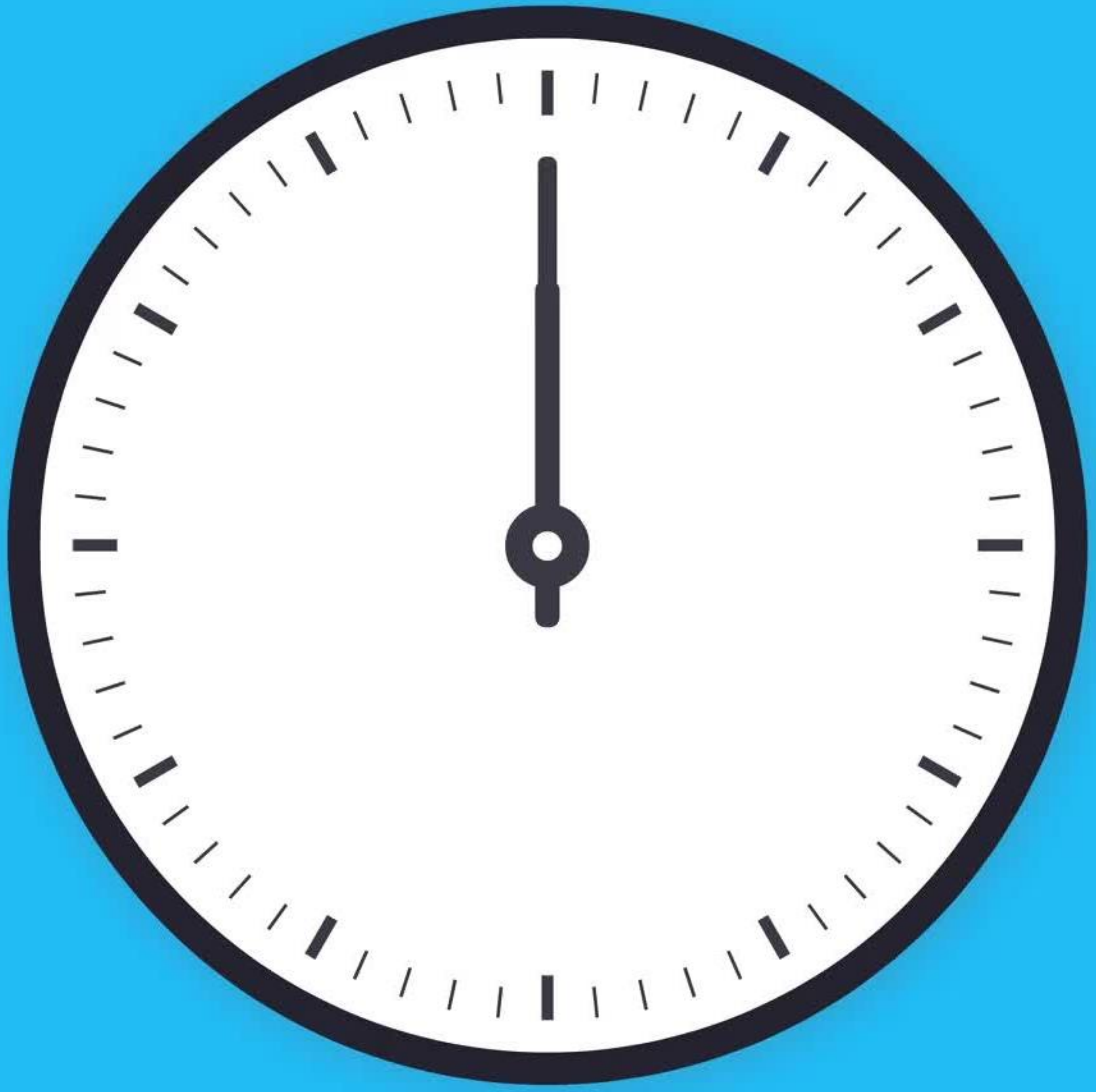
Soil nutrient availability (***N_{soil}***): the availability of C and N play an important role in GHG emissions from soil, as both of them are essential for microbial respiration. The interaction between different soil gases and nutrients can be summarized as follows:

- A negative correlation between ***N_{soil}*** (i.e. C/N) and N_2O emissions; the optimum value for releasing N_2O is C/N= 11 (Pilegaard et al. 2006)
- Low pH values and drought, besides C/N<20, N_2O emissions can be significantly affected (*Christiansen et al.* 2012)
- Application of N fertilization and conventional tillage increases N2O emissions (*Malhi et al.* 2006)
- Application of animal manure increases CO_2, and N_2O emissions, while a mixture of manure and inorganic fertilizer significantly increases CH_4 uptake (*Deng et al.* 2020)
- A positive correlation between ***N_{soil}*** (i.e. C/N) and CO_2, and CH_4 emissions; the optimum value for releasing N_2O is C/N= 11 (*Pilegaard et al.* 2006)

Land cover (*LC*): *LC* extends to include **vegetation type and age**, which directly affect soil respiration. Young trees are recorded to have high soil respiration, which decreases gradually with stand age; this point can be explained by the loss of young hair roots (*Oertel et al.* 2016). Mixed *LC* trees and grasslands, with variety of *C3* and *C4* have led to an increase in C-sinks in the soil (*Fornara and Tilman* 2008)

Land use and land use changes (*LULUCs*): changing the terrestrial ecosystem from one land use to another alters the carbon budget and leads to an increase in GHG emissions. For example, in the last few decades forest and peat lands have been transformed into agricultural land, which has led to a tremendous loss of soil carbon, estimated to be over 30% of the total carbon in the top soil layer (70 mm) (*DeGryze et al.* 2004).

Impact of climate change on the agricultural sector



It's time for group work.

Impact of climate change on the agricultural sector

- Climate change affects the agricultural sector both positively, by enhancing plant growth through increased CO2, and negatively, by causing extreme events like droughts and floods that reduce agricultural production.

Table 1. CC impacts on different agroecosystem components

Agroecosystem components	Factor	Evaluation	CC impacts
Crop	CO_2 enrichment	+	Enhanced photosynthesis especially for C3 crops (i.e. wheat, rice)
	Yield	-	Decrease in grain-filling duration, due to decrease in rainfall (R), as well as, increase in evapotranspiration and extreme events.
	Rainfed system	-	Reduction in R due to climate shifting
	Product quality	0	May be affected
	Pest and diseases	+	Climate shifting leads to rapid pathogen transmission and invasion of new areas.
Ecology	Biodiversity	_	Increase in temperature (T) and decrease in R amounts
Water	Irrigation	+	Increase in T and decrease in R amounts
	Runoff	+	Increase in extreme events
	Water balance	-	Change in climate variables
	Groundwater	-	Less rainfall
Soil	Organic matter (OM) content	-	Rapid mineralization of OM
	Plant residual decomposition	-	Elevated CO_2 leads to high C/N
	T_{soil}	-	Rapid mineralization of OM
Livestock	Feed and fodder	-	Decrease in production, water scarcity and increase in T
	Disease	+	Climate shifting
	Production	-	Heat stress
Fisheries	Breeding and migration	-	Increase in T
	Production	-	Increase in T

Climate adaptation

- Climate adaptation refers to the process of adjusting to the changing climate conditions and mitigating the negative impacts that result from those changes. Climate adaptation measures can include a range of actions such as:
- Implementing infrastructure that is more resilient to extreme weather events, such as building seawalls or improving drainage systems.
- Modifying agricultural practices to cope with changing precipitation and temperature patterns.
- Developing new drought-resistant crop varieties.
- Creating early warning systems to help people prepare for natural disasters such as hurricanes, floods or wildfires.
- Establishing new land use regulations that consider the potential impacts of climate change.

Climate mitigation

- Climate mitigation refers to actions taken to reduce the emissions of greenhouse gases into the atmosphere and limit the magnitude of future climate change. The primary objective of climate mitigation is to address the root causes of climate change by reducing greenhouse gas emissions.
- There are many ways to achieve climate mitigation. Some examples of mitigation measures include:

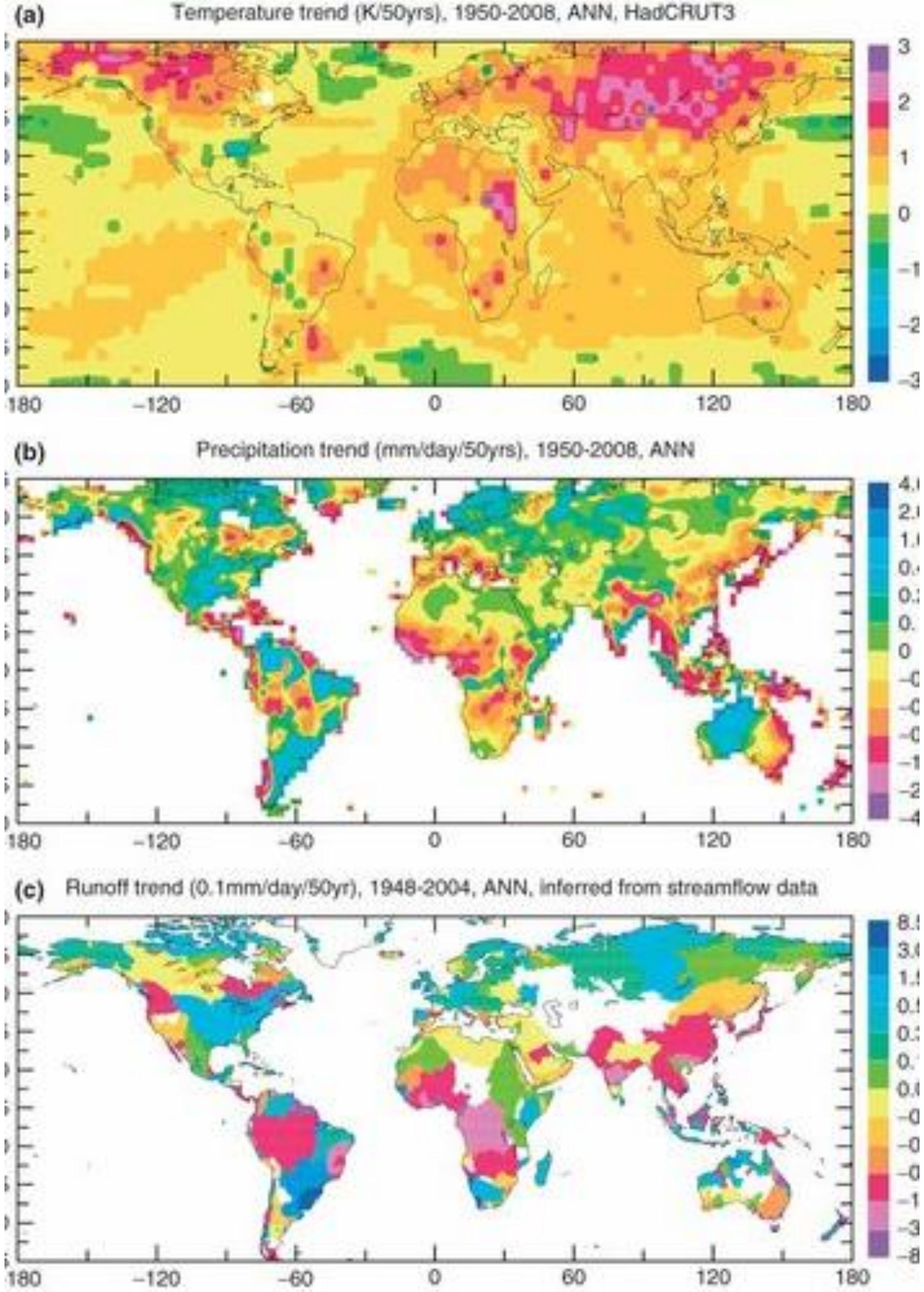
1. Implementing energy-efficient technologies in homes, buildings, and industries to reduce energy consumption and carbon emissions.
2. Expanding the use of renewable energy sources such as wind, solar, geothermal, and hydro power to replace fossil fuels.
3. Promoting the use of electric vehicles and improving public transportation systems to reduce greenhouse gas emissions from transportation.
4. Implementing carbon capture and storage technologies to capture carbon dioxide emissions from power plants and other industrial processes.
5. Encouraging lifestyle changes that reduce individual carbon footprints, such as reducing meat consumption, using public transportation or biking, and reducing energy consumption.

- The goal of climate mitigation is to limit the magnitude of future climate change and reduce its impacts on the planet and human societies.

2-5 Drought as an indicator of climate change

2-5 Drought as an indicator of climate change

- The IPCC reports indicate a warming trend with increased warm days, higher global temperatures by 1-3°C from 1950 to 2008, and rising Arctic permafrost temperatures by 2-4°C, leading to more intense and prolonged drought



- **Figure 8.** Trends in T(a), P(b), and runoff (c) between 1950 and 2008, as presented by *Dai (2011)*

- On a global scale, of all-natural disasters drought is reported to be the costliest one. Between 1900 and 2011 drought killed around 11 million people and badly affected approximately 2 billion people (Mohammed and Harsányi 2019; Ivits et al. 2014).
- Notably, the impact of drought has been amplified over the last decade (1999-2010) which has affected more than 900 million people (Spinoni et al., 2014).
- The average drought damages range between $ 6 and 8 billion per year in the USA alone Dai (2011) .
- Moreover, between 1949 and 1995 drought events cost China more than US $12 billion (Dai et al. 2020).

2.5.1. The definition of drought

The simple definition of drought is a significant decrease in precipitation below the average for a sustained period

However, an absence of a precise definition of drought in specific cases is an obstacle to tackling drought, and taking appropriate actions

Table 2. Criteria for drought definition by different international organizations

Organization	Criteria for drought definition	Reference
World Meteorological Organization	Rainfall deficiency for a continued period of time	WMO, (1986)
Secretary-General of the United Nations	Links between rainfall and land resource production systems	UN Secretariat General, (1994)
Food and Agriculture Organization	Links between soil moisture and crops failure	FAO, (1983)

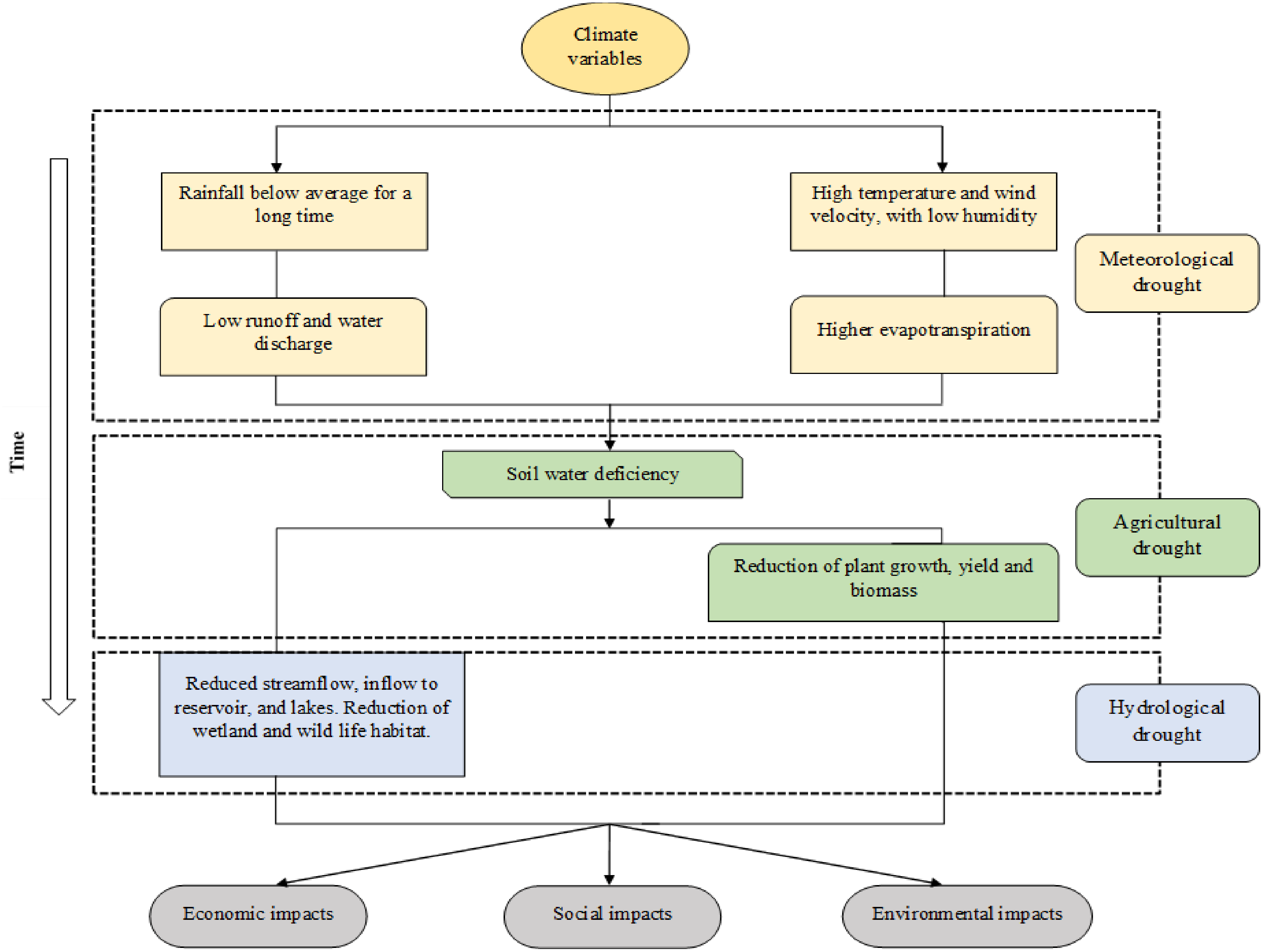


Figure 9. Drought classification and impacts (adapted from *Wilhite* (2000))

Drought indices

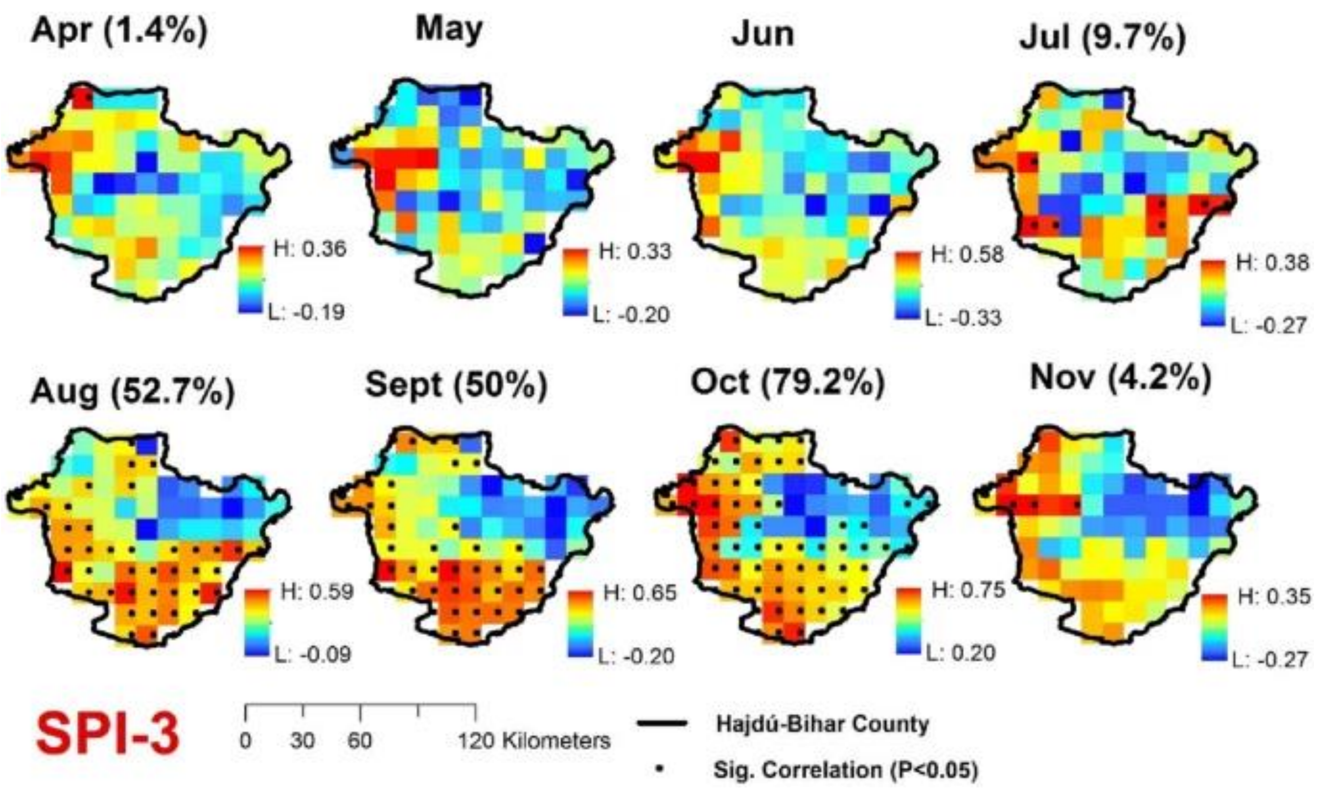
Drought indices	Abbreviation	Reference	Input parameters	Disadvantage	Application
Palmer drought severity index	PDSI	Palmer (1965)	• Rainfall, Temperature, Local water content	• Underestimation of Runoff. Responding slowly to dry spell evolution	China Iran Mongolian Plateau Europe
Standardized precipitation index	SPI	McKee et al. (1993)	• Rainfall	• Availability of monthly R data for a long period. Depends only on R and neglected other factors	Syria Hungary China Mongolian India
Standardized precipitation evapotranspiration index	SPEI	Vicente-Serrano et al. (2010)	• Rainfall, Temperature, (ET_0)	• Using Thornthwaite equation for calculating potential ET_0	China Mongolian Argentinian Turkey
Soil moisture deficit index	SMDI	Narasimhan, and Srinivasan (2005)	• Soil moisture Land cover Soil type	• Input data not easy to acquire	China Brazil
Vegetation condition index	VCI	Kogan, 1995	NOAA-AVHRR NDVI data	Not applicable in winter time	India China United States Chile India Greece

Drought and irrigation

- The need for irrigation in the agricultural sector is becoming increasingly important in the face of a changing climate. As the climate changes, many areas are experiencing more frequent and severe droughts, and changes in rainfall patterns. This can lead to reduced crop yields, and in some cases, crop failures.
- Irrigation can help mitigate the impact of these climate changes on agricultural production by providing a reliable source of water to crops. Irrigation can help farmers to maintain consistent crop yields, even during periods of drought or reduced rainfall. In addition, irrigation can be used to supplement water during periods of low rainfall, ensuring that crops have enough water to grow and mature.
- However, Overuse of irrigation can lead to problems such as soil salinization, and depletion of groundwater resources. Therefore, it is important to implement sustainable irrigation practices that take into account the availability and quality of water resources, soil conditions, and the specific needs of different crops.

Hungary and climate change:

- In central Europe, drought incidents have become more active and larger, correlated with raised temperatures and shortages of rainfall, as reported by many researchers, including *Bartholy et al.* (2013) in Hungary, *Kern et al.* (2016) in Central Europe, and *Cheval et al.* (2014) in Romania.
- As in other European countries, Hungary is subjected to CC, where drought episodes have started to hit Hungary regularly in the last few decades, causing diverse impacts in different sectors (*Csete et al.*, 2013, *Gálos et al.*, 2007). Interestingly, *its* projected that drought events would continue to hit Hungary until the end of the 21st century, with a special tendency in summer.
- Within this context, heatwave cycles were reported to have increased in the Carpathian Region (including Hungary), while cold waves were shorter and less frequent (*Spinoni et al.* 2015).



- *Mohammed et al.* (2019) reported that the drought in 2011 was the worst - especially in Siófok – during the reference period 1985-2016.
- Meanwhile, *Makra et al.* (2002) reported that over the last few decades, Hungary has witnessed drier conditions, comparing with the early years of the last century – i.e. between 1901 and 1940 - when wetter conditions were recorded. In that same context, *Szép et al.* (2005) highlighted that drier soil conditions were observed in the 20th century.

Coffee break

How to analyze drought?

Hands on:

Trend analysis by MK test

SPI calculation

Drought impact on crop yield

Trend analysis by MK test

The Mann-Kendall (MK) test is a statistical method used for trend analysis to detect trends in time series data. It is a non-parametric test that does not make assumptions about the distribution of the data and is therefore useful for analyzing datasets that do not follow a normal distribution.

The MK test works by comparing the rank order of data values at different time points. Specifically, it tests whether there is a monotonic trend (either increasing or decreasing) in the data over time. The test calculates a statistic called the MK statistic, which measures the difference between the number of increasing and decreasing data values.

If the MK statistic is positive, it indicates an increasing trend, while a negative MK statistic indicates a decreasing trend. A significance level (usually set at 0.05) is used to determine whether the trend is statistically significant or not. If the p-value is less than the significance level, the trend is considered statistically significant.

The MK test has many applications in environmental and climate research, where it is used to detect trends in variables such as temperature, precipitation, and river flow. By identifying trends in these variables, researchers can better understand the impact of climate change on different environmental systems and develop strategies for adapting to these changes.

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Table 5. Trends in Ag.D indices (SPI-6, SPEI-6) and sunflower production (kg/ha) across Hungary.

County	Code	SPI-6		SPEI-6		Sunflower	
		MK and β	p	MK and β	p	MK and β	p
Bács-Kiskun	BC	0.0005	0.05	-5×10^{-5}	0.83	+55.83	0
Baranya	BA	0.0002	0.32	-2×10^{-4}	0.40	+48.04	0
Békés	BE	0.0005	0.05	6×10^{-5}	0.79	+59.03	**<0.0001**
Borsod-Abaúj-Zemplén	BO	0.0005	0.06	7×10^{-5}	0.75	+75.19	**<0.0001**
Budapest	BU	0.0003	0.28	-3×10^{-4}	0.27	+70.28	0
Csongrád-Csanád	CS	0.0003	0.21	-1×10^{-4}	0.55	+32.18	**0.01**
Fejér	FE	0.0001	0.67	-4×10^{-4}	0.06	+47.99	**0.01**
Győr-Moson-Sopron	GY	0.0001	0.74	-5×10^{-4}	**0.03**	+38.33	**0.01**
Hajdú-Bihar	HB	0.0006	**0.01**	2×10^{-4}	0.46	+71.6	**<0.0001**
Heves	HE	0.0005	**0.02**	1×10^{-4}	0.60	+71.34	0
Jász-Nagykun-Szolnok	JN	0.0007	**0.00**	2×10^{-4}	0.44	+60	**<0.0001**
Komárom-Esztergom	KE	0.0003	0.21	-2×10^{-4}	0.26	+58.06	**<0.0001**
Nógrád	NO	0.0003	0.24	-1×10^{-4}	0.65	+65	**0.01**
Pest	PE	0.0003	0.16	-2×10^{-4}	0.48	+65.15	0
Somogy	SO	−0.0004	0.07	-8×10^{-4}	**0.00**	+61.46	0

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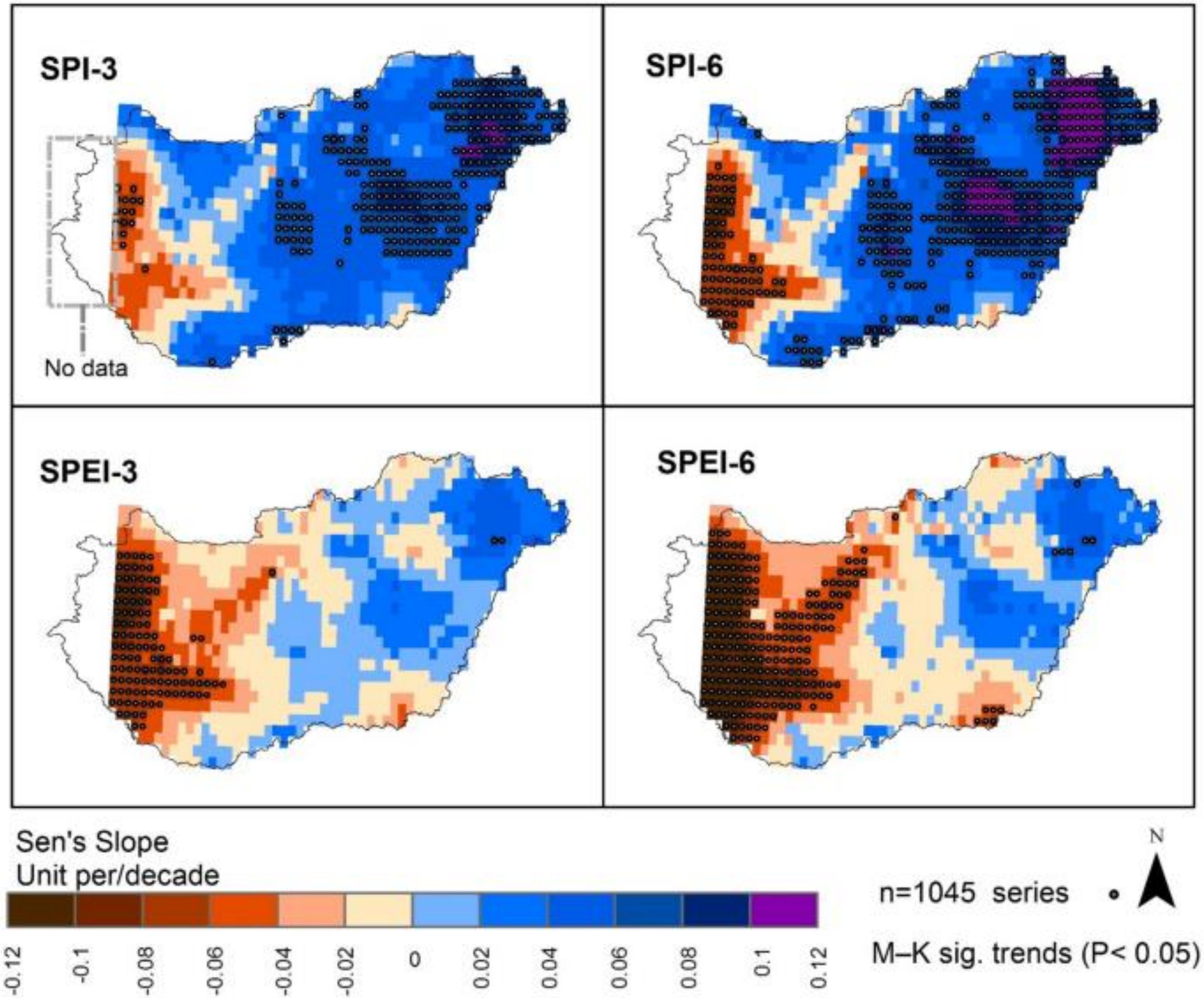

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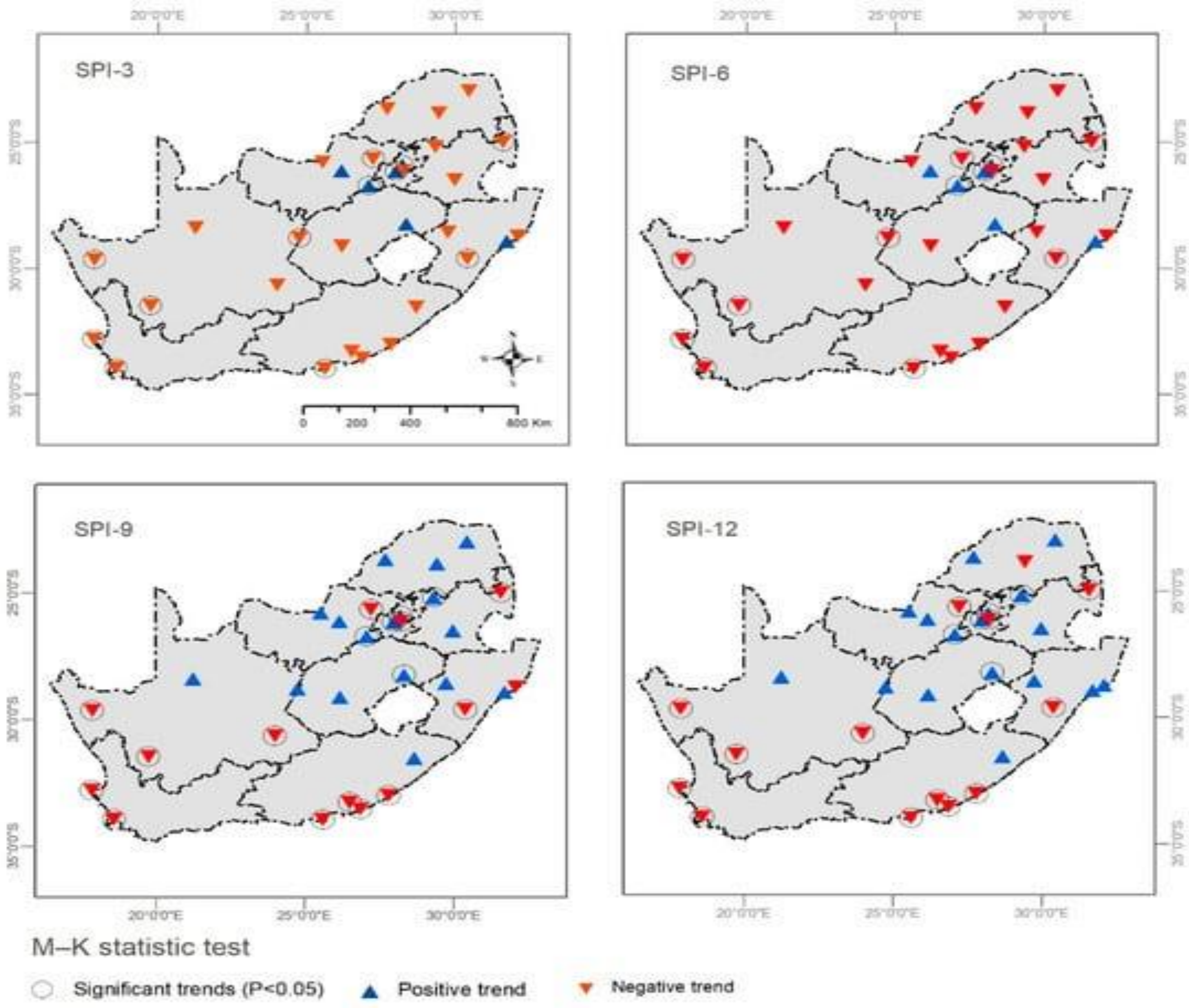

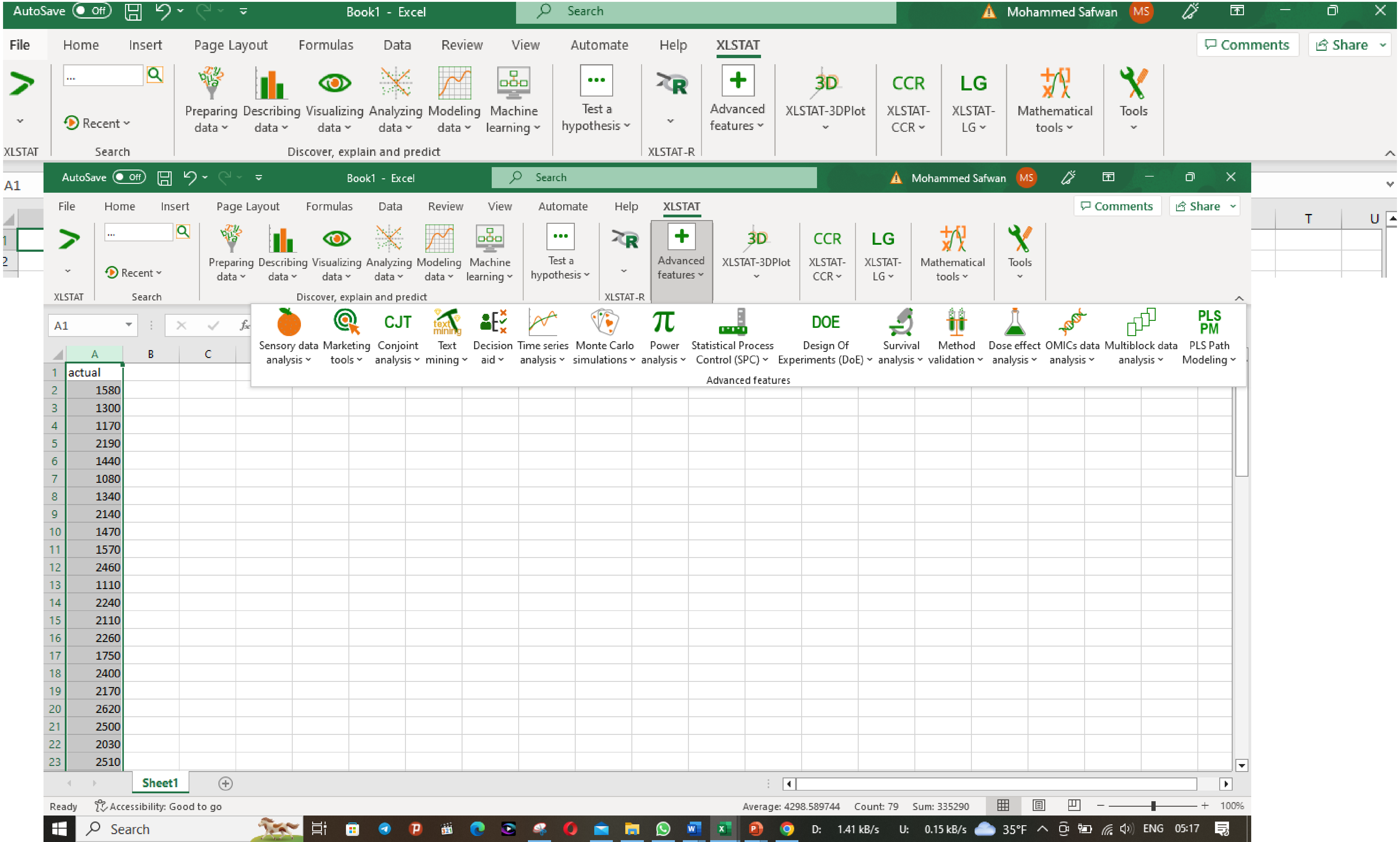
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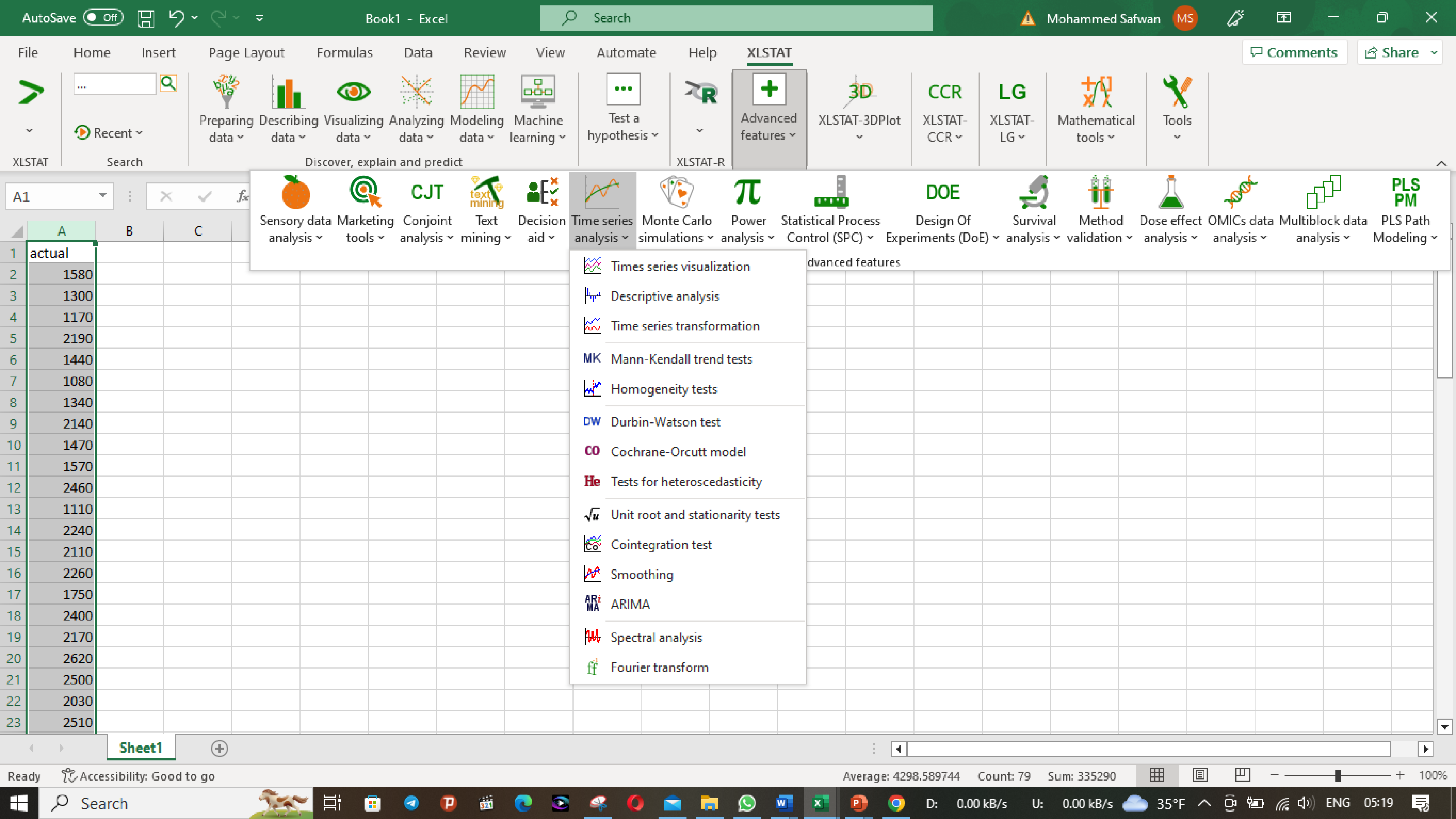
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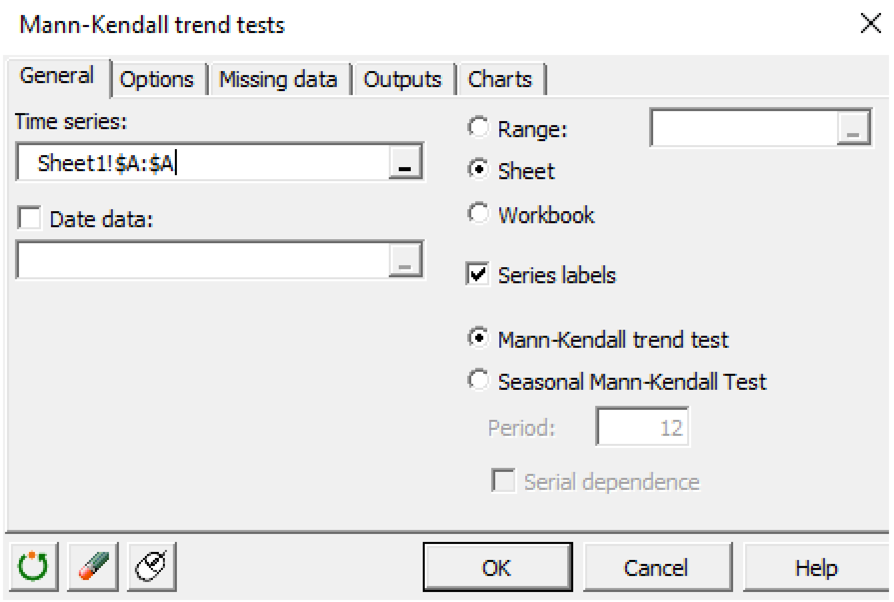
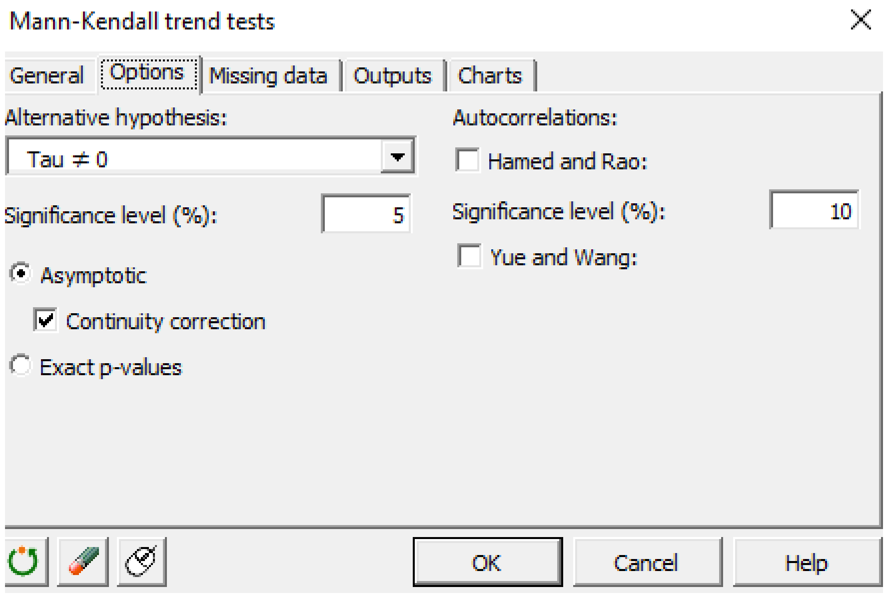
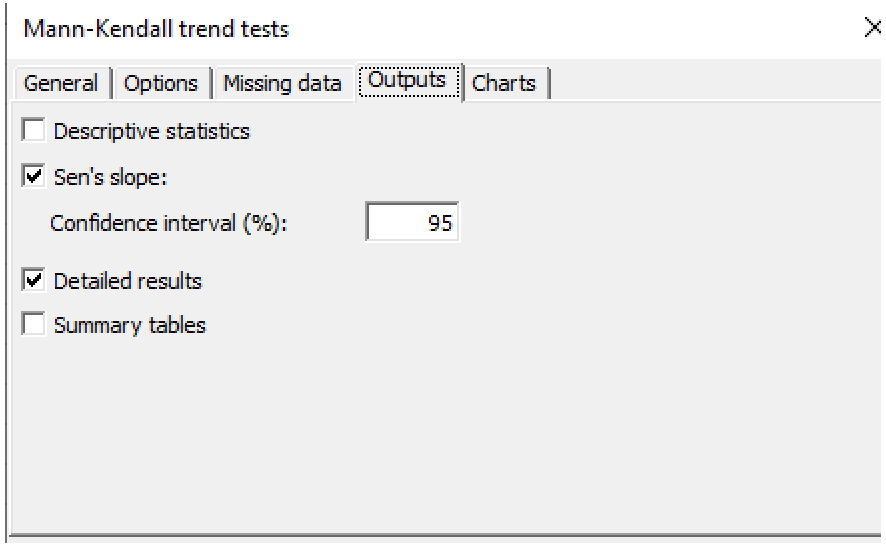
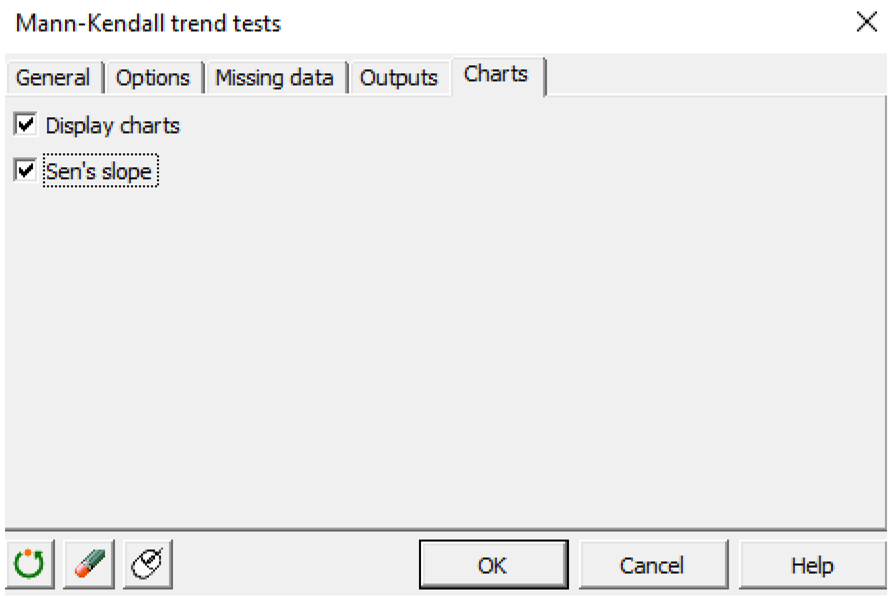
Homogeneity tests
Durbin-Watson test
Cochrane-Orcutt model
Tests for heteroscedasticity
Unit root and stationarity tests
Cointegration test
Smoothing
ARIMA
Spectral analysis
Fourier transform
A1
actual
1580
1300
1170
2190
1440
1080
1340
2140
1470
1570
2460
1110
2240
2110
2260
1750
2400
2170
2620
2500
2030
2510
Sheet1
Ready
Accessibility: Good to go
Average: 4298.589744
Count: 79
Sum: 335290
100%


Mann-Kendall trend tests
General
Options
Missing data
Outputs
Charts
Time series:
Sheet1!$A:$A
Date data:
Range:
Sheet
Workbook
Series labels
Mann-Kendall trend test
Seasonal Mann-Kendall Test
Period:
12
Serial dependence
OK
Cancel
Help


Mann-Kendall trend tests
General
Options
Missing data
Outputs
Charts
Alternative hypothesis:
Tau ≠ 0
Significance level (%):
5
Asymptotic
Continuity correction
Exact p-values
Autocorrelations:
Hamed and Rao:
Significance level (%):
10
Yue and Wang:
OK
Cancel
Help


Mann-Kendall trend tests
General
Options
Missing data
Outputs
Charts
Descriptive statistics
Sen's slope:
Confidence interval (%):
95
Detailed results
Summary tables


Mann-Kendall trend tests
General
Options
Missing data
Outputs
Charts
Display charts
Sen's slope
OK
Cancel
Help

Mann-Kendall trend test / Two-tailed test (actual):

Kendall's t	0.7201
S	2162.0000
Var(S)	#########
p-value (Tv	< 0.0001
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

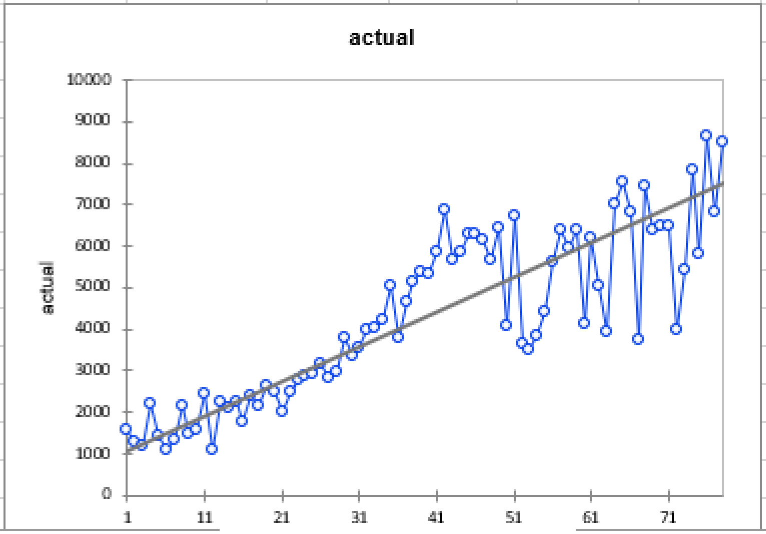
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

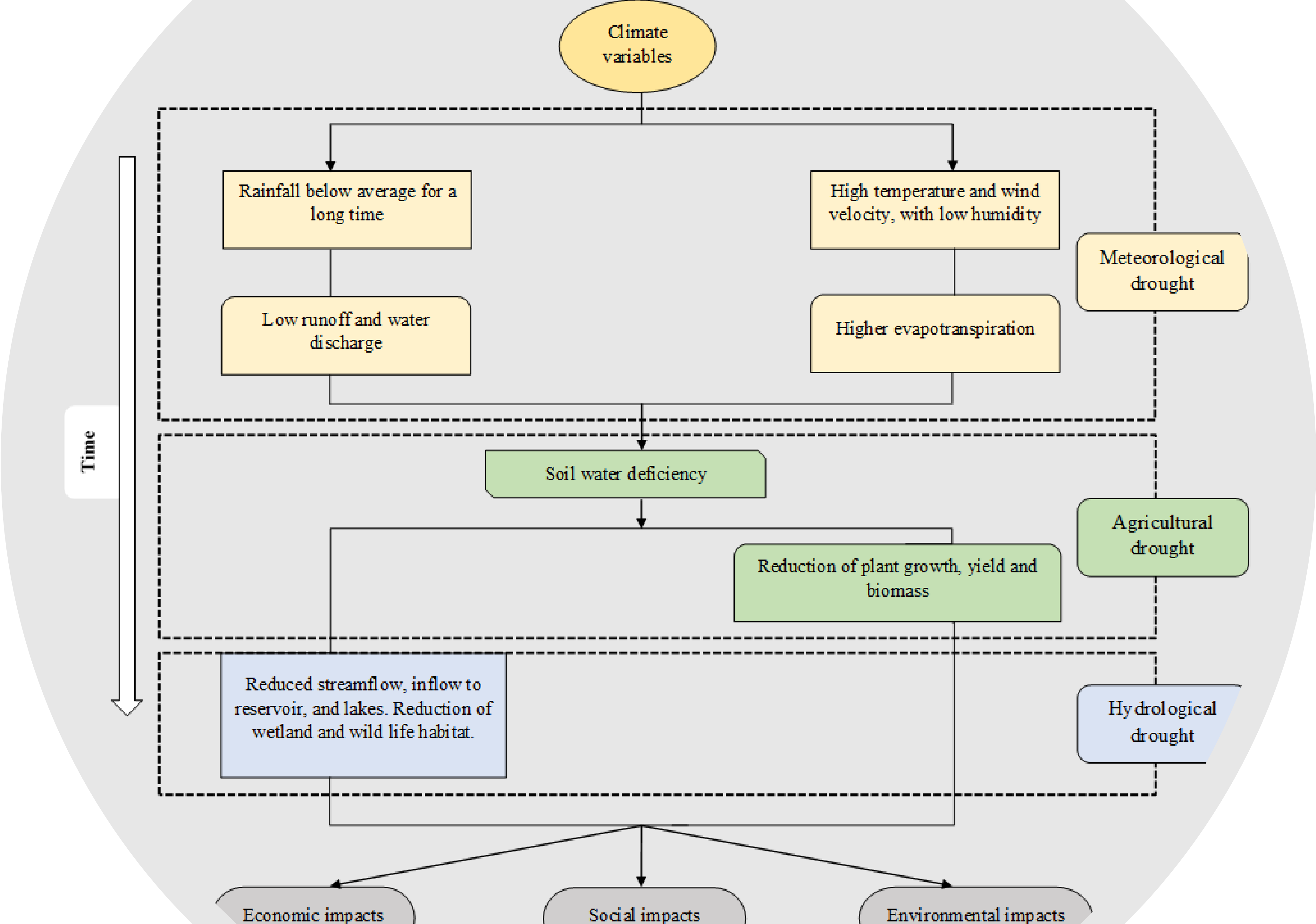
Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	er bound (9	er bound (95%)
Slope	83.8462	73.8095	94.3333
Intercept	991.1538	854.8205	########



Drought tracking: SPI


Climate variables
Rainfall below average for a long time
High temperature and wind velocity, with low humidity
Low runoff and water discharge
Higher evapotranspiration
Meteorological drought
Soil water deficiency
Reduction of plant growth, yield and biomass
Agricultural drought
Reduced streamflow, inflow to reservoir, and lakes. Reduction of wetland and wild life habitat.
Hydrological drought
Time
Economic impacts
Social impacts
Environmental impacts

Meteorological drought

- Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

Agricultural drought

- What factors contribute to agricultural drought and how does it impact crop growth and yield during different stages of development?

Agricultural drought

- Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil.
- A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity.
- Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. However, if topsoil moisture is sufficient for early growth requirements, deficiencies in subsoil moisture at this early stage may not affect final yield if subsoil moisture is replenished as the growing season progresses or if rainfall meets plant water needs.

Hydrological drought

- Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale.
- Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system.

Socioeconomic

- Socioeconomic definitions of drought associate the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. It differs from the types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts.

Ecological drought

- A more recent effort focuses on ecological drought, defined as "a prolonged and widespread deficit in naturally available water supplies — including changes in natural and managed hydrology — that create multiple stresses across ecosystems."

Drought indicators: the SPI and SPEI

- Although, precipitation is a critical indicator of the availability of water, but also both of precipitation and temperature together have an important role that influence in availability and stability of water. Therefore, they effect on the urban, agricultural, and ecosystems water supply, as well as, on agricultural production and forest stress, by control in the ratio of actual and potential evapotranspiration.
- A several parameters such as rainfall, temperature, soil moisture, streamflow, river discharge, vegetation condition, and ecosystem responses can be used as indicators of drought

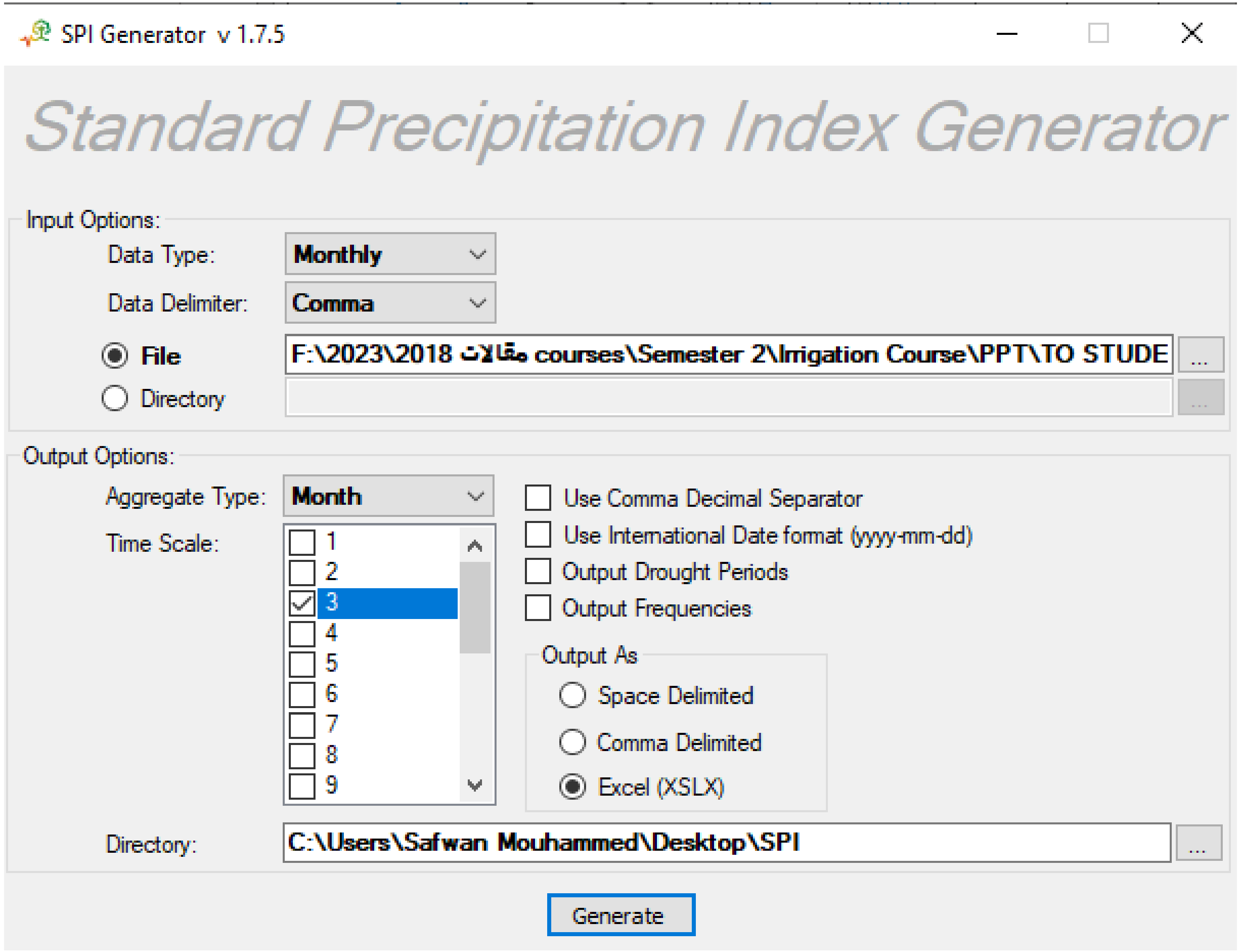
SPI/SPEI

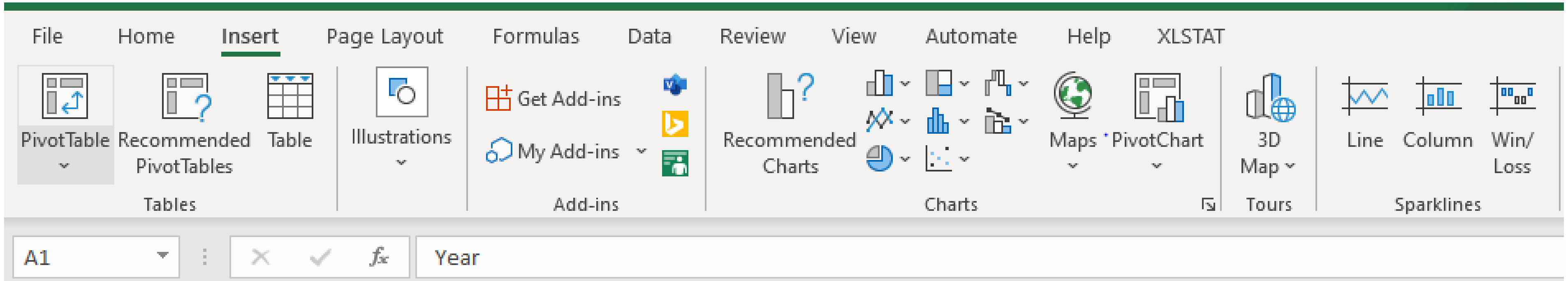
- The SPI is based only on monthly rainfall data; so, geographical and topographical differences are not considered. Meanwhile, SPEI is a newly improved index developed from the same background as SPI but based on rainfall and potential evapotranspiration (PET) (i.e. the monthly climatic water balance)
- However, both are statistical indices and can be calculated for any time scale (i.e. for 1-, 3-, 6-, 9-, or 12-month time scales). The choice of the time scale is, in practice, dependent on the goal of the study. If it is related to agriculture drought then a 1-, 3-, or 6-month scale should be chosen, while a 9-, or 12-month scale is used for monitoring hydrological drought (Tan et al. 2015).
- SPI and SPEI values for drought can be classified, as can be seen in Table 1. The positive values indicate wet conditions, while negative values indicate drought conditions (less than median rainfall) (Bordi & Sutera, 2001).

Interestingly, the SPEI is superior to the SPI in term of drought characterization and climate change monitoring due to the fact that the SPEI takes into consideration both temperature and soil moisture content (used to compute PET) .

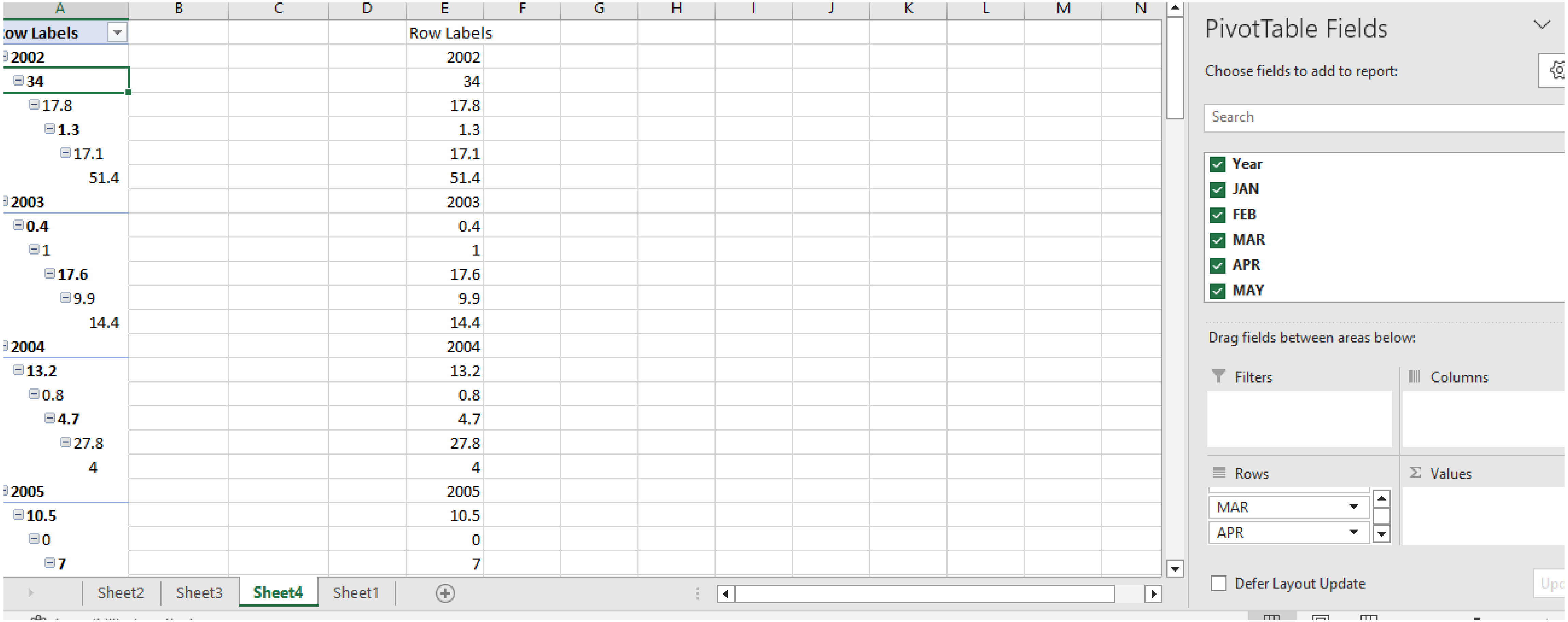
Tab. I Drought categories based on Agnew's scheme (2000).

SPI and SPEI values	Drought category
> 0	No drought
0 to -0.5	Mild drought
-0.5 to -0.84	Moderate drought
-0.84 to -1.28	Severe drought
-1.28 to -1.65	Extreme drought
1.65- >	Very extreme drought


SPI Generator v 1.7.5
Standard Precipitation Index Generator
Input Options:
Data Type:
Monthly
Data Delimiter:
Comma
File
F:\2023\2018 مقالات courses\Semester 2\Irrigation Course\PPT\TO STUDE
Directory
Output Options:
Aggregate Type:
Month
Time Scale:
1
2
3
4
5
6
7
8
9
Use Comma Decimal Separator
Use International Date format (yyyy-mm-dd)
Output Drought Periods
Output Frequencies
Output As
Space Delimited
Comma Delimited
Excel (XSLX)
Directory:
C:\Users\Safwan Mouhammed\Desktop\SPI
Generate

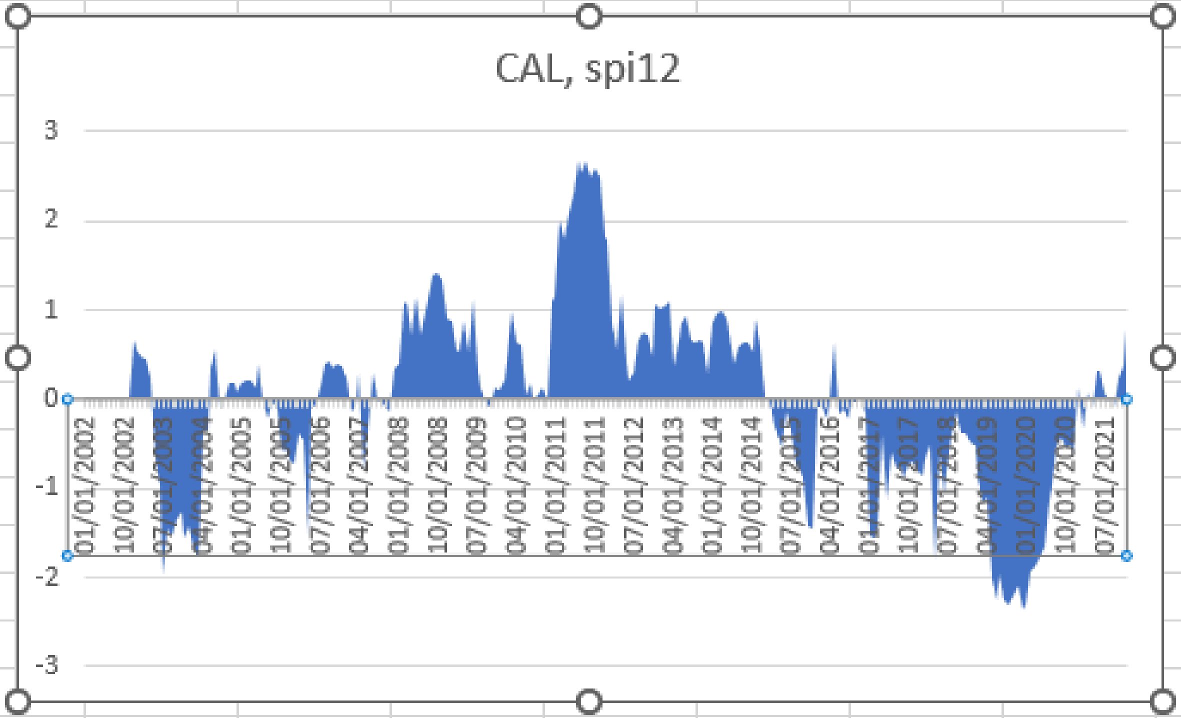


	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2	2002	34	17.8	1.3	17.1	51.4	28.2	44.1	48.5	16.5	18.1	4	27.3
3	2003	0.4	1	17.6	9.9	14.4	7	9.8	80.8	24.8	6.1	2.8	14.6
4	2004	13.2	0.8	4.7	27.8	4	50.5	36.7	27.7	9.5	45	3.3	1.4
5	2005	10.5	0	7	19.5	33.4	73.1	4.4	44.3	16.7	1.5	5.2	0
6	2006	0	2.6	3.8	12.5	93.4	10	48.8	34.4	18	20	8	3
7	2007	0	26.5	12.5	51.4	24.6	103.7	36.1	73	11.3	0	15	13.4
8	2008	2.4	28.8	2.2	2.8	19.2	58.4	74	29.8	40.8	6	3.4	6
9	2009	1	0.6	0	13.2	29.2	39.4	65.8	37	23.6	2	42.4	5.4
10	2010	1.8	9.6	1.6	7.8	61.8	35.8	18.8	19.8	20.6	29.2	9.6	20.6
11	2011	0.8	0	9.4	7.8	15.6	28.8	21.4	39.6	6.2	7.6	8.6	8
12	2012	1.2	2.8	8.2	16.8	16.6	44.2	44	49.8	16.2	6	1.6	1.2
13	2013	3.4	11.2	10.2	14.4	14	43.4	41	63.8	16.2	2.4	1.2	2.2
14	2014	17.6	1.4	31.8	10	24.6	55.2	43.6	35	4.4	0.8	18	0
15	2015	7.4	0	1.8	2.4	10	24.8	23.4	6.8	10	0.6	3.2	2.2
16	2016	15.8	0.4	9.2	15.8	2.4	59.8	42.8	21.4	26.8	3.2	1.2	9.6
17	2017	0.4	0	2.4	6.4	8.6	36.2	26	26.6	13.6	10.8	13.4	1.4
18	2018	1	2.4	9	15	38.6	52.8	36.3	24.8	34.6	0.6	1.4	14.6
19	2019	4.8	0	16.6	12.2	12.4	45.6	29	12.8	11.6	8.2	0	14
20	2020	2.6	1	1.4	8.8	20.8	42.6	57.4	28	14.4	6.6	13.4	1.8
21	2021	0.4	6.2	8.4	1.2	49	52.6	42.6	65.2	5.4	22.4	18.4	18



A B C D E F G H I J K L M N
ow Labels
2002
34
17.8
1.3
17.1
51.4
2003
0.4
1
17.6
9.9
14.4
2004
13.2
0.8
4.7
27.8
4
2005
10.5
0
7
Row Labels
2002
34
17.8
1.3
17.1
51.4
2003
0.4
1
17.6
9.9
14.4
2004
13.2
0.8
4.7
27.8
4
2005
10.5
0
7
Sheet2
Sheet3
Sheet4
Sheet1
PivotTable Fields
Choose fields to add to report:
Search
Year
JAN
FEB
MAR
APR
MAY
Drag fields between areas below:
Filters
Columns
Rows
Values
MAR
APR
Defer Layout Update

A	B	C	D
CAL,			
date	spi3	spi12	
01/01/200	0	0	0
02/01/200	0	0	0
03/01/200	0.08	0	0
04/01/200	0.05	0	0
05/01/200	0.92	0	0
06/01/200	0.38	0	0
07/01/200	0.98	0	0
08/01/200	0.63	0	0
09/01/200	1.49	0	0
10/01/200	0.92	0	0
11/01/200	0.35	0	0
12/01/200	-0.01	0.66	0.66
01/01/200	-0.43	0.57	0.57
02/01/200	-0.48	0.47	0.47
03/01/200	-0.7	0.45	0.45
04/01/200	-1.01	0.23	0.23
05/01/200	-1.44	-0.67	-0.67
06/01/200	-3.01	-0.96	-0.96
07/01/200	-3.27	-1.96	-1.96
08/01/200	-0.84	-1.45	-1.45
09/01/200	0.37	-1.52	-1.52



Impact of agricultural drought evolution on crop production

SYRS

- Crop production has recently witnessed a remarkable increase , because of the adaptation of modern agricultural technology. Therefore, to remove the bias attributed to non-climatic factors, the yield data were detrended using simple linear regression model.

- Studies have shown that by detrending and transforming yield data using the Standardized Yield Residuals Series (SYRS) (mean=0, standard deviation=1), the effects of non-climatic factors on agricultural production can be eliminated.

- The Standardized Yield Residuals Series (SYRS) was calculated using the formular in equation (3):

- $$\boldsymbol{SYRS_{cr,c,y,t}} = \frac{(\boldsymbol{\xi_{cr,c,y,t}} - \boldsymbol{\beta_{cr,c,y,t}})}{\boldsymbol{\Omega_{c,s,y,t}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\mathbf{3}$$

- where $\boldsymbol{c}$: crop, $\boldsymbol{c}$: county, $\boldsymbol{y}$: year, $\boldsymbol{t}$: timescale, $\boldsymbol{SYRS_{cr,c,y,t}}$: Standardized Yield Residual Series, $\boldsymbol{\xi_{cr,c,y,t}}$: standardize residual from the LGM (detrended), $\beta^{T}_{c,s,y}$: mean of $\xi_{cr,c,y,t}$, $\Omega_{c,s,y,t}$: standard deviation of $\xi_{cr,c,y,t}$. The categories of the SYRS are presented in Table 2

Table 2. SYRS classification

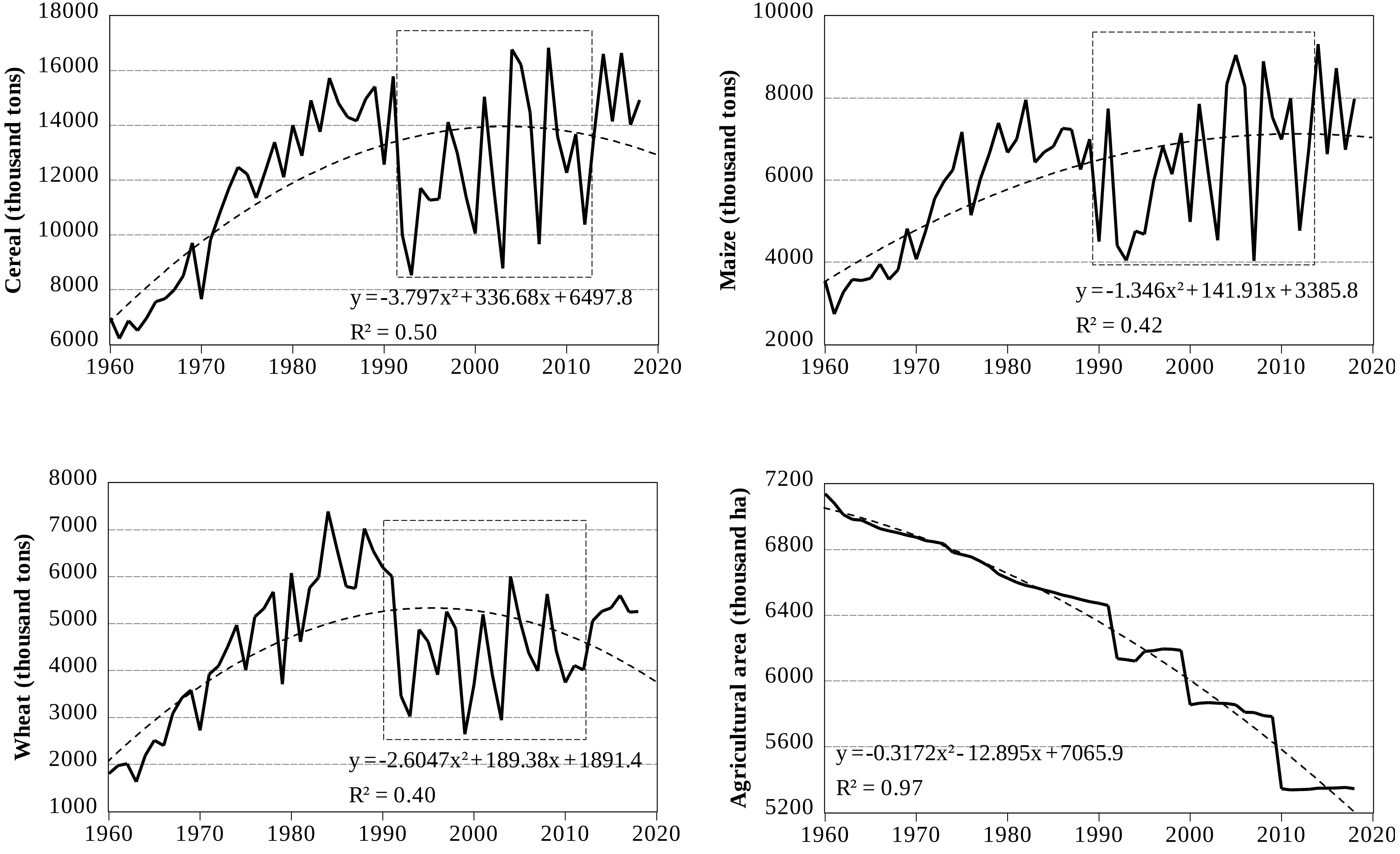
Yield	$\mathbf{SYRS}_{c,r,y,t}$
Normal	−0.5 < SYRS ≤ 0.5
Mild losses	−0.5 < SYRS ≤ −1.0
Moderate losses	−1.0 < SYRS ≤ −1.5
High losses	−1.5 < SYRS < −2.0
Extreme losses	SYRS ≤ −2.0

CDRF

- To highlight the impact of agricultural drought (SPI & SPEI-3, -6) on crop yield, the crop-drought resilient factor (CDRF) is recommended.
- The CDRF refers to a crop's ability to withstand external stresses (such as drought) while maintaining its structure and functions [18].
- The *CDRF* was calculated following equation (4) [18,89,90].
- $$\boldsymbol{CDRF = \frac{d_{dr}}{d_{dt}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{4}$$
- Hence, $\boldsymbol{d_{dr}}$ donates yield value in the driest year (growing cycle) during the monitoring period at regional scale, while $\boldsymbol{d_{dt}}$ refers to detrended yield value in the same year. **Table 3** shows the CDRF classification. To obtain the driest year, the average gridded points for SPI-3, -6 & SPEI-3, -6 values that covered each county was calculated, then the lowest value (in each county) was highlighted, then the corresponding year was chosen for CDRF calculation.

Table 3. Classification of the CDRF value

Crop yield resilience to drought	CYR_T value
Resilient	CDRF> 1
Slightly non-resilient	0.9 < CDRF< 1
Moderately non-resilient	0.8 < CDRF< 0.9
Severely non-resilient	CDRF< 0.8


Cereal (thousand tons)
y = -3.797x² + 336.68x + 6497.8
R² = 0.50
Maize (thousand tons)
y = -1.346x² + 141.91x + 3385.8
R² = 0.42
Wheat (thousand tons)
y = -2.6047x² + 189.38x + 1891.4
R² = 0.40
Agricultural area (thousand ha)
y = -0.3172x² - 12.895x + 7065.9
R² = 0.97

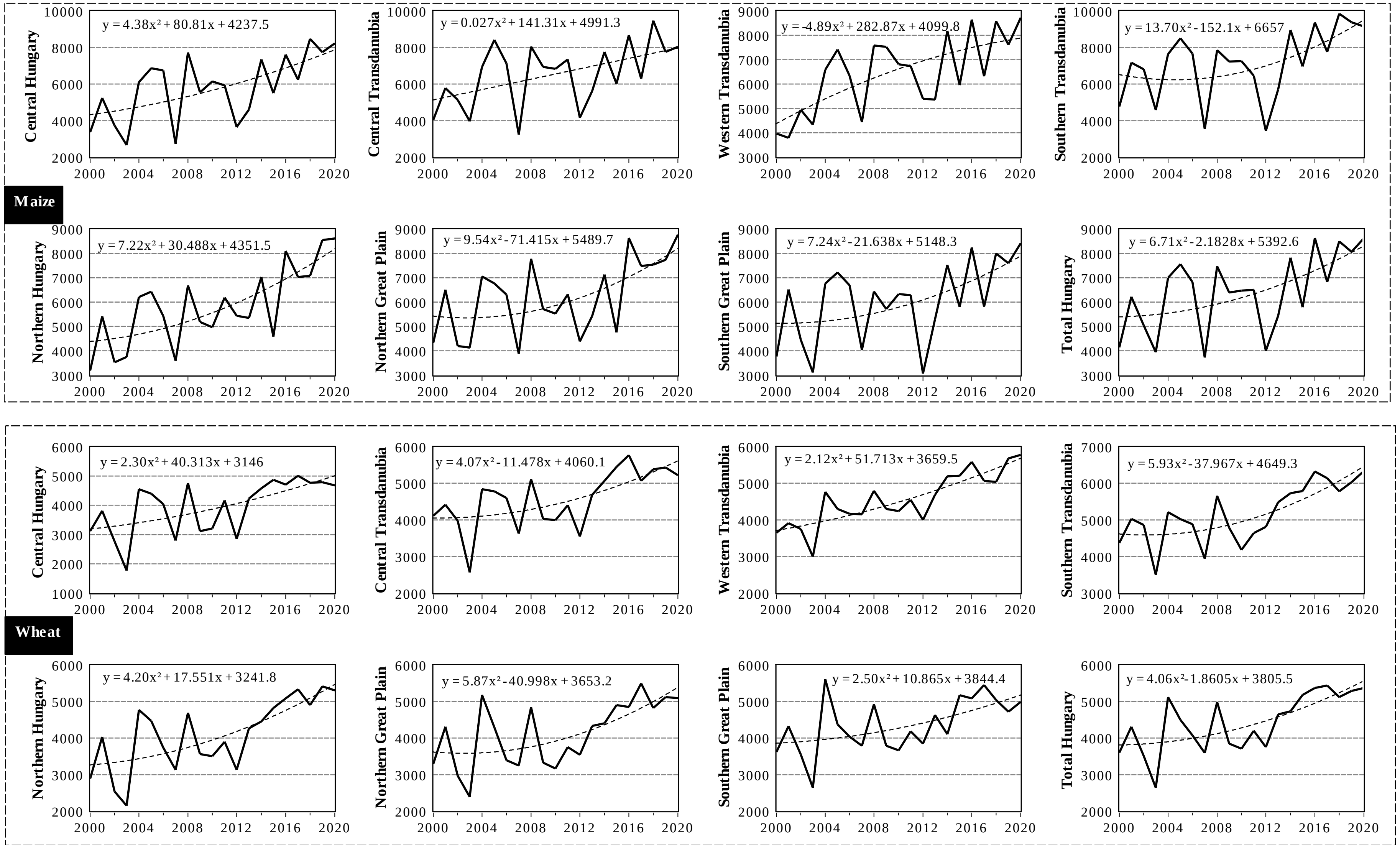
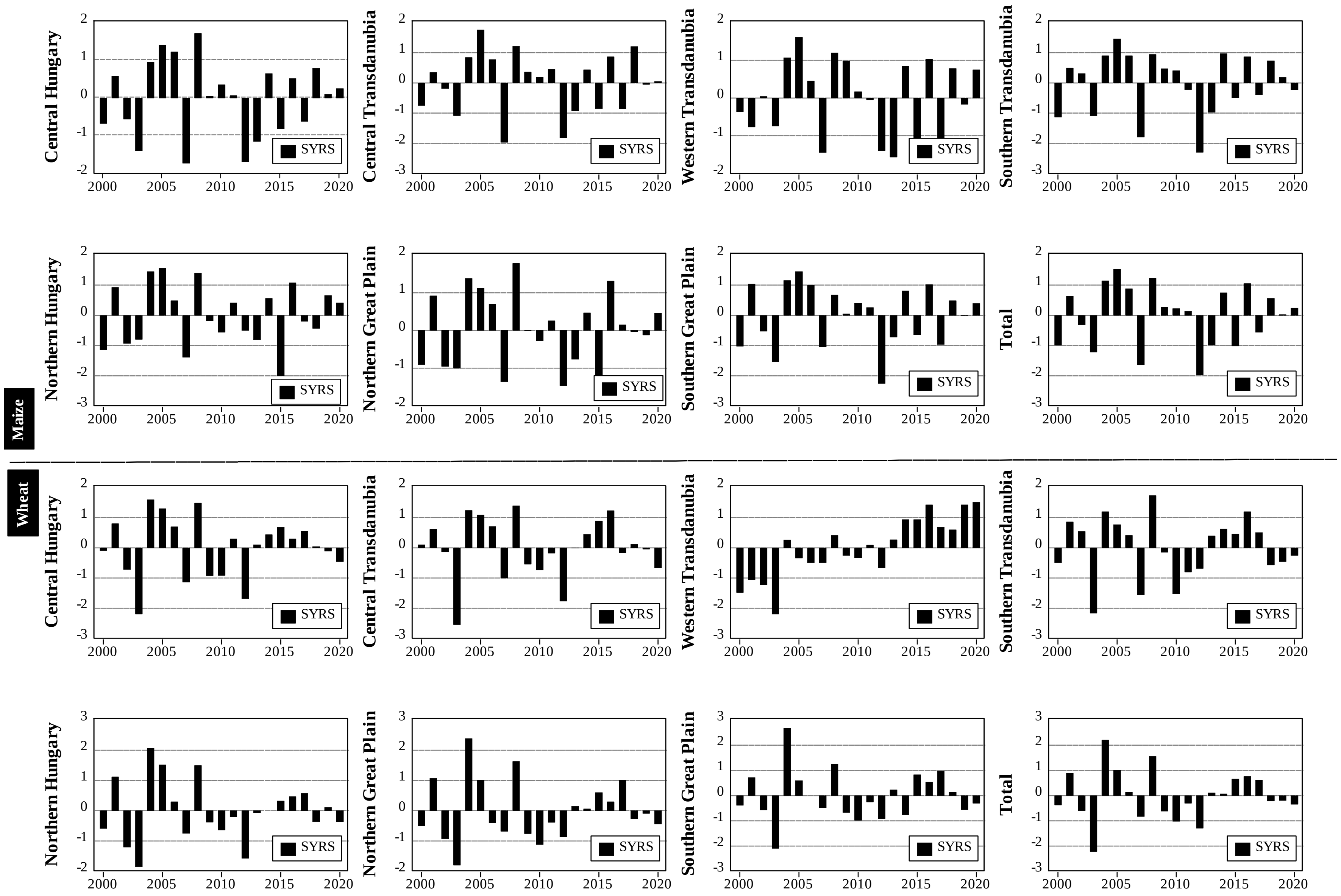
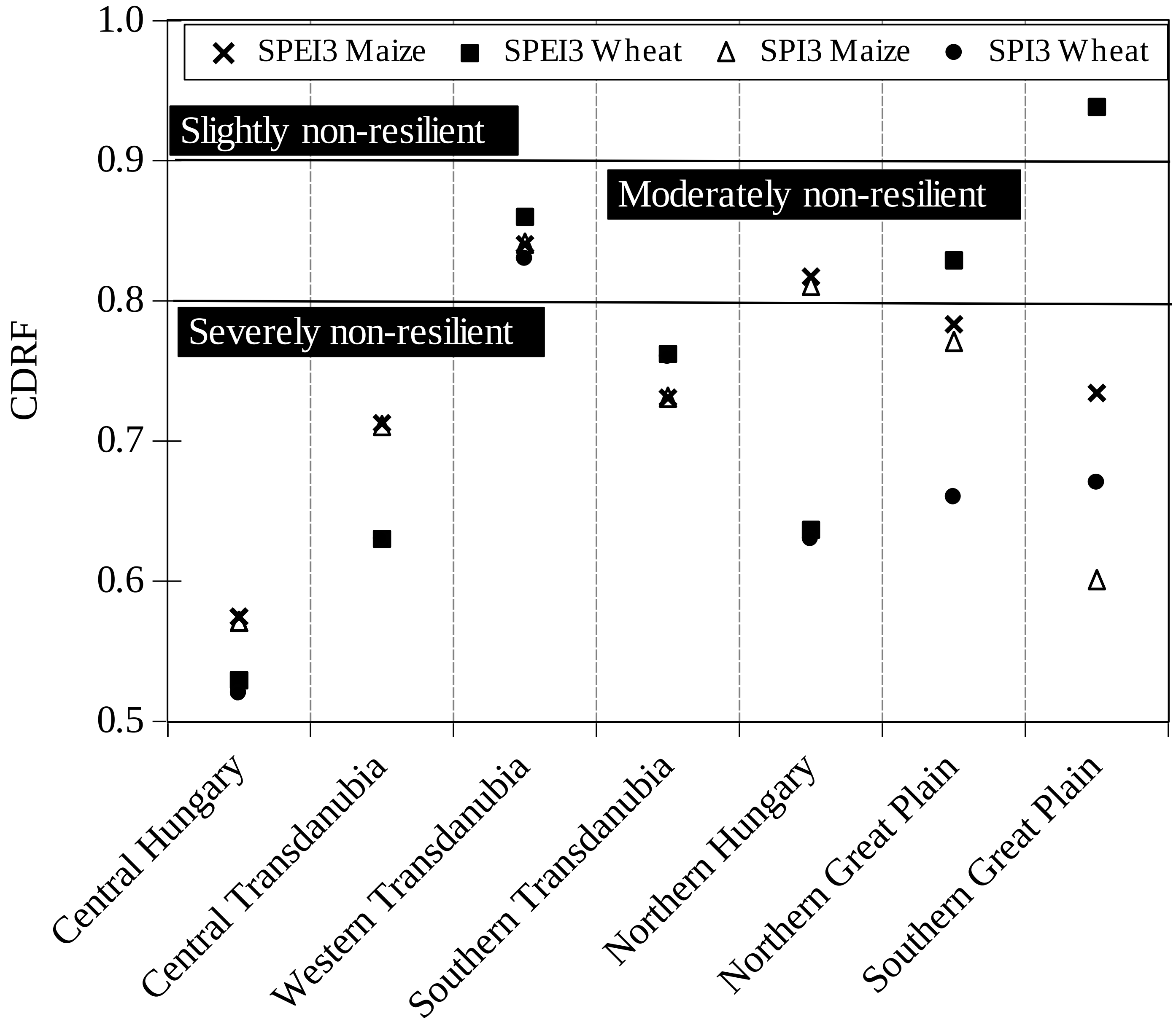


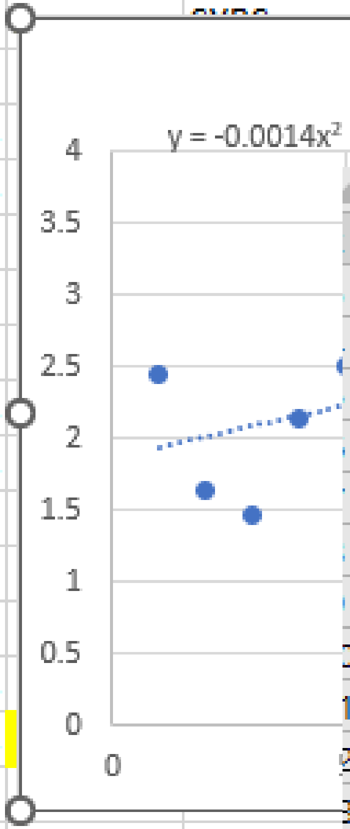
Fig. 9. Maize and wheat yields (kg/ha) across Hungarian regions (2000-2020) (Figure was generated


Maize
Wheat
Central Hungary
Central Transdanubia
Western Transdanubia
Southern Transdanubia
Northern Hungary
Northern Great Plain
Southern Great Plain
Total
SYRS
2000
2005
2010
2015
2020

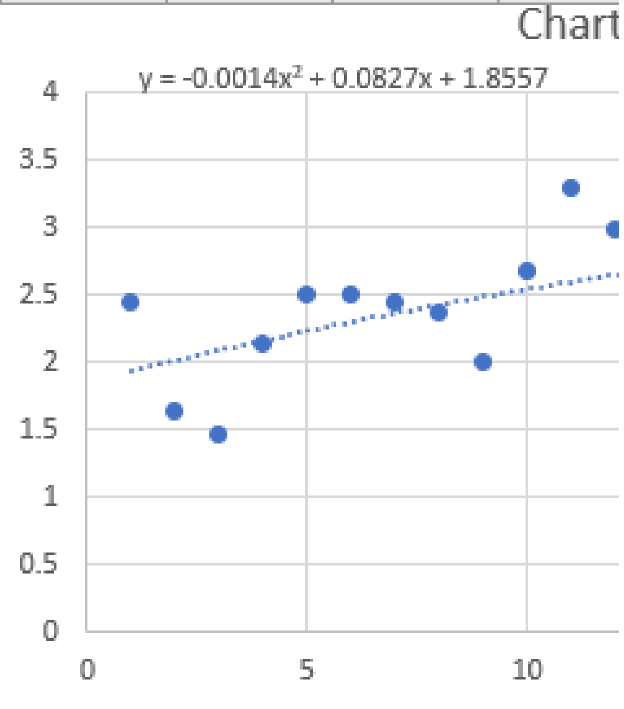


SPEI3 Maize
SPEI3 Wheat
SPI3 Maize
SPI3 Wheat
Slightly non-resilient
Moderately non-resilient
Severely non-resilient
CDRF
1.0
0.9
0.8
0.7
0.6
0.5
Central Hungary
Central Transdanubia
Western Transdanubia
Southern Transdanubia
Northern Hungary
Northern Great Plain
Southern Great Plain

y	Noord-Kaap	Py		
1	2.45	1.9286		
2	1.63	2.0044		
3	1.47	2.0774		
4	2.14	2.1476		
5	2.50	2.215		
6	2.50	2.2796		
7	2.46	2.3414		
8	2.38	2.4004		
9	2.00	2.4566		
10	2.68	2.51		
11	3.30	2.5606		
12	2.99	2.6084		
13	2.90	2.6534		
14	2.25	2.6956		
15	3.40	2.735	0.67	1.25
16	1.80	2.7716	-0.97	-2.00
17	2.80	2.8054	-0.01	-0.08
18	2.00	2.8364	-0.84	-1.74
19	3.38	2.8646	0.52	0.96



A	B	C	D	E	F	G	H	I
1	2.45	=-0.0014*(A2)^2+0.08*A2+1.85						
2	1.63	2.0044	-0.37	-0.82				
3	1.47	2.0774	-0.61	-1.28				
4	2.14	2.1476	-0.01	-0.10				
5	2.50	2.215	0.29	0.49				
6	2.50	2.2796	0.22	0.36				
7	2.46	2.3414	0.12	0.16				
8	2.38	2.4004	-0.02	-0.11				
9	2.00	2.4566	-0.46	-0.98				
10	2.68	2.51	0.17	0.26				
11	3.30	2.5606	0.74	1.39				
12	2.99	2.6084	0.39	0.69				
13	2.90	2.6534	0.25	0.42				
14	2.25	2.6956	-0.45	-0.96				
15	3.40	2.735	0.67	1.25	2016	0.79	0.58	0.8
16	1.80	2.7716	-0.97	-2.00	2017	-0.6575	-0.345	-0.
17	2.80	2.8054	-0.01	-0.08	2018	-0.55	-0.645	-0.
18	2.00	2.8364	-0.84	-1.74	2019	-0.8525	-0.3975	-0.64
19	3.38	2.8646	0.52	0.96	2020	-0.865	0.135	-0.
20	3.50	2.89	0.61	1.14	2021	0.4775	-0.3875	0.47
			0.03728					
			0.503443					



y	Noord-Kaap	Py	res
1	2.45	1.9286	=B2-C2
2	1.63	2.0044	-0.37
3	1.47	2.0774	-0.61
4	2.14	2.1476	-0.01
5	2.50	2.215	0.29
6	2.50	2.2796	0.22
7	2.46	2.3414	0.12
8	2.38	2.4004	-0.02
9	2.00	2.4566	-0.46
10	2.68	2.51	0.17
11	3.30	2.5606	0.74
12	2.99	2.6084	0.39
13	2.90	2.6534	0.25
14	2.25	2.6956	-0.45
15	3.40	2.735	0.67
16	1.80	2.7716	-0.97
17	2.80	2.8054	-0.01
18	2.00	2.8364	-0.84
19	3.38	2.8646	0.52

y	Noord-Kaap	Py	res	SYRS
1	2.45	1.9286	0.52	0.96
2	1.63	2.0044	-0.37	-0.82
3	1.47	2.0774	-0.61	-1.28
4	2.14	2.1476	-0.01	-0.10
5	2.50	2.215	0.29	0.49
6	2.50	2.2796	0.22	0.36
7	2.46	2.3414	0.12	0.16
8	2.38	2.4004	-0.02	-0.11
9	2.00	2.4566	-0.46	-0.98
10	2.68	2.51	0.17	0.26
11	3.30	2.5606	0.74	1.39
12	2.99	2.6084	0.39	0.69
13	2.90	2.6534	0.25	0.42
14	2.25	2.6956	-0.45	-0.96
15	3.40	2.735	0.67	1.25
16	1.80	2.7716	-0.97	-2.00
17	2.80	2.8054	-0.01	-0.08
18	2.00	2.8364	-0.84	-1.74
19	3.38	2.8646	0.52	0.96

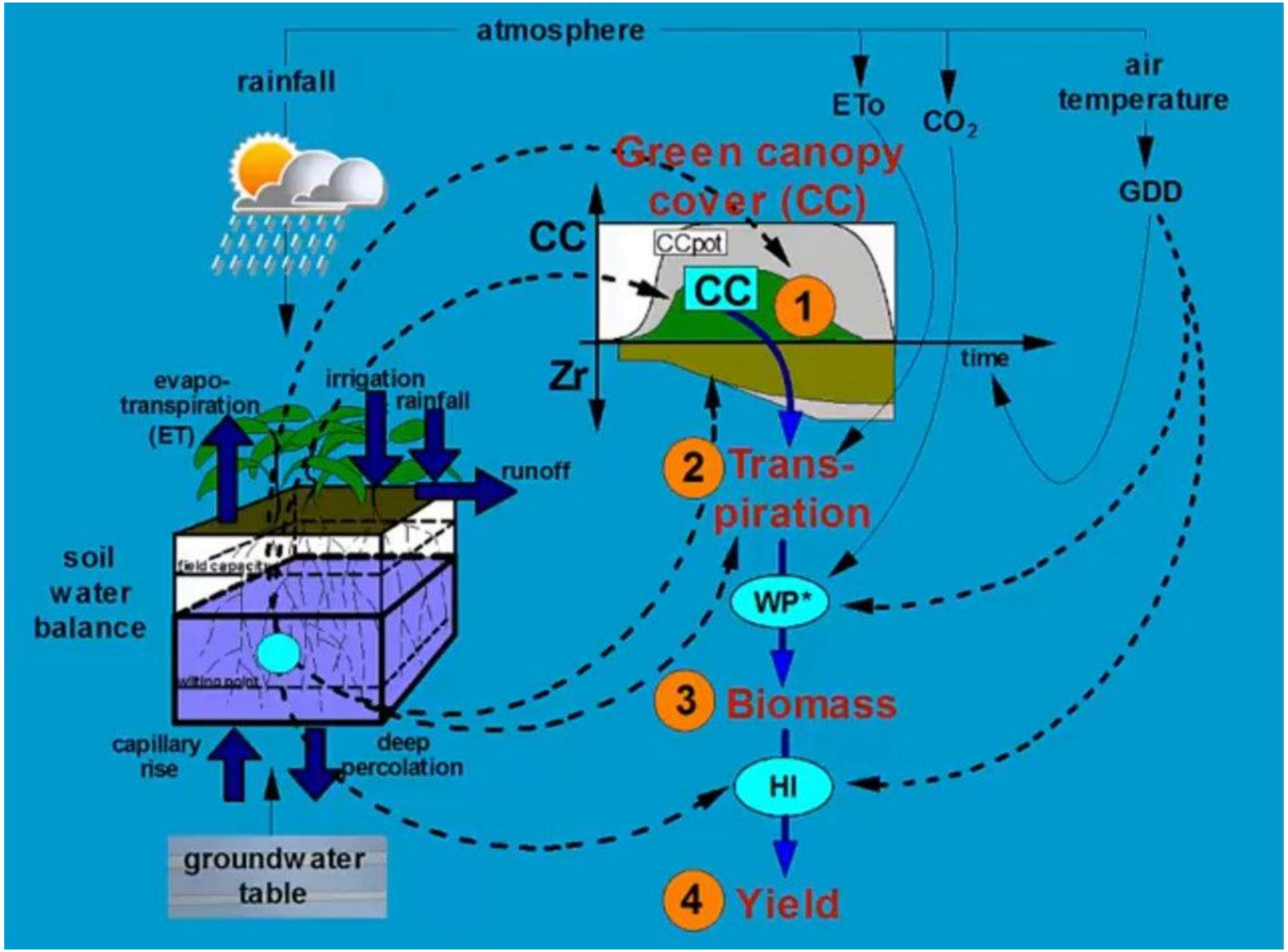
y	Noord-Kaap	Py	res	SYRS
1	2.45	1.9286	0.52	=(D2-D$22
2	1.63	2.0044	-0.37	-0.82
3	1.47	2.0774	-0.61	-1.28
4	2.14	2.1476	-0.01	-0.10
5	2.50	2.215	0.29	0.49
6	2.50	2.2796	0.22	0.36
7	2.46	2.3414	0.12	0.16
8	2.38	2.4004	-0.02	-0.11
9	2.00	2.4566	-0.46	-0.98
10	2.68	2.51	0.17	0.26
11	3.30	2.5606	0.74	1.39
12	2.99	2.6084	0.39	0.69
13	2.90	2.6534	0.25	0.42
14	2.25	2.6956	-0.45	-0.96
15	3.40	2.735	0.67	1.25
16	1.80	2.7716	-0.97	-2.00
17	2.80	2.8054	-0.01	-0.08
18	2.00	2.8364	-0.84	-1.74
19	3.38	2.8646	0.52	0.96
20	3.50	2.89	0.61	1.14
			0.03728	
			0.50344	

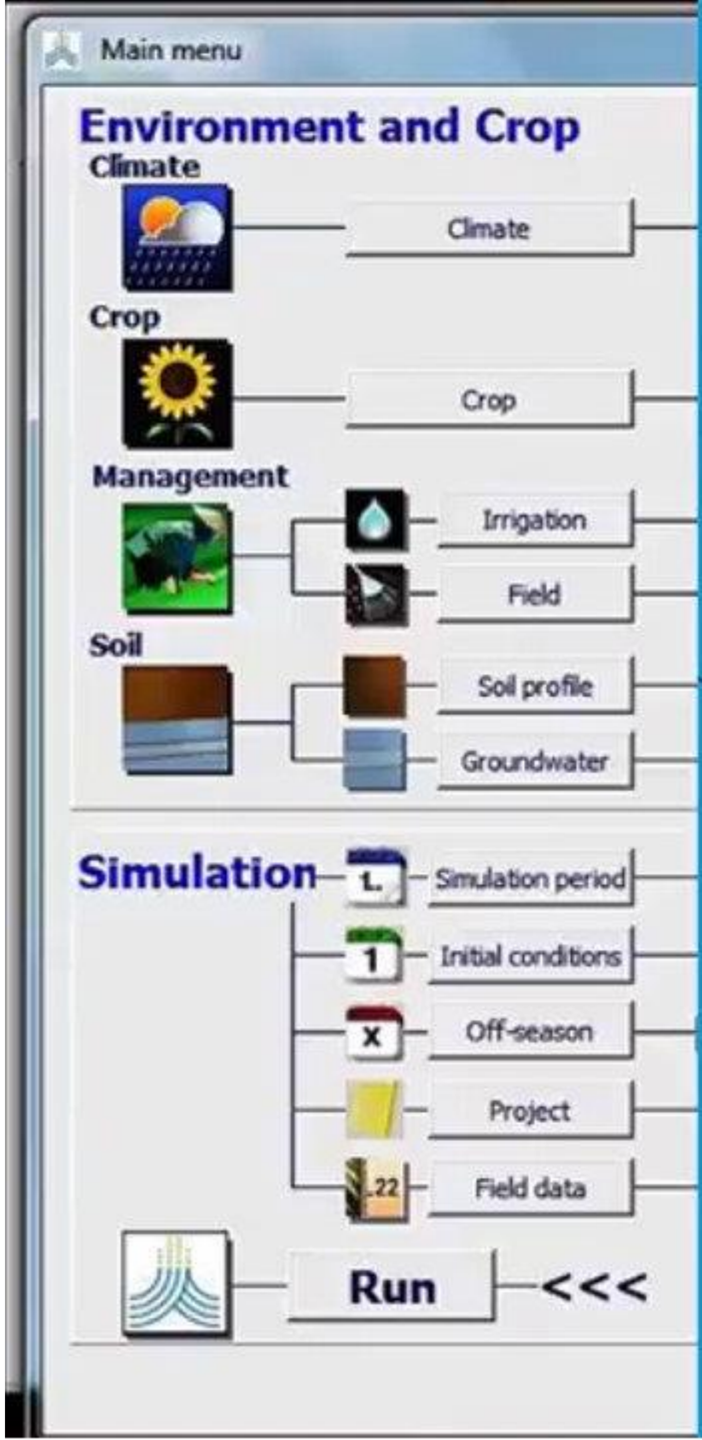
EAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ACC
2002	0	0	1.1825	0.4775	0.88	0.3625	0.74	0.405	0.62	0.24	0.015	0.2775	=SUM(J2:O2)
2003	-0.1325	0.0475	-0.15	-0.3225	-0.895	-2.195	-2.385	-0.69	0.84	1.4575	0.4675	0.035	SUM(numb
2004	0.18	0.2325	-0.345	0.3625	-0.26	0.045	-0.73	0.0325	0.2725	1.1575	1.115	0.695	-0.2775
2005	-0.445	-0.07	-0.02	0.67	1.045	1.16	0.145	-0.4325	-0.8425	-0.1	-0.45	-0.6525	1.745
2006	-0.6275	-0.395	-0.0425	0.1825	1.1625	0.745	0.6725	-0.5925	-0.075	-0.095	0.065	-0.02	2.095
2007	-0.69	-0.3275	-0.37	0.5925	0.49	0.9225	0.89	1.2175	0.5075	0.4075	-0.385	0.845	4.62
2008	0.92	1.2725	0.5075	0.04	-0.2375	0.125	1.3725	1.465	1.355	0.495	0.82	-0.4825	4.12
2009	-0.6825	-0.785	-1.055	-0.2425	0.0625	0.3275	0.485	0.4375	0.13	0.105	1.0925	0.8675	1.2
2010	1.26	0.01	0.1625	-0.145	0.465	0.1475	-0.2725	-1.1575	-0.8825	-0.575	0.5825	1.36	-1.845
2011	1.2	1.21	0.7575	0.89	0.66	0.42	0.1825	0.0425	-0.6375	-0.4325	-0.4475	0.075	1.5575
2012	0.0175	-0.0775	-0.155	0.6875	0.2125	0.495	0.0975	0.8625	0.7525	0.73	-0.0225	-0.0325	3.1075
2013	-0.48	0.5475	0.285	0.245	0.02	-0.155	0.1375	0.985	1.0025	0.7875	0.0425	0.1	2.235
2014	0.915	0.67	1.18	0.505	0.3325	0.1225	0.575	0.63	0.5275	-0.045	0.1775	-0.245	2.6925
2015	0.13	-1.2875	-0.685	-1.4675	-1								
2016	0.79	0.58	0.895	-0.1									
2017	-0.6575	-0.345	-0.87	-0.3175									
2018	-0.55	-0.645	-0.43	0.0775									
2019	-0.8525	-0.3975	-0.6475	-0.93	-1								
2020	-0.865	0.135	-0.71	-0.495	-								
2021	0.4775	-0.3875	0.4725	-0.6975	-0								

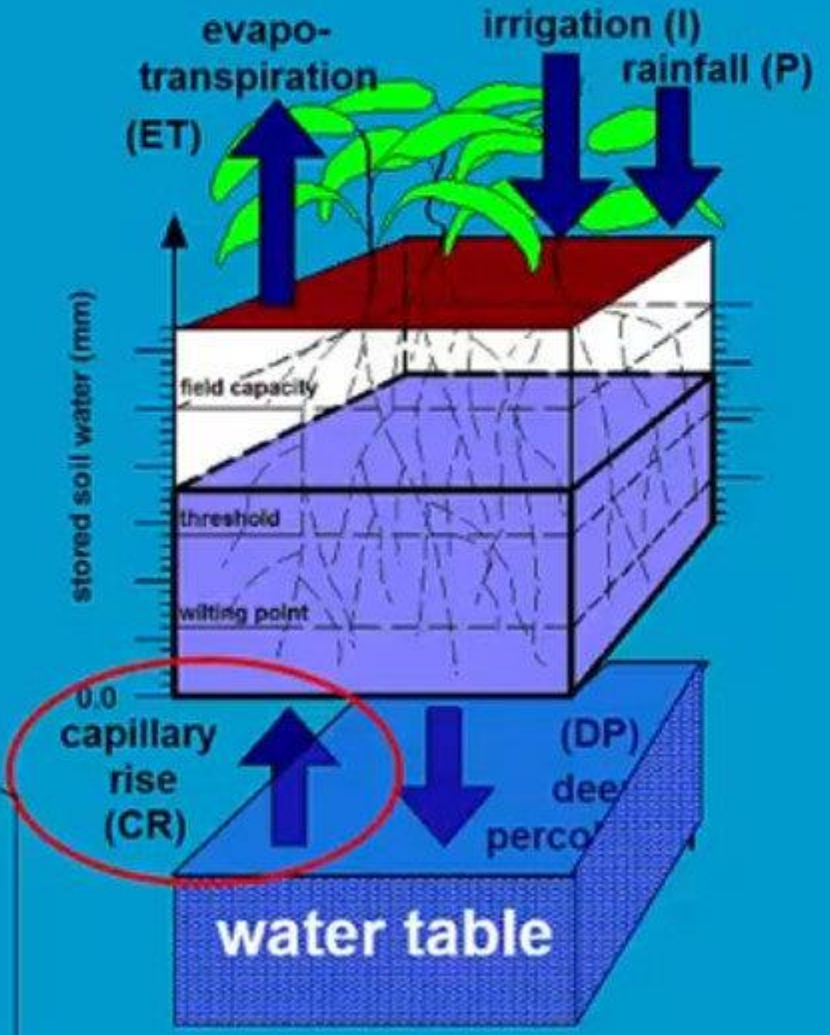
aap	Py	res	SYRS	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2.45	1.9286	0.52	0.96	2002	0	0	1.1825	0.4775	0.88	0.3625	0.74	0.405	0.62	0.24	0.015	0.277
1.63	2.0044	-0.37	-0.82	2003	-0.1325	0.0475	-0.15	-0.3225	-0.895	-2.195	-2.385	-0.69	0.84	1.4575	0.4675	0.03
1.47	2.0774	-0.61	-1.28	2004	0.18	0.2325	-0.345	0.3625	-0.26	0.045	-0.73	0.0325	0.2725	1.1575	1.115	0.69
2.14	2.1476	-0.01	-0.10	2005	-0.445	-0.07	-0.02	0.67	1.045	1.16	0.145	-0.4325	-0.8425	-0.1	-0.45	-0.652
2.50	2.215	0.29	0.49	2006	-0.6275	-0.395	-0.0425	0.1825	1.1625	0.745	0.6725	-0.5925	-0.075	-0.095	0.065	-0.0
2.50	2.2796	0.22	0.36	2007	-0.69	-0.3275	-0.37	0.5925	0.49	0.9225	0.89	1.2175	0.5075	0.4075	-0.385	0.84
2.46	2.3414	0.12	0.16	2008	0.92	1.2725	0.5075	0.04	-0.2375	0.125	1.3725	1.465	1.355	0.495	0.82	-0.482
2.38	2.4004	-0.02	-0.11	2009	-0.6825	-0.785	-1.055	-0.2425	0.0625	0.3275	0.485	0.4375	0.13	0.105	1.0925	0.867
2.00	2.4566	-0.46	-0.98	2010	1.26	0.01	0.1625	-0.145	0.465	0.1475	-0.2725	-1.1575	-0.8825	-0.575	0.5825	1.3
2.68	2.51	0.17	0.26	2011	1.2	1.21	0.7575	0.89	0.66	0.42	0.1825	0.0425	-0.6375	-0.4325	-0.4475	0.07
3.30	2.5606	0.74	1.39	2012	0.0175	-0.0775	-0.155	0.6875	0.2125	0.495	0.0975	0.8625	0.7525	0.73	-0.0225	-0.032
2.99	2.6084	0.39	0.69	2013	-0.48	0.5475	0.285	0.245	0.02	-0.155	0.1375	0.985	1.0025	0.7875	0.0425	0.
2.90	2.6534	0.25	0.42	2014	0.915	0.67	1.18	0.505	0.3325	0.1225	0.575	0.63	0.5275	-0.045	0.1775	-0.24
2.25	2.6956	-0.45	-0.96	2015	0.13	-1.2875	-0.685	-1.4675	-1.2625	-0.445	-0.17	-0.08	-0.56	-1.31	-1.22	-0.86
3.40	2.735	0.67	1.25	2016	0.79	0.58	0.895	-0.1	0.06	-0.185	0.0025	-0.59	-0.21	-0.8225	-0.735	-1.212
1.80	2.7716	-0.97	-2.00	2017	-0.6575	-0.345	-0.87	-0.3175	-0.83	-0.2525	-0.9225	-0.94	-1.43	-0.8875	-0.41	-0.22
2.80	2.8054	-0.01	-0.08	2018	-0.55	-0.645	-0.43	0.0775	0.415	0.4875	0.1025	-0.5575	-0.11	-0.445	-0.47	-1.45
2.00	2.8364	-0.84	-1.74	2019	-0.8525	-0.3975	-0.6475	-0.93	-1.1975	-1.24	-0.6	-0.965	-0.95	-1.295	-0.985	-0.0
3.38	2.8646	0.52	0.96	2020	-0.865	0.135	-0.71	-0.495	-1.045	-0.485	-0.18	0.19	0.2775	-0.17	-0.0025	-0.287
3.50	2.89	0.61	1.14	2021	0.4775	-0.3875	0.4725	-0.6975	-0.0125	-0.1725	0.1475	0.17	-0.33	0.6525	0.765	1.2
		0.03728						CR	0.64944							

Crop modeling

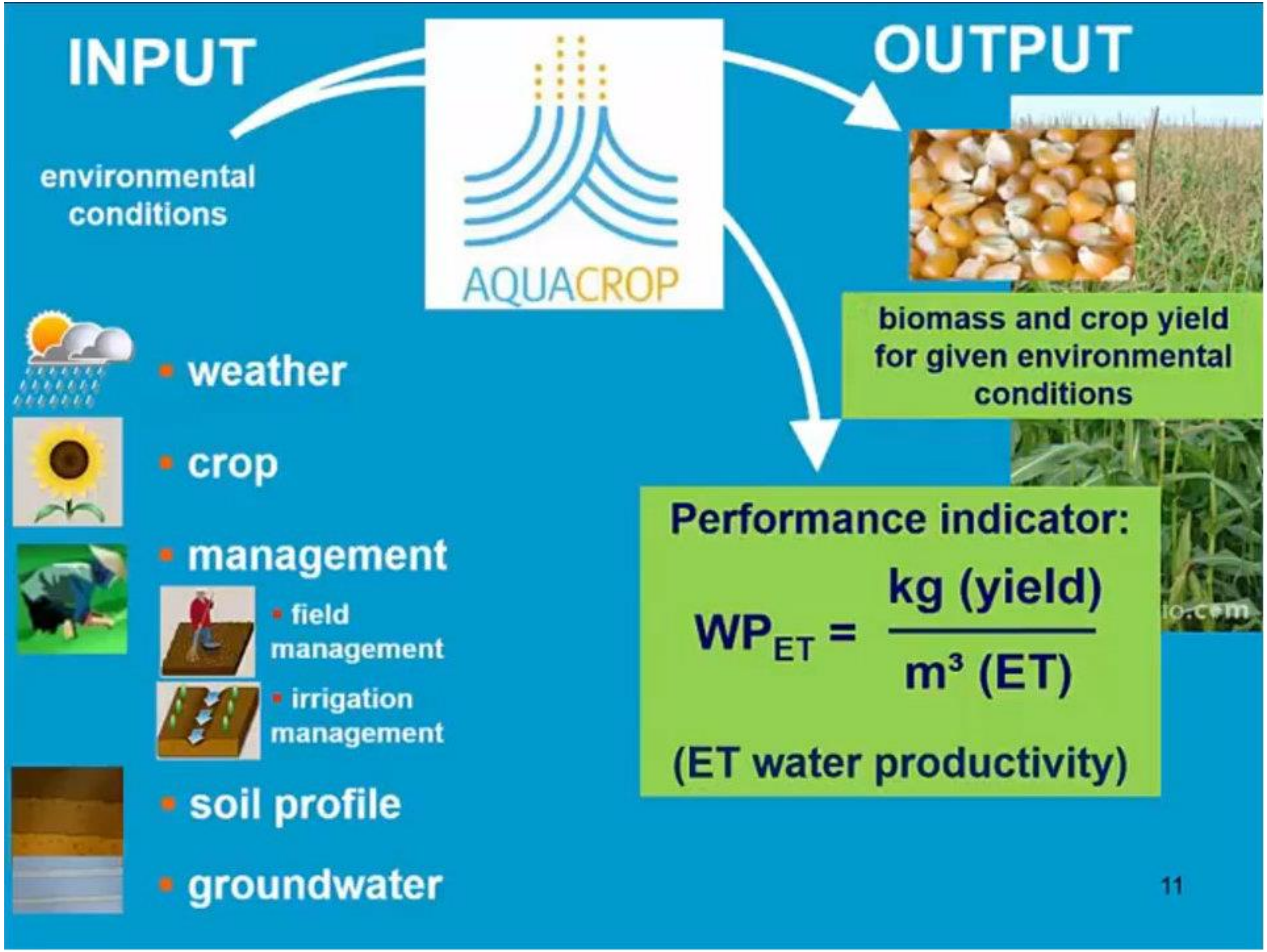
AQUACROP MODEL







- Depth of the groundwater table
- Water quality (salinity)


INPUT
environmental conditions
AQUACROP
OUTPUT
biomass and crop yield for given environmental conditions
weather
crop
management
field management
irrigation management
soil profile
groundwater
Performance indicator:
$WP_{ET} = \frac{kg\ (yield)}{m^3\ (ET)}$
(ET water productivity)
11

efficiency

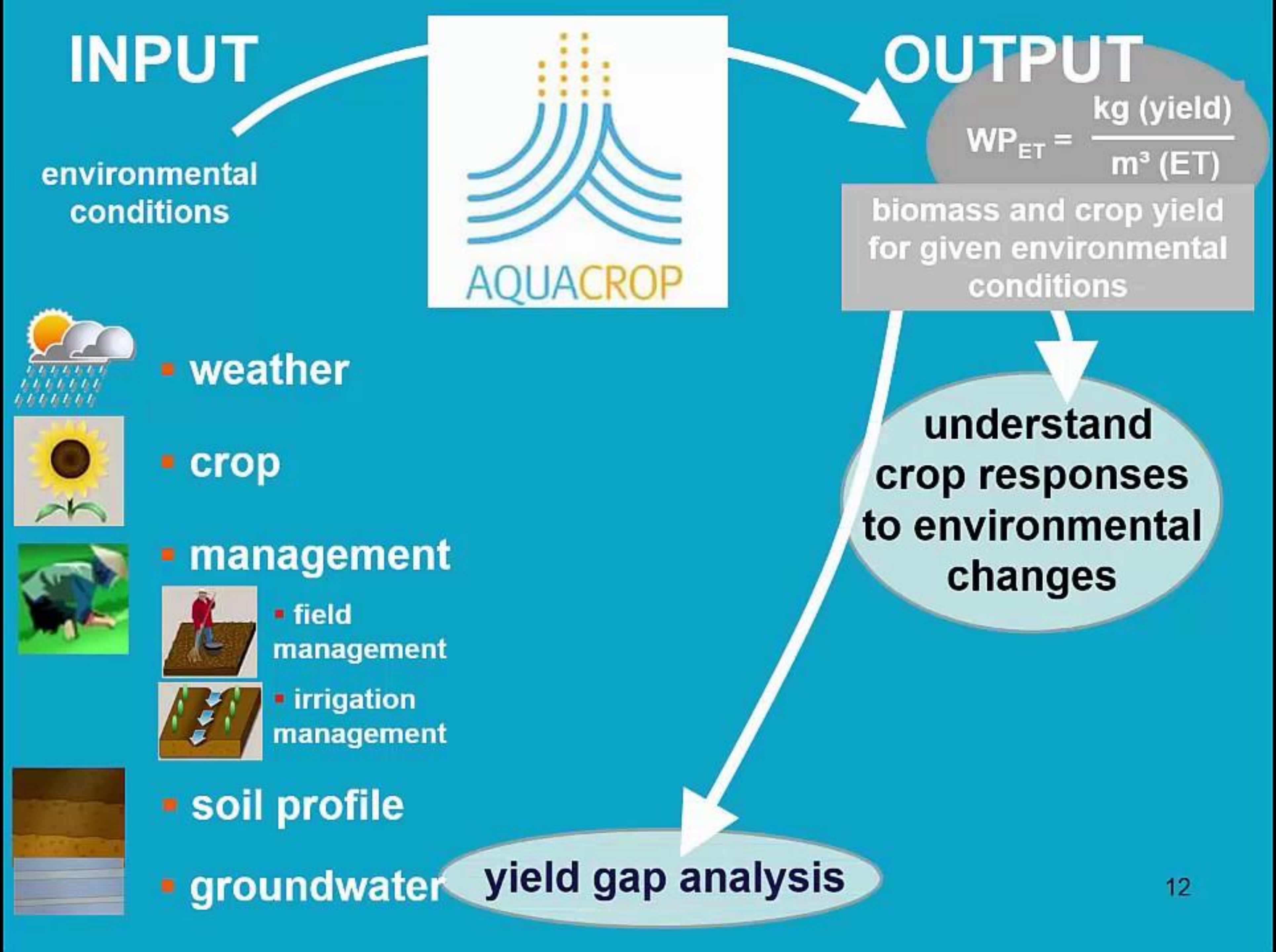
amount of water evapotranspired at field level

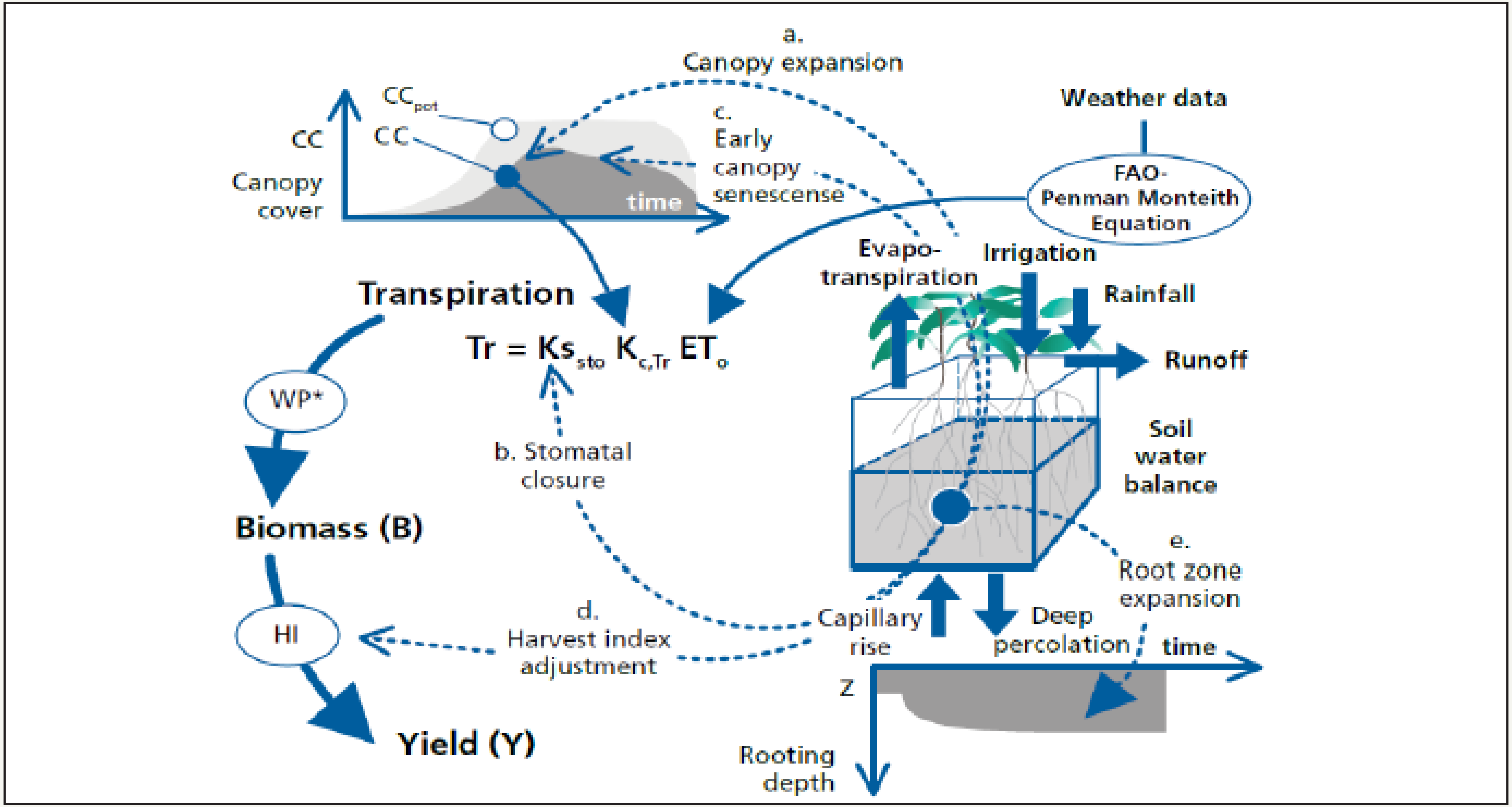
- **distribution losses (channels)**
- **application losses (field)**

Efficiency quantify the output obtained from a given input

Irrigation project efficiency (average ~ 50 %)

amount of water taken from source (river, well, reservoir)


INPUT
environmental conditions
AQUACROP
OUTPUT
WP_ET = kg (yield) / m³ (ET)
biomass and crop yield for given environmental conditions
weather
crop
management
field management
irrigation management
soil profile
groundwater
understand crop responses to environmental changes
yield gap analysis
12


a.
Canopy expansion
CC
Canopy cover
CC pot
CC
time
c.
Early canopy senescense
Weather data
FAO-Penman Monteith Equation
Evapo-transpiration
Irrigation
Rainfall
Runoff
Transpiration
Tr = Ks sto Kc,Tr ETo
WP*
b. Stomatal closure
Biomass (B)
Soil water balance
e.
Root zone expansion
HI
d.
Harvest index adjustment
Capillary rise
Deep percolation
time
Z
Yield (Y)
Rooting depth

How the Agricultural Production Systems sIMulator (APSIM) is used for irrigation in a changing climate?

- The Agricultural Production Systems sIMulator (APSIM) is a powerful tool used for simulating and optimizing agricultural production systems, including irrigation. As climate change continues to have an impact on the agricultural sector, it is becoming increasingly important to identify and implement adaptive management strategies to mitigate the impact of changing weather patterns on crop production.
- One of the key features of APSIM is its ability to simulate and model different irrigation strategies in response to changing climate conditions. By inputting data such as weather patterns, soil type, and crop requirements, APSIM can help farmers and researchers make informed decisions about when and how to irrigate their crops.
- For example, in a changing climate where droughts and water scarcity are becoming more common, APSIM can be used to identify the most water-efficient irrigation techniques for a particular crop or soil type. This can include strategies such as drip irrigation, which uses less water than traditional sprinkler systems, or rainwater harvesting, which captures and stores rainwater for later use.
- In addition to simulating different irrigation strategies, APSIM can also be used to model the impact of climate change on crop yields and water availability. This allows farmers and researchers to identify potential risks and adapt their management strategies accordingly.

How the Decision Support System for Agrotechnology Transfer (DSSAT) is used for irrigation in a changing climate?

- The Decision Support System for Agrotechnology Transfer (DSSAT) is a computer-based software system used to simulate and optimize crop growth and yield under different weather, soil, and management scenarios. It includes a suite of crop models that can be used to assess the impact of climate change on crop production and to identify optimal irrigation management strategies.
- In a changing climate where water availability and crop productivity are increasingly uncertain, DSSAT can be used to evaluate different irrigation scenarios and identify the most effective water management practices. For example, DSSAT can simulate the effects of different irrigation schedules, water application rates, and irrigation depths on crop growth and yield.
- Furthermore, DSSAT can also be used to evaluate the impact of different climate scenarios on crop yield and irrigation requirements. By incorporating historical weather data, future climate projections, and other environmental data, DSSAT can help farmers and researchers to identify the most sustainable and efficient irrigation strategies for a particular crop or region.
- In addition to irrigation management, DSSAT can also be used to optimize other management practices such as fertilizer application, crop rotation, and tillage. By integrating these different management practices with irrigation management, DSSAT can help to develop more comprehensive and sustainable agricultural management strategies that are resilient to the impacts of climate change.

Conclusion

- In this training, we learned about greenhouse gas emissions, the relationship between agriculture and climate, analyzing drought, and crop modeling.