GOBIERNO DE ESPAÑA
MINISTERIO DE AGRICULTURA, PESCA Y ALIMENTACIÓN

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

IMPACTO DEL CAMBIO CLIMÁTICO EN LA AGRICULTURA

Prof. Alberto García Prats

DEPARTAMENTO DE INGENIERÍA HIDRÁULICA Y MEDIO AMBIENTE

Escuela Técnica Superior de Ingeniería Agronómica y del Medio Natural

Instituto de Ingeniería del Agua y Medio Ambiente

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¿Qué es el Cambio Climático?

- **Tiempo: Conjunto de fenómenos atmosféricos que ocurren en la atmósfera en un momento determinado**. Incluye, entre otras cosas, la dirección y la velocidad del viento, las precipitaciones, la presión barométrica, la temperatura y la humedad relativa, etc.. El tiempo varía en un espacio corto de tiempo.
- **El clima: promedio del estado del tiempo** y abarca períodos de tiempo prolongados (p. ej., 30 años).

Reflection: Weather vs. Climate

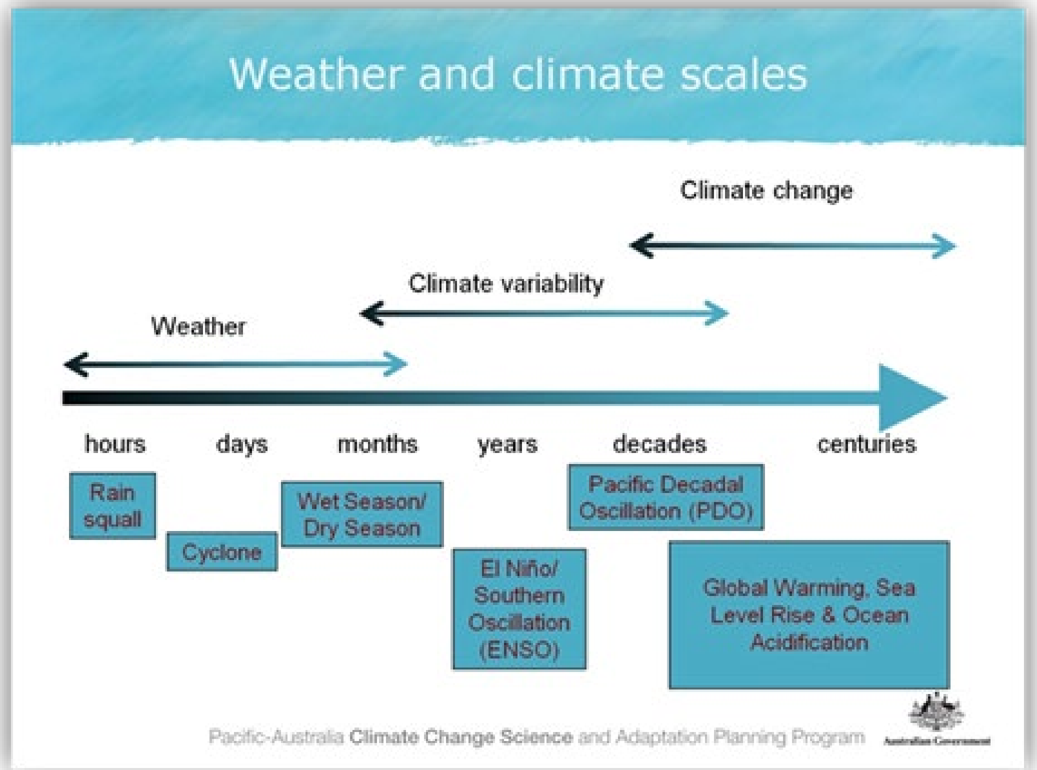
Very often people confuse the words "weather" and "climate" when discussing global warming and changes in the world's climate. Read the quotes below and reflect on the differences between the two concepts. Think of your own analogy!

"Climate is what we expect, weather is what we get." Mark Twain

"Weather is one football game, climate is the history of the National Football League." @MikeNelson247 via @CC_Yale

"Climate tells you what clothes to buy, weather tells you what clothes to wear." – middle school student

¿Qué es el Cambio Climático?



Pacific Madden-Julian Oscillation (MJO)

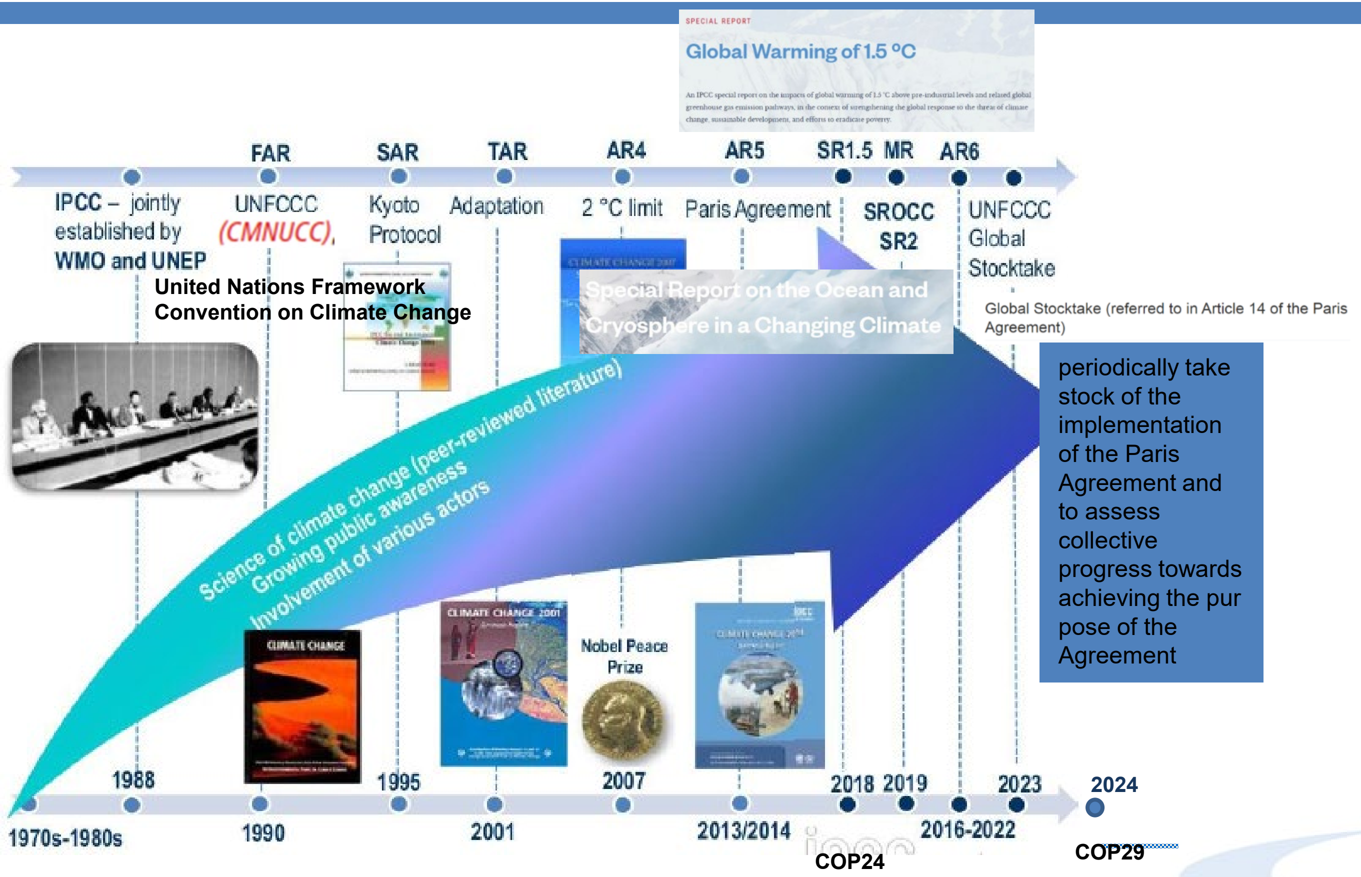
The North Atlantic Oscillation (NAO)

Equator, The quasi-biennial oscillation (QBO)

……

Fuente: https://www.pacificclimatefutures.net/en/help/climate-projections/understanding-climate-variability-and-change/

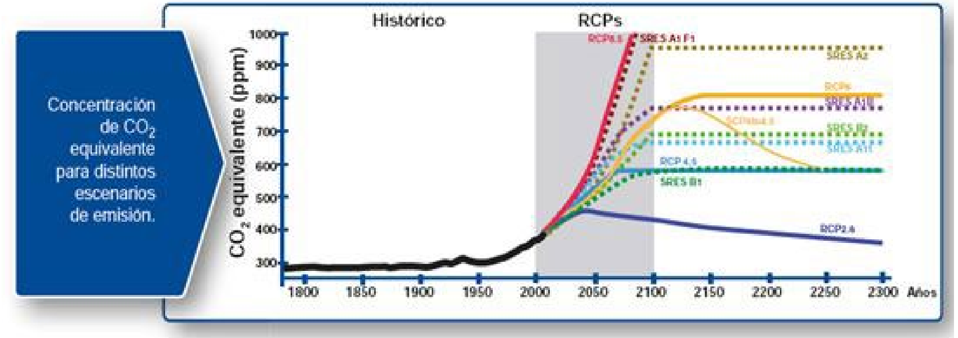
Historia de la Ciencia del CC

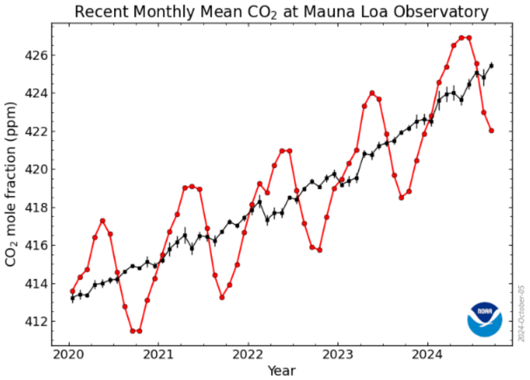


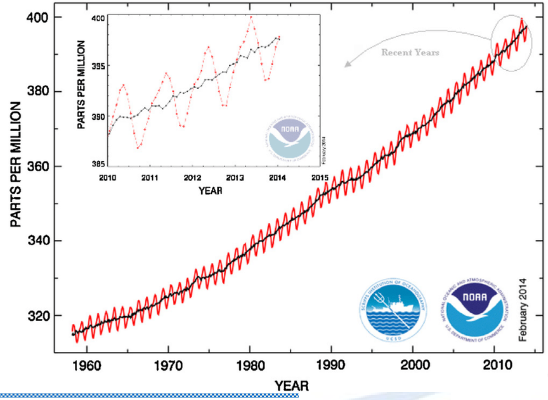
periodically take stock of the implementation of the Paris Agreement and to assess collective progress towards achieving the pur pose of the Agreement

Introducción

- **Qué dicen los escenarios del IPCC (AR5/6)**
- **Representative Concentration Pathways (RCPs)**







En la Región Mediterránea se han proyectado efectos específicos si no se reducen las emisiones, como son:

•Un incremento de temperatura por encima de la media global, más pronunciado en los meses estivales que en los invernales. Para el escenario RCP8.5 y para finales del siglo XXI, esta Región experimentará incrementos medios de temperatura de 3,8ºC y de 6,0ºC en los meses invernales y estivales, respectivamente.

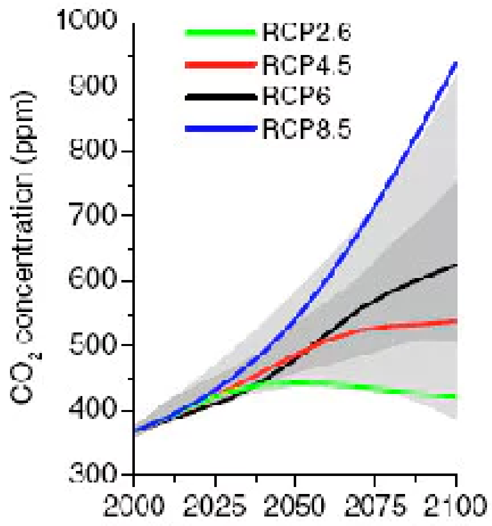
•En la Península Ibérica se reducirá la precipitación anual, de manera más acusada cuanto más al sur. Las precipitaciones se reducirán fuertemente en los meses estivales. Para el escenario RCP8.5 y para finales del siglo XXI, la Región Mediterránea experimentará reducciones medias de precipitación de 12% y de 24% en los meses invernales y estivales, respectivamente.

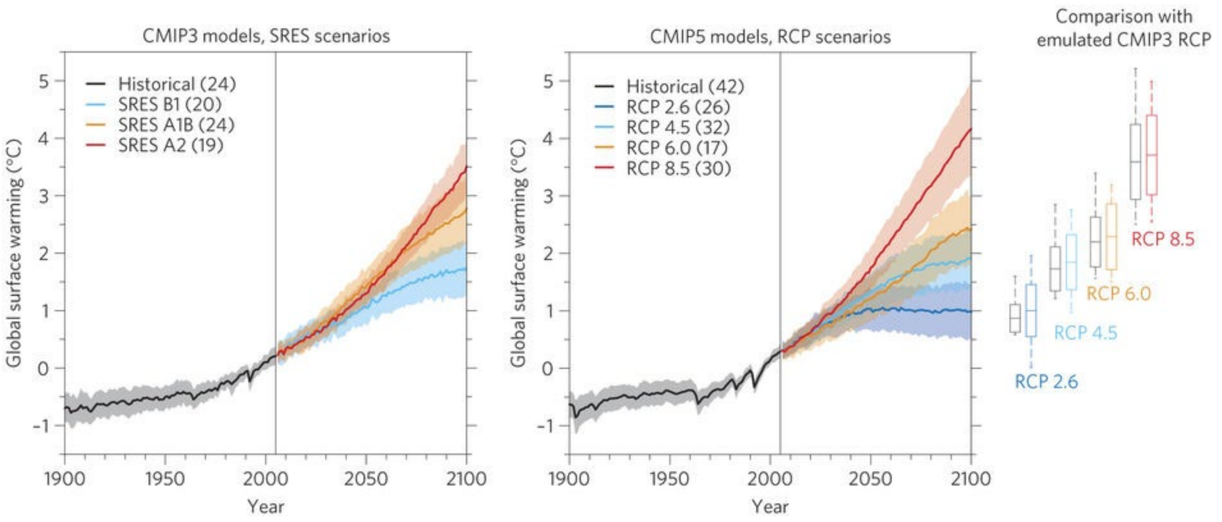
•Un aumento de los extremos relacionados con las precipitaciones de origen tormentoso.

Introducción

- **Qué dicen los escenarios del IPCC**

https://www.ipcc.ch/index.htm

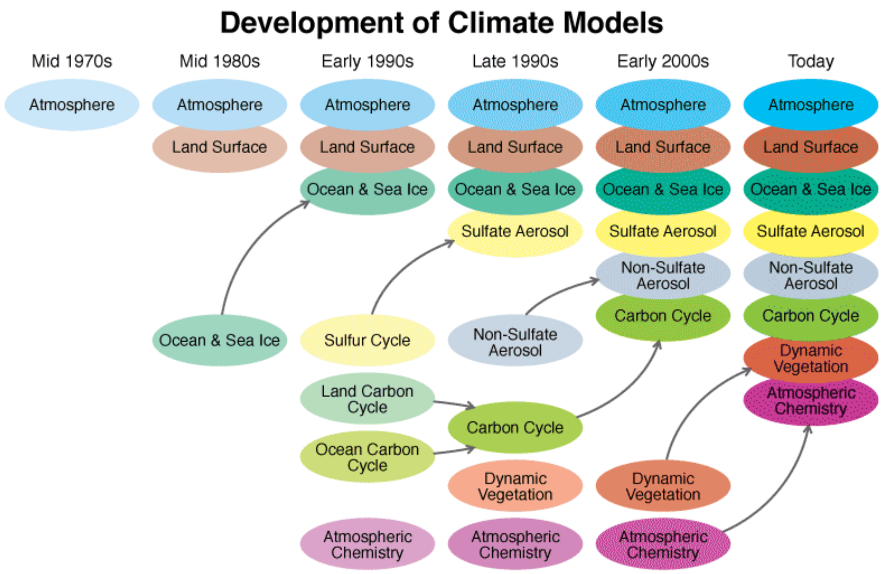




<u>Forzamiento radiativo</u>: Variación desde 1750, expresada en W·m^{-2}, del flujo radiativo (la descendente menos la ascendente) en la tropopausa o en la parte superior de la atmósfera, debida a una variación del causante externo del cambio climático; por ejemplo, una variación de la concentración de dióxido de carbono o de la radiación solar.

Cómo se estudia el CC

El concepto **“seamless prediction”** (“predicción unificada” o “predicción sin costuras”)



Fuente: https://www.nap.edu/catalog/13430/a-national-strategy-for-advancing-climate-modeling

IPCC AR6. Chapter 5.

Figure 5.3 | Synthesis of literature on observed impacts of climate change on productivity by crop type and region. The figure draws on >150 articles categorized by: agriculture total factor productivity including literature estimating all agricultural outputs in a region; major crop species including literature assessing yield changes in the four major crops; crop categories including productivity changes (yield, quality and other perceived changes) in a range of crops with different growth habits. The assessment uses literature published since AR5, although the timespan often extends prior to 2014. The direction of the effect and the confidence are based on the reported impacts and attribution, and on the number of articles. See SM5.1 and SM5.2 for details.

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IPCC AR5. Chapter 7.

CHAPTER

20

Crop modeling for climate change impact and adaptation

Senthold Asseng[1], *Yan Zhu*[2], *Enli Wang*[3], *Weijian Zhang*[4]

[1]University of Florida, Gainesville, USA
[2]Nanjing Agricultural University, China
[3]CSIRO, Australia
[4]Institute of Crop Sciences, Chinese Academy of Agricultural Sciences, Beijing, China

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TABLE 20.1 Summary of climate change factors and general impact on crops

Climate variables		Realized trends	Projected trends	General impacts on crop growth
CO_2		1.4 ppm/a (379 ppm in 2005)	1.9 ppm/a (450 ppm by 2050)	Increased net photosynthesis, plant biomass production and transpiration-use efficiency
				Reduced transpiration
				Increased canopy temperature
				Reduced crop nutrient concentration
Temperature	Min	0.56°C (2005) since 1906	0.02°C/a (1.3°C– 1.7°C in 2050)	Reduced frost risk
	Avg	0.74°C (2005) since 1906	1.8–4.0°C in 2100	Increased stomatal conductance, photosynthesis, respiration, and transpiration; faster growth and development, phenological shifts; reduced transpiration efficiency
	Max	0.92°C (2005) since 1906		Increased heat stress
Rainfall		0.11 mm/a	Variable changes across the globe, in general, increase at high latitude and decrease at low latitude	Positive or negative, depending on the direction and other factors
Solar radiation		Reduction in solar radiation and increased diffused light fraction (1365 W m^{-2} in 2005)	Reduction in solar radiation and increased diffused light fraction	Increase photosynthesis and growth due to increase diffused light fraction
Ozone	Troposphere	0.5–2.5%/a (50 ppb in 2000)	0.5–2.5%/a (60– 100 ppb by 2050)	Increased foliar injury, decreased growth and yield
	Stratosphere	0.6 %/a (265 DU in 2000)	0.1–0.2 %/a (275– 286 DU by 2050)	Reduce leaf expansion and biomass accumulation

After IPCC, 2013.

iiama

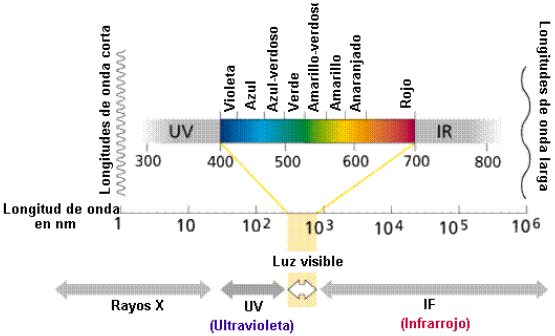
Introducción

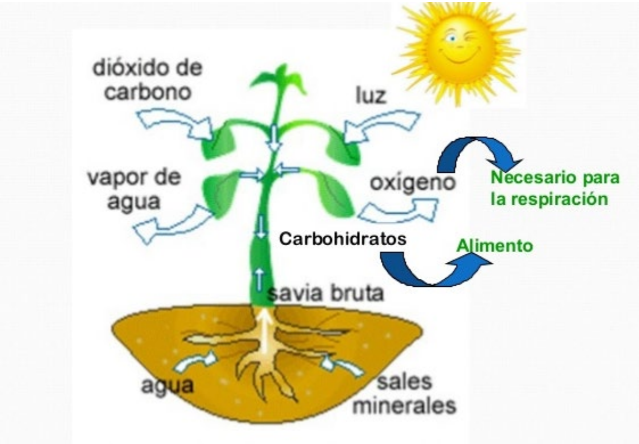
- **Procesos básicos**
  - Fotosíntesis
  - Transpiración
  - CO_2 Experimentos FACE
  - Fenología
  - Ciclos
    - Agua
    - Energía
    - Biogeoquímicos

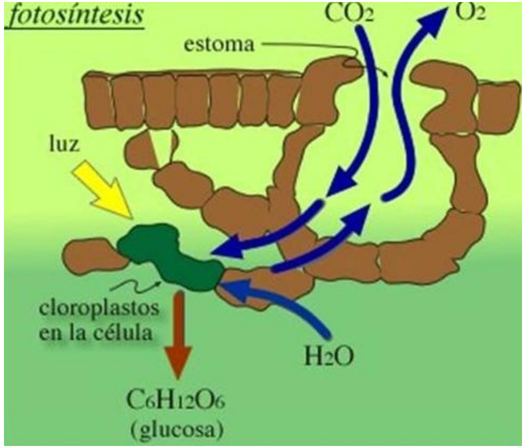
- **Crop Modeling**

Fotosíntesis

- **Fotosíntesis**







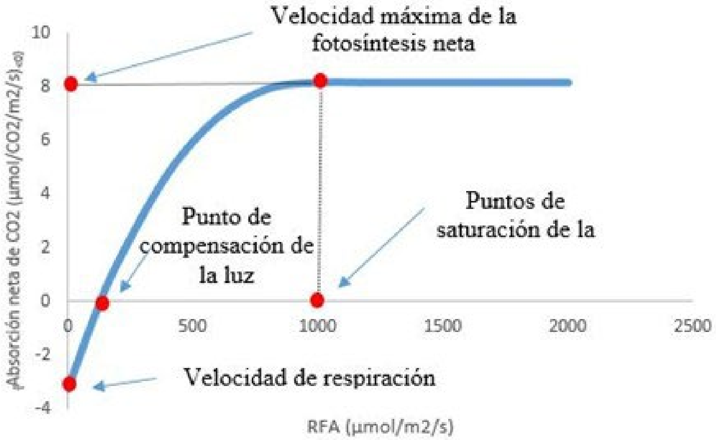
FOTOSÍNTESIS	$CO_2 + H_2O$ + energía luminosa	→	$C_6H_{12}O_6 + O_2$
RESPIRACIÓN	$C_6H_{12}O_6 + O_2$	→	$CO_2 + H_2O$ + energía

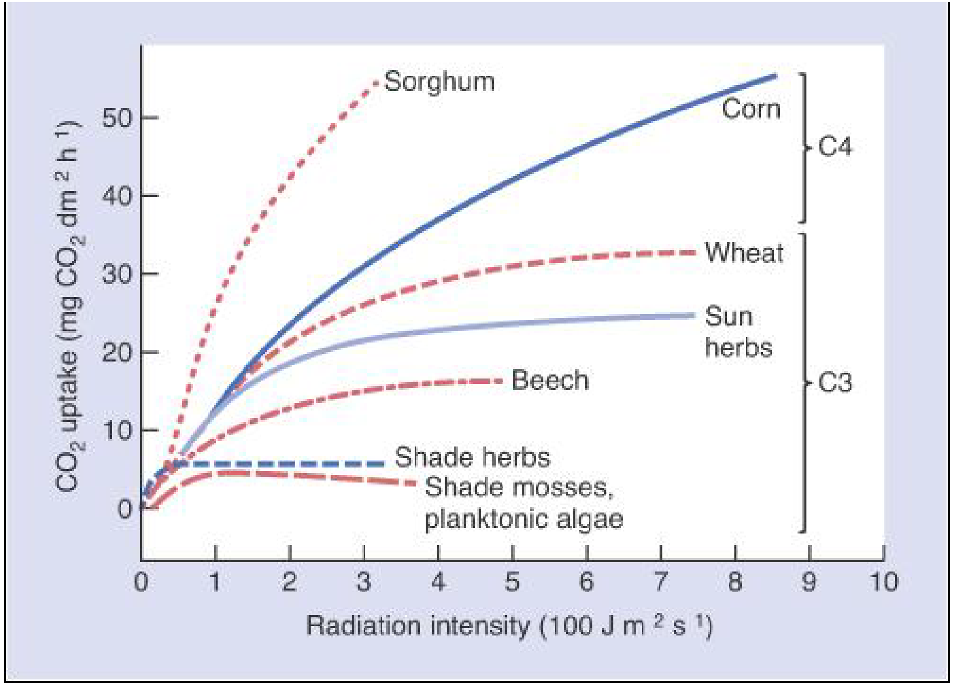
Fotosíntesis

- Factores ambientales que condicionan la fotosíntesis

Fotosíntesis

Factores ambientales que condicionan la fotosíntesis





Fotosíntesis

- **Factores ambientales que condicionan la fotosintesis**

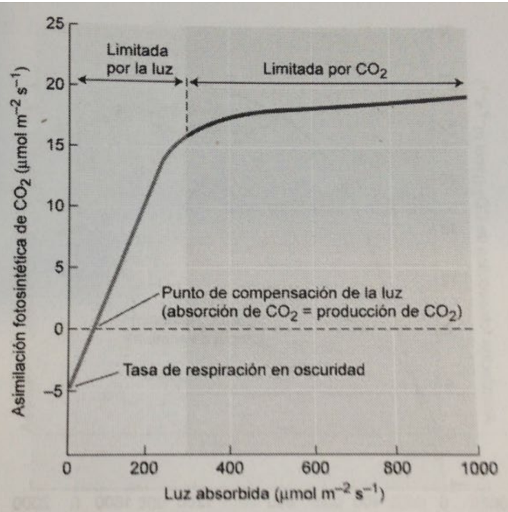
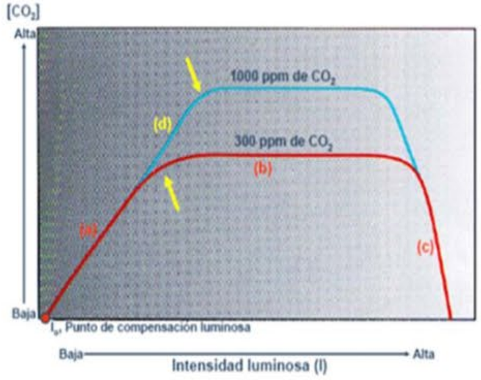
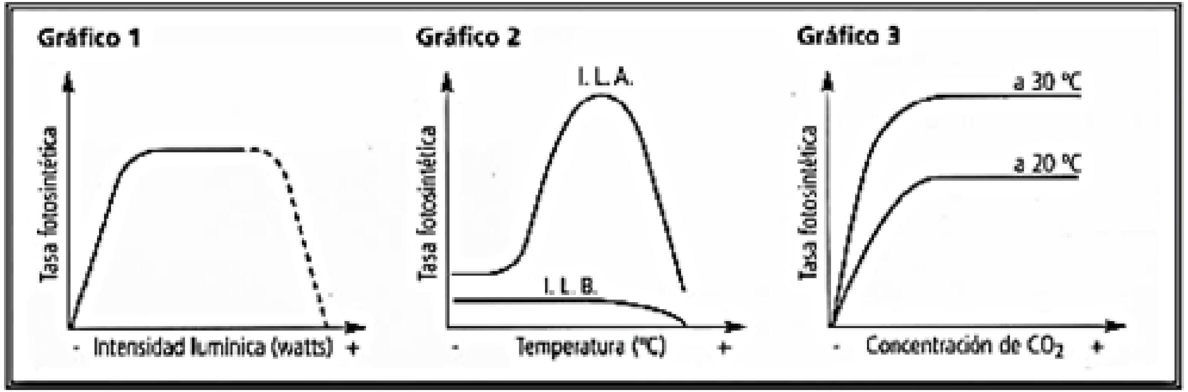


Figura 9.8 Respuesta de la fotosíntesis a la luz en plantas C_3. En oscuridad, la respiración produce un flujo neto de CO_2 desde la planta. Se alcanza el punto de compensación de la luz cuando la asimilación fotosintética de CO_2 iguala la cantidad de CO_2 producido en la respiración. Un aumento de la irradiancia por encima del punto de compensación de la luz aumenta la fotosíntesis proporcionalmente, indicando que la fotosíntesis está limitada por la tasa de transporte electrónico que, de hecho, está limitada por la cantidad de luz disponible. Esta parte de la curva se considera que está limitada por la luz. Los aumentos posteriores de la fotosíntesis están limitados por la capacidad de carboxilación de la rubisco o el metabolismo de las triosas fosfato. Esta parte de la curva se considera que está limitada por CO_2.

Fotosíntesis

- **Factores ambientales que condicionan la fotosíntesis**



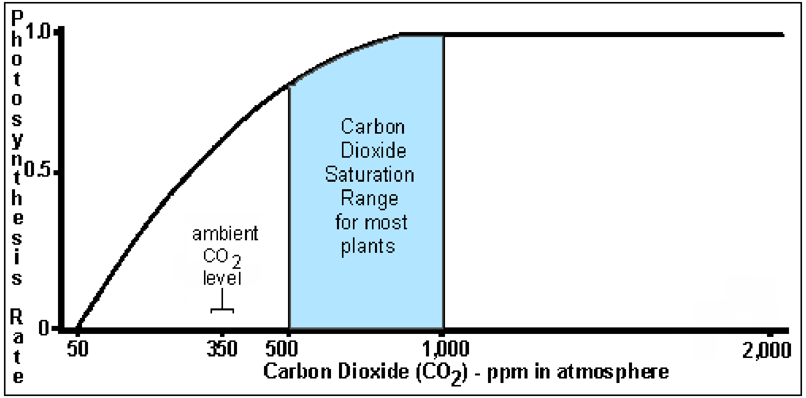


I.L.A.: Intensidad lumínica alta

I.L.B.: Intensidad lumínica baja

Fotosíntesis

Factores ambientales que condicionan la fotosíntesis



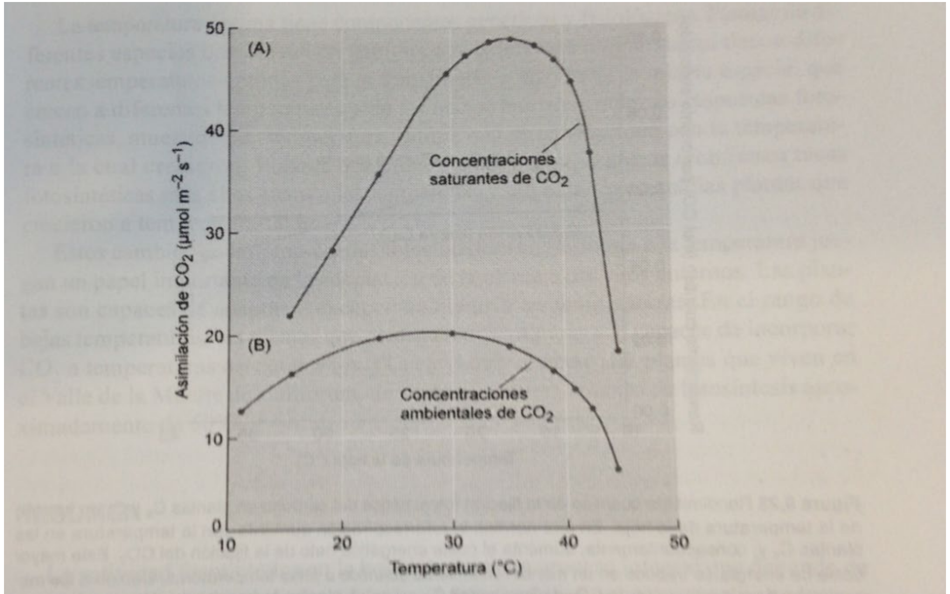
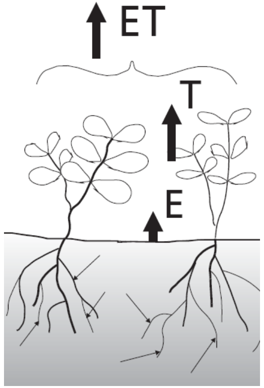


Figura 9.22 Cambios en la fotosíntesis en función de la temperatura a concentraciones de CO_2 que saturan la asimilación fotosintética (A) y a concentraciones atmosféricas normales de CO_2 (B). La fotosíntesis depende fuertemente de la temperatura en condiciones de concentraciones de CO_2 saturantes. Obsérvese que las tasas fotosintéticas son significativamente mayores a concentraciones de CO_2 saturantes. (Redibujado de Berry y Bjorkam 1980).

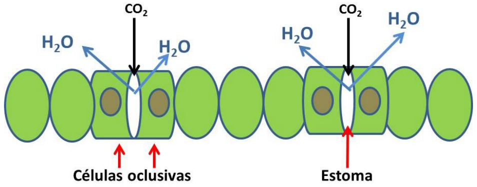
Índice

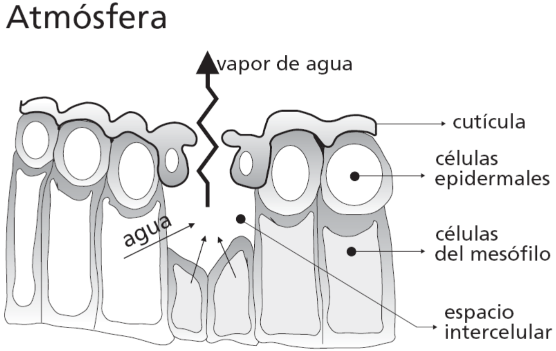
El fenómeno ET

- **Evapotranspiración = Evapo-Transpiración   E+T=ET**
  - El agua contenida en una porción de suelo (con vegetación) pasa a la atmósfera en forma de vapor de agua.
  - Se trata de la combinación de dos fenómenos, uno físico o **evaporación (E)** y otro fisiológico o **transpiración (T)**.
  - La superficie donde tiene lugar es la **superficie evapotranspirante** (desde la superficie del suelo hasta el límite superior donde alcanza la vegetación.)



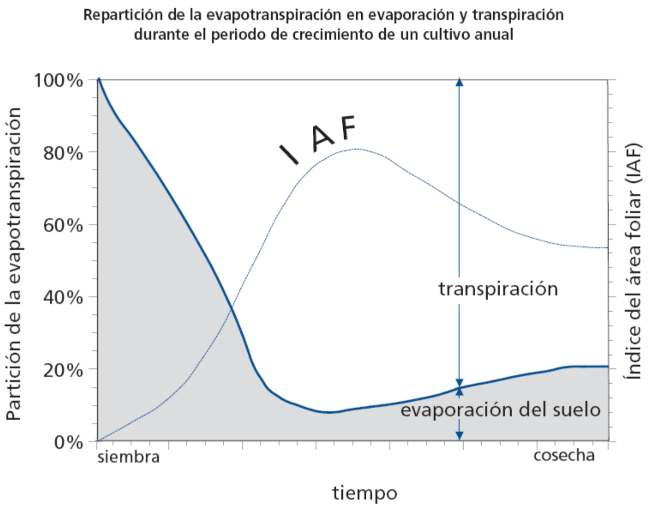
La T ocurre en las hojas a través de unas células modificadas llamadas estomas.

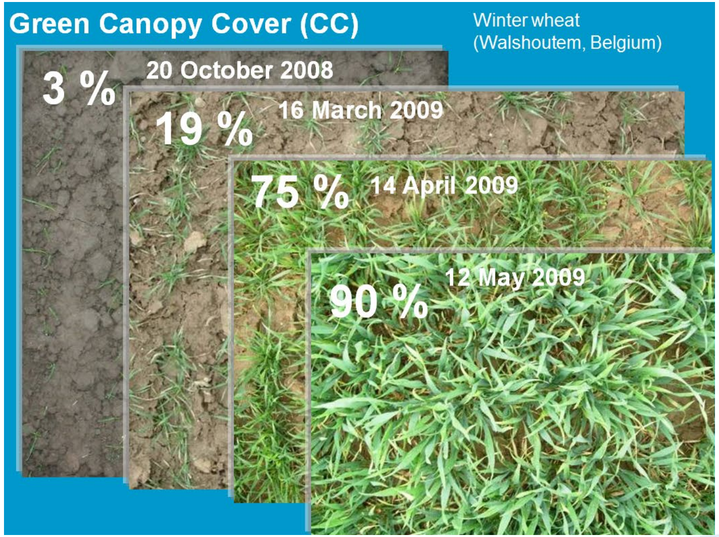




El fenómeno ET

- **¿Cómo se relacionan E y T?**
- El mayor o menor **peso de cada una de las componentes** viene influido principalmente por el **grado de cobertura vegetal del suelo**.
- Un buen indicador de la capacidad para transpirar por parte del cultivo es a partir del índice de área foliar **LAI (Leaf Area Index)**, el cual relaciona la superficie total asimiladora y la superficie ocupada por la planta.

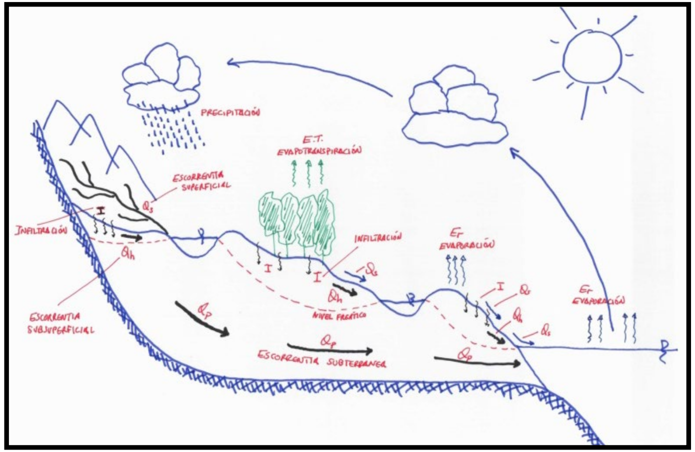




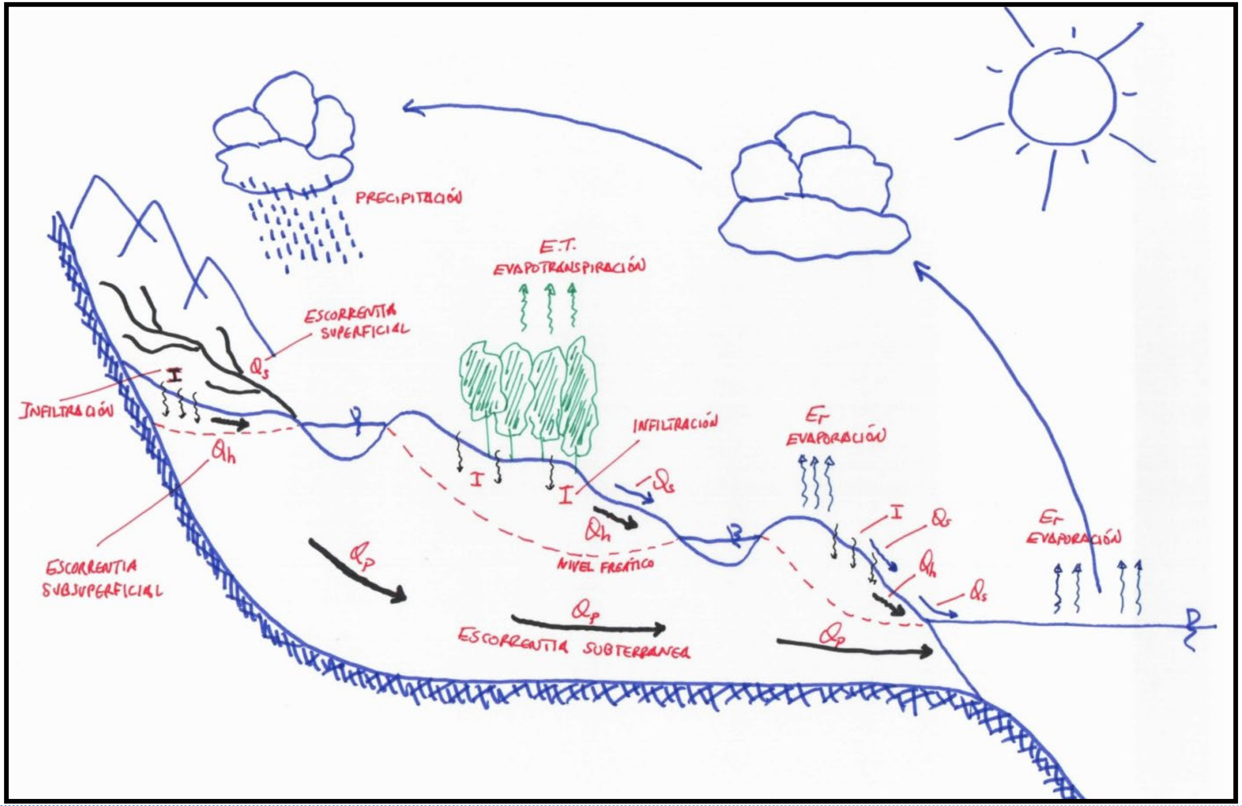
El fenómeno ET

- **Evapotranspiración Potencial (ETP) y real (ETR)**
- **Thornwaite en 1.944**. Se define como *la cantidad de agua que es devuelta a la atmósfera en forma de vapor desde un suelo completamente cubierto de vegetación y con un aporte continuo de agua y por tanto sin limitaciones de humedad*.
  - Es por tanto la **máxima tasa de evapotranspiración** que puede obtenerse.
  - Es un término sumamente **ambiguo y obsoleto, válido para cerrar un balance a nivel de cuenca**.

- **Hacia la Evapotranspiración de Referencia (ETo)**
- Mismo concepto que ETP pero para un cultivo concreto.
- Pruitt et al. 1.986. *Tasa de **evapotranspiración de una extensa superficie cultivada con gramíneas** pratenses perennes de altura uniforme entre 8 y 15 cm, en crecimiento activo, que sombrea completamente el suelo y que se encuentra **bien aprovisionada de agua**.*
  - Aparecen dos tendencias. Jensen et at. que la definen para alfalfa, Pruitt et al. que la definen para gramíneas.



El fenómeno ET



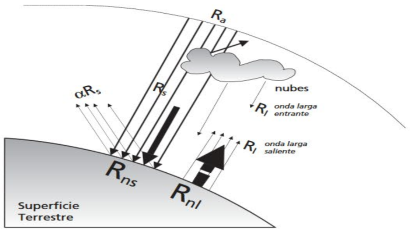
Importancia de T

>½ de P a nivel de cuenca

El fenómeno ET

- **Formas de llegar a la ET**
- Método del **Balance de Energía**.
  - El fenómeno está gobernado por el intercambio energético entre la superficie evapotranspirante y la atmósfera y está **limitado por la cantidad de energía disponible**. Con un balance se puede predecir ET.

FIGURA 15
Componentes de la radiación

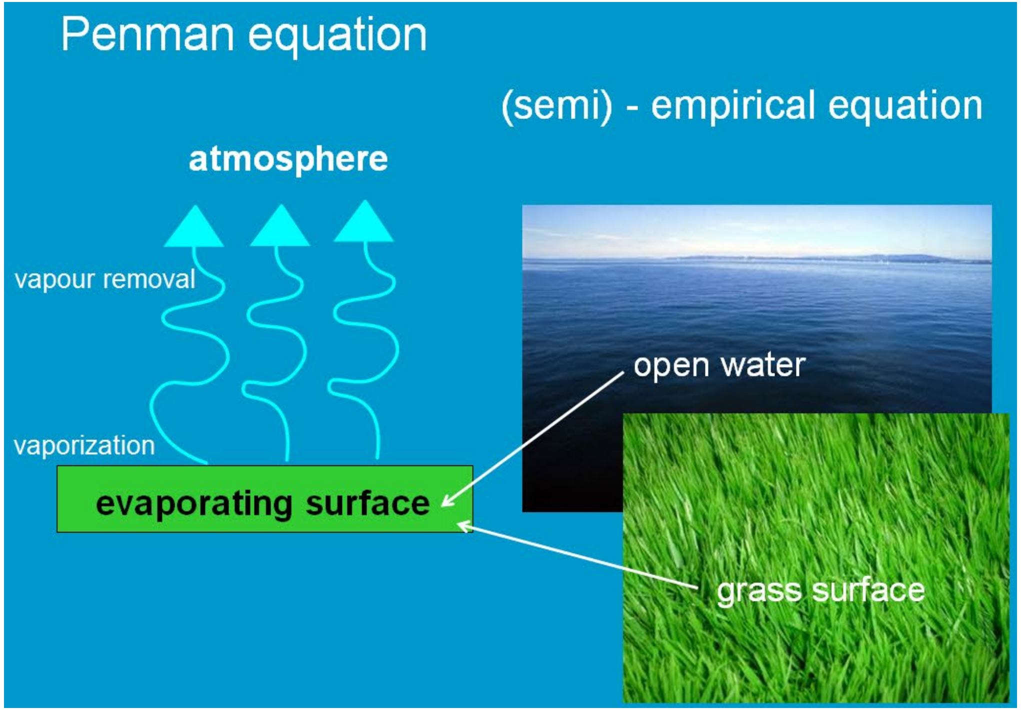


$$Rn - G - \lambda ET - H = 0$$

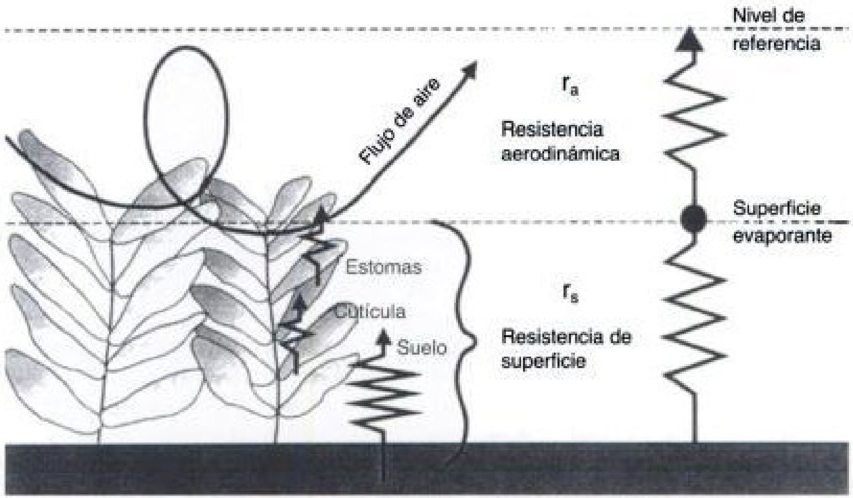
donde:
- Rn, radicación neta
- H, flujo de calor sensible. (pasa al aire calentándolo)
- G, flujo de calor en el suelo (almacenado produciendo calentamiento)
- λET, flujo de calor latente (evaporación)

- Método **Aerodinámico**
  - Además del suministro de energía calórica, el segundo factor que controla la tasa de evaporación desde una superficie abierta de agua es la **habilidad para transportar el vapor lejos de la superficie**.
  - **La tasa de transporte** (flujo vertical de vapor) se puede determinar a partir del gradiente de humedad en el aire cercano a la superficie evaporante a varias alturas, y por la velocidad del viento a través de dicha superficie, y estos dos procesos pueden analizarse utilizando simultáneamente las **ecuaciones de transporte de masa y de cantidad de movimiento en el aire**.

- **La Ecuación de Pennman: El método combinado**
- Método del **Balance de Energía**.
- Método **Aerodinámico**



- La Ecuación de Monteith: Introducción de las resistencias



local calibration of resistances (r_s and r_a) require demanding and expensive studies

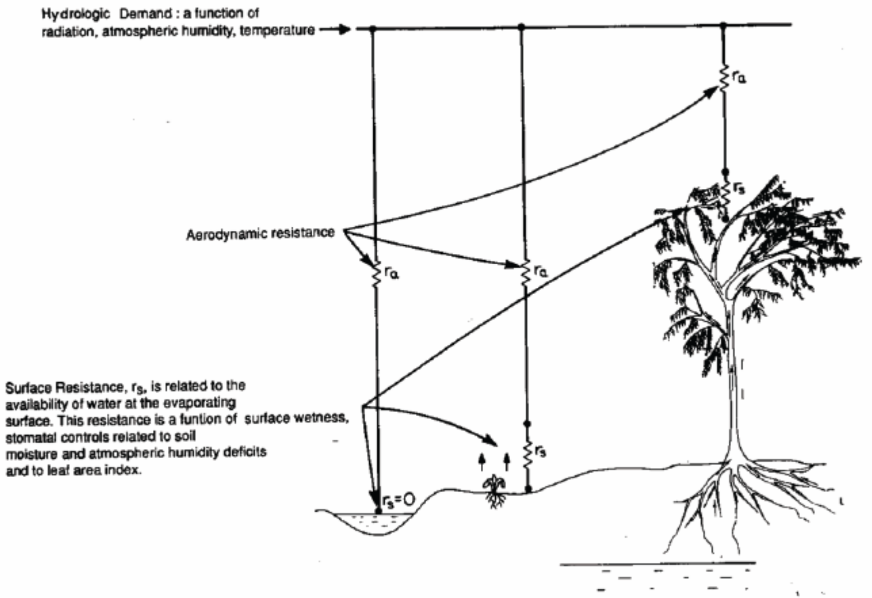


FIGURE 13.1.1 The evaporation rate is determined by the balance between meteorological demand and the availability of water at the evaporating surface.

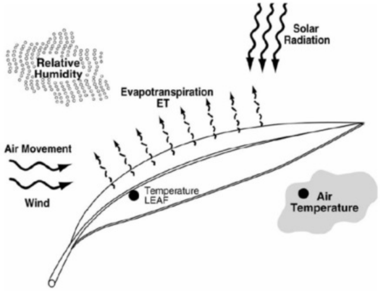
El fenómeno ET

- **Evapotranspiración de Referencia (Eto)**
- En 1990 la FAO organiza una consulta a expertos. Se **define el cultivo de referencia y la metodología más adecuada para la estimación de la ETo**.
- Cultivo de referencia:
- *Cultivo hipotético con una altura de 0,12 m, con una resistencia superficial de 70 m·s^{-1}, un albedo de 0,23 asemejándose su evapotranspiración en gran medida a una extensa superficie de pasto verde, de altura uniforme con crecimiento activo y con suficiente aporte de agua.*
- Queda plasmado en la publicación de la FAO: Irrigation and drainage paper nº 56. Crop evapotranspiration - Guidelines for computing crop water requirements- (Allen, Raes, Pereira y Smith, 1998).

Método Combinado Penman-Monteith- FAO-56

El fenómeno ET

Evapotranspiración de Referencia (Eto)



$$ET_o = \frac{1}{\lambda}\left(\frac{\Delta(Rn - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma(1 + \frac{r_s}{r_a})}\right)$$

$$r_a = \frac{208}{u_2}$$

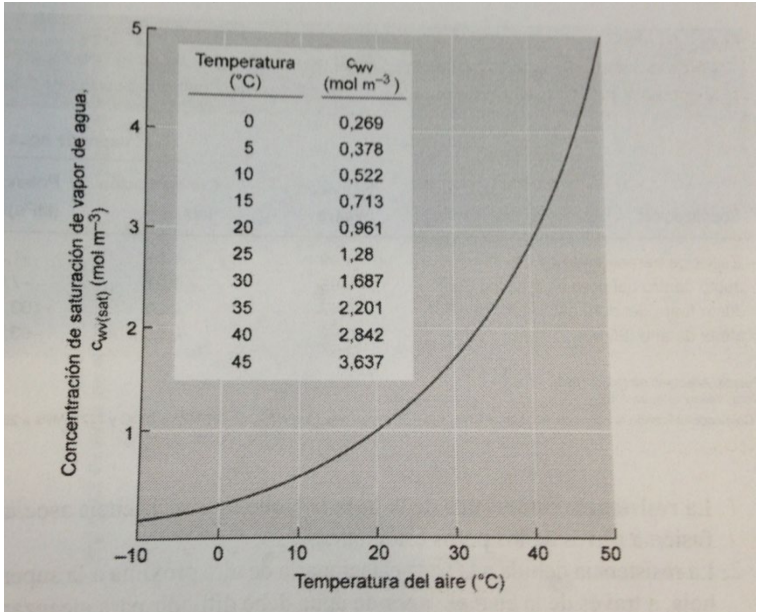
r_s = 70 s m^{-1}

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

- ETo = Evapotranspiración de referencia, en mm·d^{-1}
- Δ = pendiente de la curva que relaciona la presión de vapor con la temperatura del aire (kPa ºC^{-1}).
- R_n = radiación neta en la superficie del cultivo (MJ m^{-2} día^{-1}).
- G = flujo térmico del suelo (MJ m^{-2} día^{-1})
- U_z = velocidad del viento a la altura z (m s^{-1}).
- γ = constante psicrométrica (kPa ºC^{-1}).
- *(e_s – e_a) = déficit de presión de vapor (kPa).*
- *T_{med}, temperatura media diaria, en ºC.*
- *λ = calor latente de vaporización (MJ kg^{-1})*

El fenómeno ET

- **Evapotranspiración de Referencia (Eto)**



Temperatura (°C)	c_{wv} (mol m^{-3})
0	0,269
5	0,378
10	0,522
15	0,713
20	0,961
25	1,28
30	1,687
35	2,201
40	2,842
45	3,637

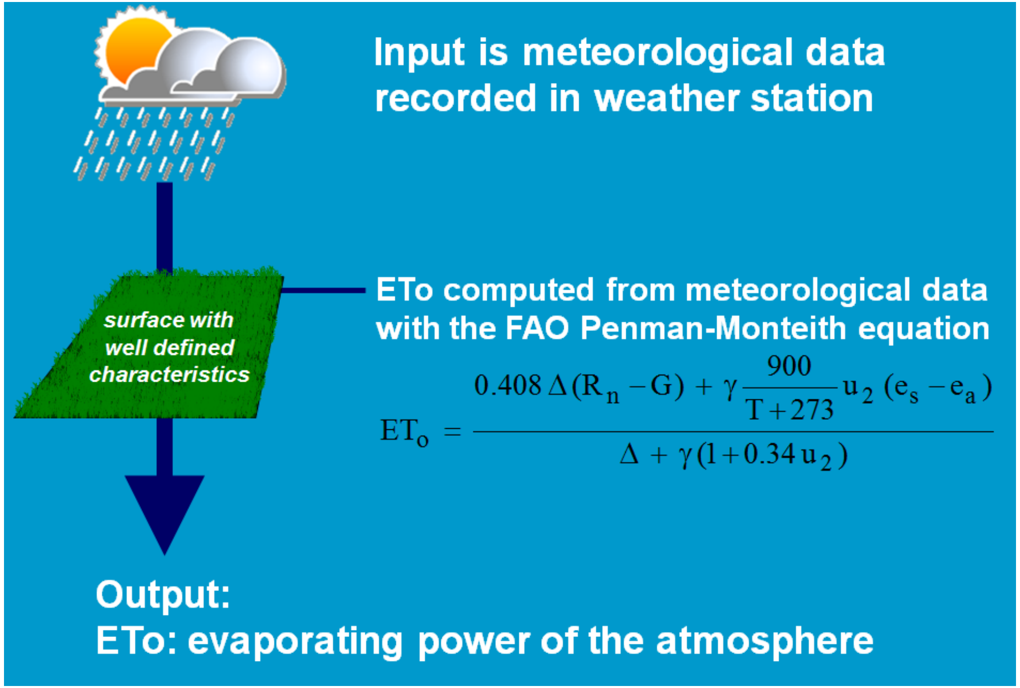
Concentración de vapor de agua en aire saturado en función de la temperatura del aire.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

- Radiación = energía
- Déficit de Presión de Vapor = Humedad Rel.
- Temperatura
- Viento

El fenómeno ET

- **Evapotranspiración de Referencia (Eto)**

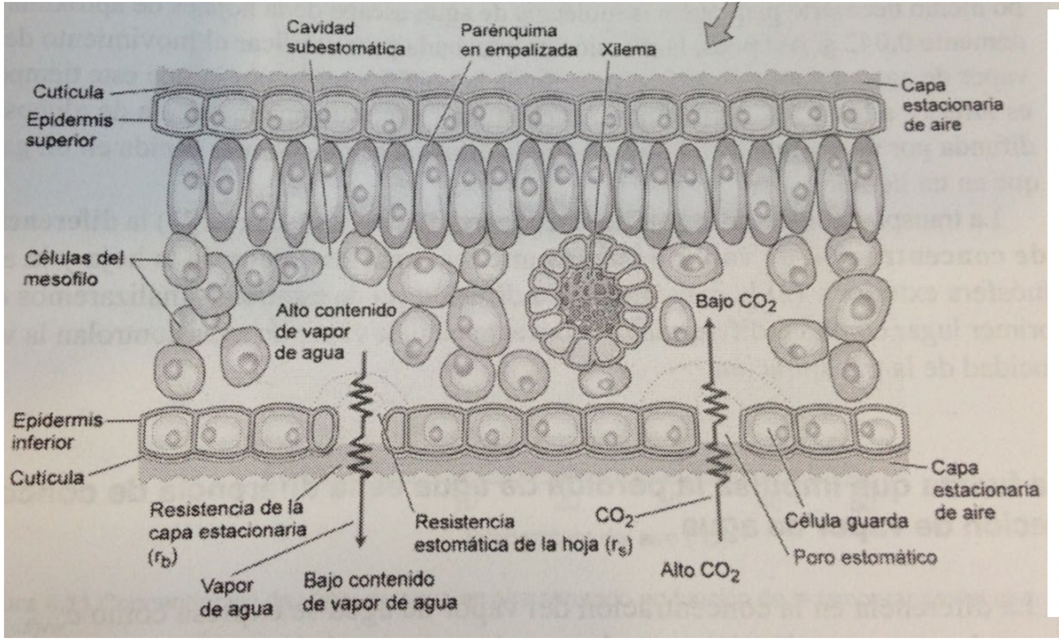


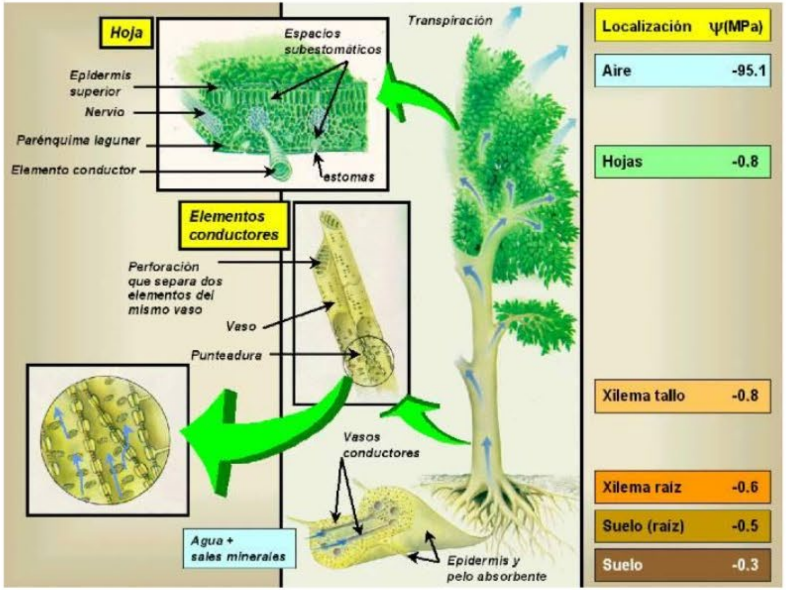
http://riegos.ivia.es/

https://eportal.mapa.gob.es/websiar/SeleccionParametrosMap.aspx?dst=1

El fenómeno ET

❑ Resistencia estomática. Control de la transpiración





El fenómeno ET

- **Resistencia/conductividad estomática. Control de la transpiración**
- **LIGHT**
- Opening and closing of stomata exhibits **diurnal rhythm**, in the sense stomata open during day time and close at nights. So light has an important role in this process.
- **TEMPERATURE**
- At **low temperatures** such as 0^0 C degree to 7-8 ^{0}C, **stomata remain closed**, but with the **increase in temperature** from 7-8 to 30 ^{0}C or so, **stomata open**. However, **high temperature** has contrary effects, and induces the **closing of stomata**.
- **CONCENTRATION OF CO_2**
- Correlative studies between the concentration of CO2 and opening closing of stomata reveal that **higher concentration of CO2 induces the closing of the stomata even during day conditions**. On the other hand, if the concentration of CO2 is very low, it induces the stomata opening even in the absence of light. Changes in the levels of CO2 content in the environs of plants are very well known. Due to active photosynthesis operating in the leaves, the concentration of CO2 decreases rapidly, but at nights, the CO2 concentration builds up because of respiration.
- **WATER SHORTAGE**
- **High water potential** induces the closing of the stomata.

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El fenómeno ET

An-isohídrica

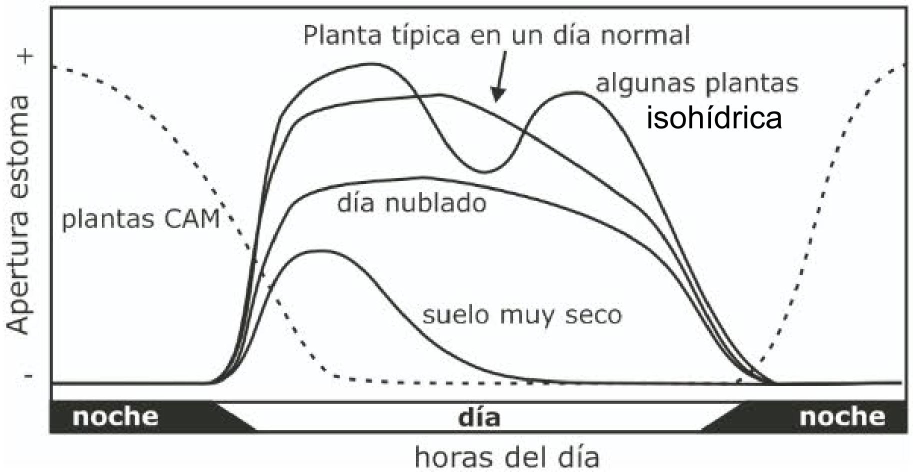
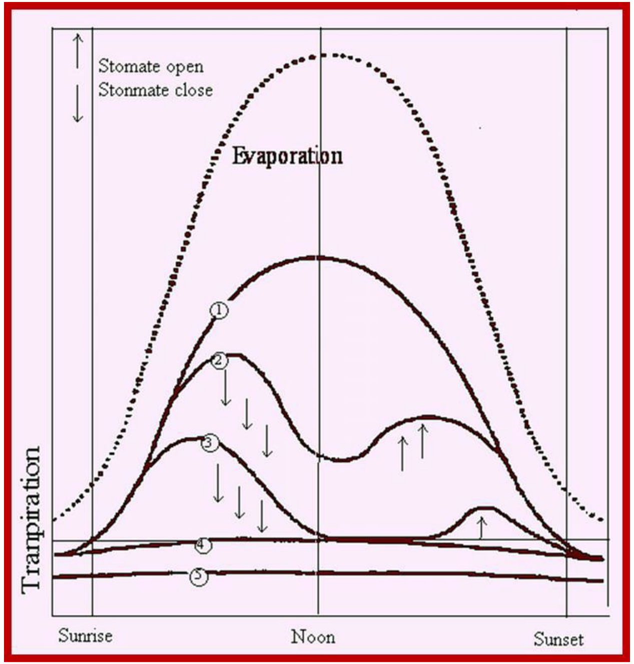
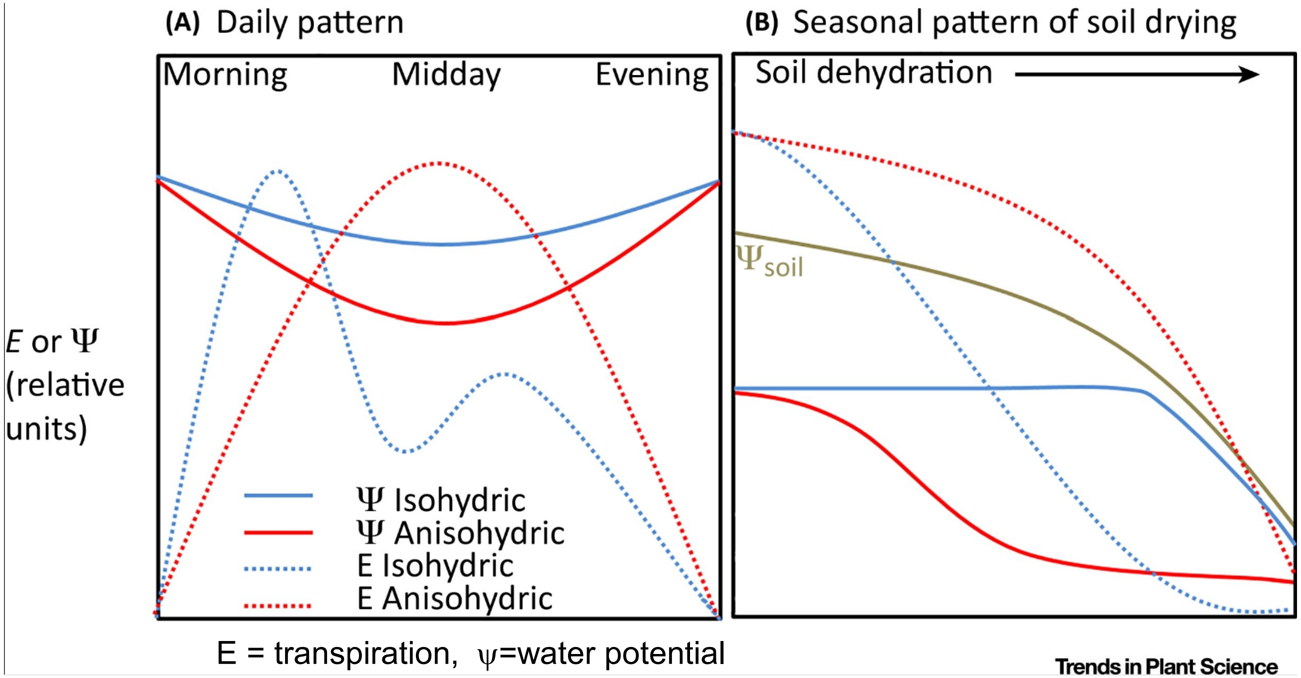


Fig. 8. Esquema que resume el comportamiento estomático a varias condiciones ambientales (Modificado de Salisbury & Ross 1994).

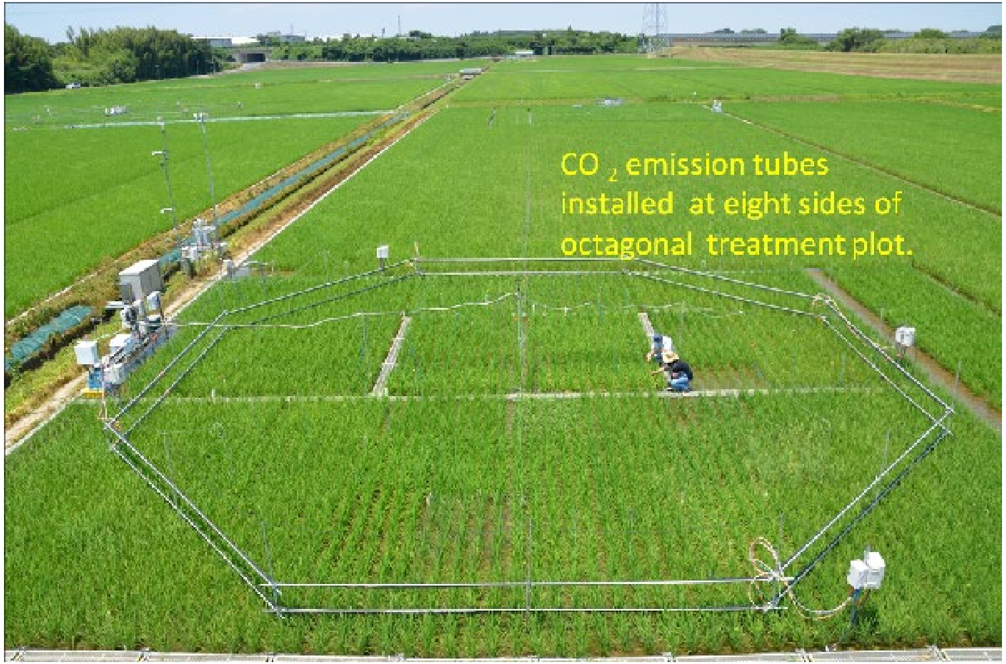


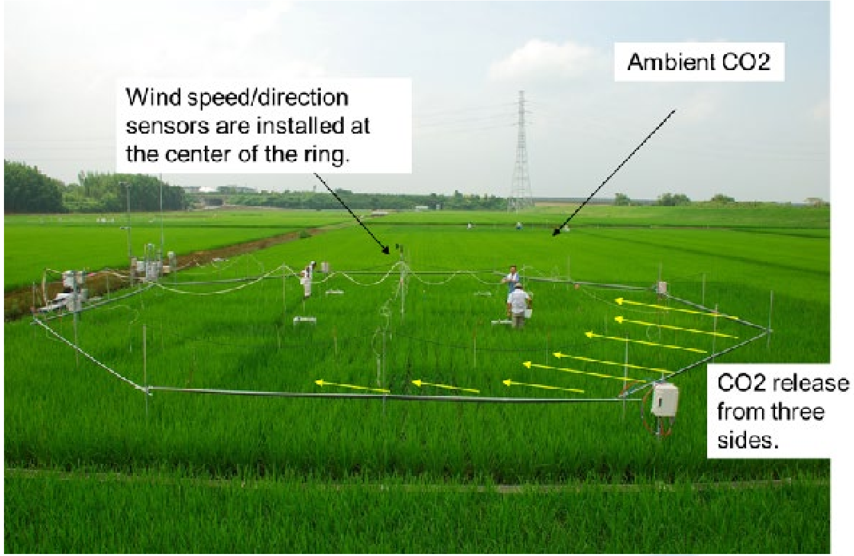
El fenómeno ET



FACE experiments

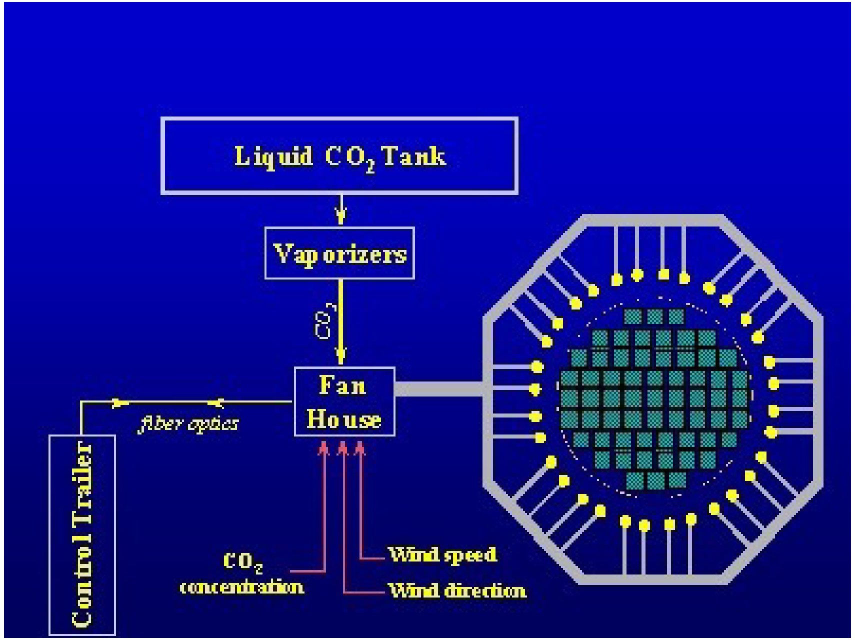
- Free Air Carbon dioxide Enrichment (FACE)

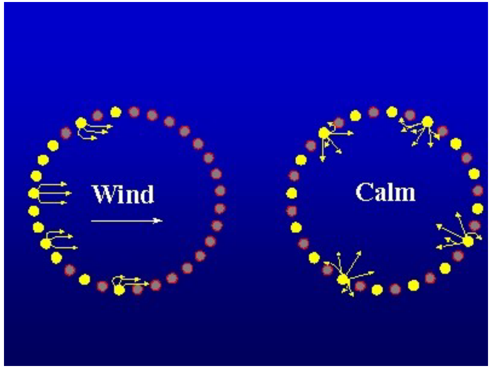


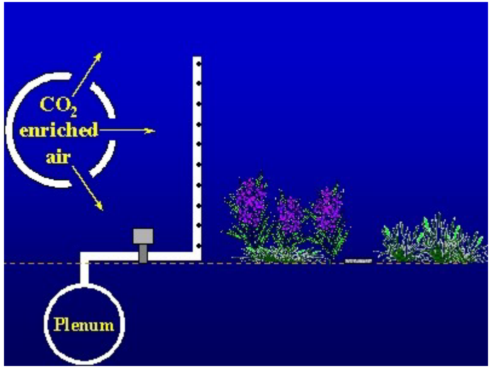


FACE experiments

- Free Air Carbon dioxide Enrichment (FACE)



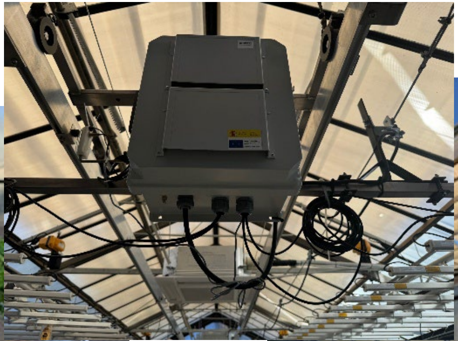




FACE experiments

- Invernaderos de clima futuro
- IFAPA (Córdoba. Junta Andalucía)









Chamber experiments

- Chambers and Open Top Chambers

Índice

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Integral Térmica (GDD, DGU)

The heat units accumulated during a day is calculated by subtracting the base temperature (T_{base}) from the average air temperature (T_{avg})

$$0 \leq GDD = T_{avg} - T_{base} \qquad [\ ^{\circ}C\ day\ ]$$

T_{base}: temperature below which crop development does not progress (conservative)

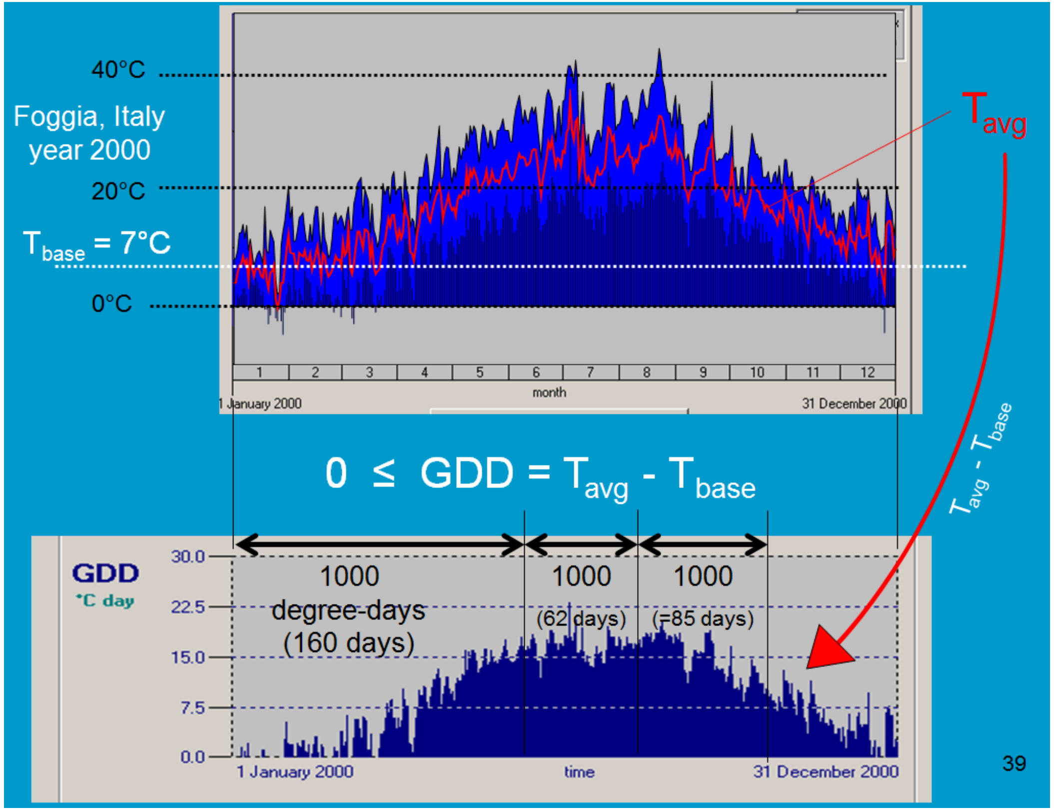
In AquaCrop an upper threshold temperature (T_{upper}) is considered as well

T_{upper}: temperature above which crop development no longer increases with an increase in air temperature

IF T_{avg} is below T_{base}, no heat units can be accumulated during that day, and GDD is zero

iiama

Integral Térmica (GDD, DGU)



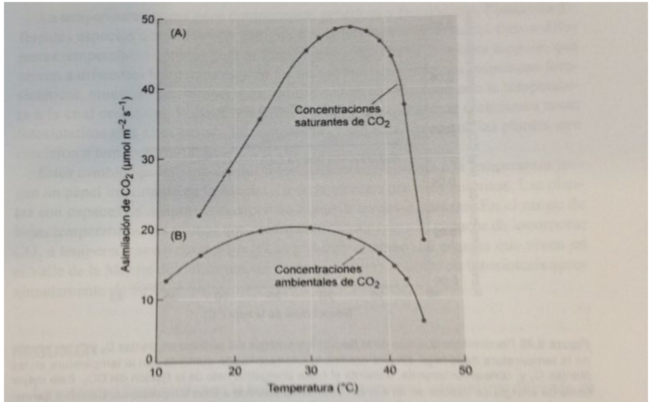


Figura 9.22 Cambios en la fotosíntesis en función de la temperatura a concentraciones de CO_2 que saturan la asimilación fotosintética (A) y a concentraciones atmosféricas normales de CO_2 (B). La fotosíntesis depende fuertemente de la temperatura en condiciones de concentraciones de CO_2 saturantes. Obsérvese que las tasas fotosintéticas son significativamente mayores a concentraciones de CO_2 saturantes. (Redibujado de Berry y Bjorkam 1980).

Fenología del cultivo

- **Staging Corn Growth (***Field Facts* written by DuPont Pioneer Agronomy Sciences)

https://www.pioneer.com/home/site/us/agronomy/library/staging-corn-growth/%23defined

Growth stages of corn are divided into vegetative stages (V) and reproductive stages (R) Table 1. Subdivisions of the V stages are designated numerically as V1, V2, V3, etc. through V(n), where (n) represents the last leaf stage before VT for the specific hybrid under consideration. The first and last V stages are designated as VE (emergence) and VT (tasseling). The number of leaves (n) will fluctuate with hybrid and environment differences. The vegetative stages and six subdivisions of the reproductive stages are designated numerically with their common.

- **Table 1.** Growth and development stages.

Table 1. Growth and development stages.

Vegetative Stages	Reproductive Stages
VE = emergence	R1 = silking
V1= first leaf collar	R2 = blister
V2 = second leaf collar	R3 = milk
V3 = third leaf collar	R4 = dough
V(n) = nth leaf collar	R5 = dent
VT = tasseling	R6 = maturity

Fenología del cultivo

- **Staging Corn Growth (***Field Facts* written by DuPont Pioneer Agronomy Sciences)

https://www.pioneer.com/home/site/us/agronomy/library/staging-corn-growth/%23defined

Reproductive Growth Stages

Tassel (VT) – bottom-most branch of tassel completely visible and silk has not emerged.

Silking (R1) – silks visible outside the husks.

Blister (R2) – kernels white on outside, clear liquid inside.

Milk (R3) – kernel yellow outside, milky white fluid inside.

Dough (R4) – kernel fluid thick/pasty, cob pink or red.

Dent (R5) – most kernels at least partially dented.

Physiological Maturity (R6) – milk line no longer evident, black layer formed. Maximum dry weight is attained.

Fenología del cultivo

- **Staging Corn Growth (***Field Facts* written by DuPont Pioneer Agronomy Sciences)

  https://www.pioneer.com/home/site/us/products/corn/seed-guide /

CORN SEED GUIDE

Johnston, IA (50131)

Print (1 Selected) | Clear Selection | Show Filters | Show Rows All

Choose Products	Product Name	CRM	Technology Segment	Hybrid Family	Market Segment	Silk CRM	Stalk Strength	Root Strength	Stress Emergence	Staygreen	Drought Tol.	Ear Flex	Test Wt.	Plant Ht.	Ear Ht.	Mid-Season Brittle Stalk	Gray Leaf Spot	No. Leaf Blight	Goss`s Wilt	Anthrac. Stalk Rot	Fus. Ear Rot	Gibberella Ear Rot	Diplodia Ear Rot
+	P0157	101		P0157	AQ HAE HTF	102	5	7	5	4	9	6	6	4	4	5	4	5	8	4	5	4	5
✔	P0157AM	101	AM LL RR2	P0157	AQ HAE HTF	102	5	7	5	4	9	6	6	4	4	5	4	5	8	4	5	4	5
+	P0157AMXT	101	AMXT LL RR2	P0157	AQ HAE HTF	102	5	7	5	4	9	6	6	4	4	5	4	5	8	4	5	4	5
+	P0157R	101	RR2	P0157	AQ HAE HTF	102	5	7	5	4	9	6	6	4	4	5	4	5	8	4	5	4	5
+	P0339AM	103	AM LL RR2	P0339	AQ HES HTF	101	6	8	6	6	9	5	5	3	4	5	4	6	8	5	5	4	4
+	P0339AMXT	103	AMXT LL RR2	P0339	AQ HES HTF	101	6	8	6	6	9	5	5	3	4	5	4	6	8	5	5	4	4
+	P0306AM	103	AM LL RR2	P0306	AQ HAE HTF	101	6	8	5	6	9	5	6	3	4	5	4	5	7		3	4	5

Fenología del cultivo

- **Staging Corn Growth (***Field Facts* written by DuPont Pioneer Agronomy Sciences)

https://www.pioneer.com/home/site/us/products/corn/seed-guide/

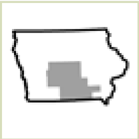
PRODUCT PROFILE

Corn Grain:

P0157AM (AM,LL,RR2)

CRM:	**101**
Silk CRM:	102
GDUs to Silk:	1270
Phy. CRM:	102
GDUs to Phy. Mat.:	2450

Positioning for



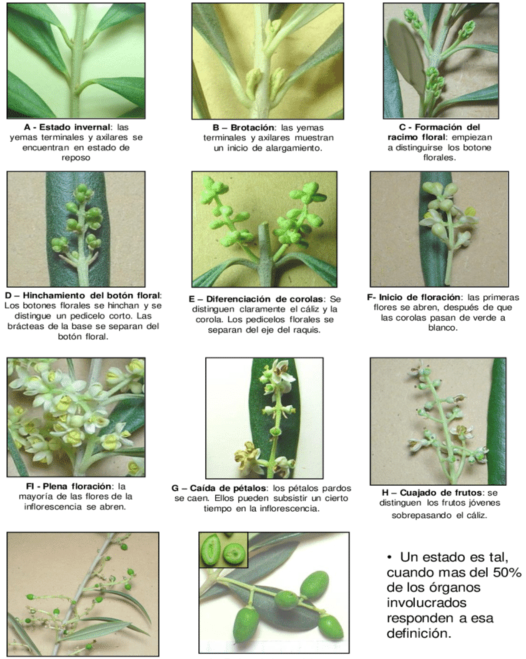
CRM (comparative relative maturity) or RM (relative maturity). In the U.S., this is reported in calendar days such as a 105-day hybrid.

Fenología del cultivo

Planilla 1

Fases Fenológicas del olivo

Fases de "A a I" según Colbrant y Fabre, 1975 .Modificada por Vanesa Aybar. (INTA)



A - Estado invernal: las yemas terminales y axilares se encuentran en estado de reposo

B – Brotación: las yemas terminales y axilares muestran un inicio de alargamiento.

C - Formación del racimo floral: empiezan a distinguirse los botone florales.

D – Hinchamiento del botón floral: Los botones florales se hinchan y se distingue un pedicelo corto. Las brácteas de la base se separan del botón floral.

E – Diferenciación de corolas: Se distinguen claramente el cáliz y la corola. Los pedicelos florales se separan del eje del raquis.

F- Inicio de floración: las primeras flores se abren, después de que las corolas pasan de verde a blanco.

FI - Plena floración: la mayoría de las flores de la inflorescencia se abren.

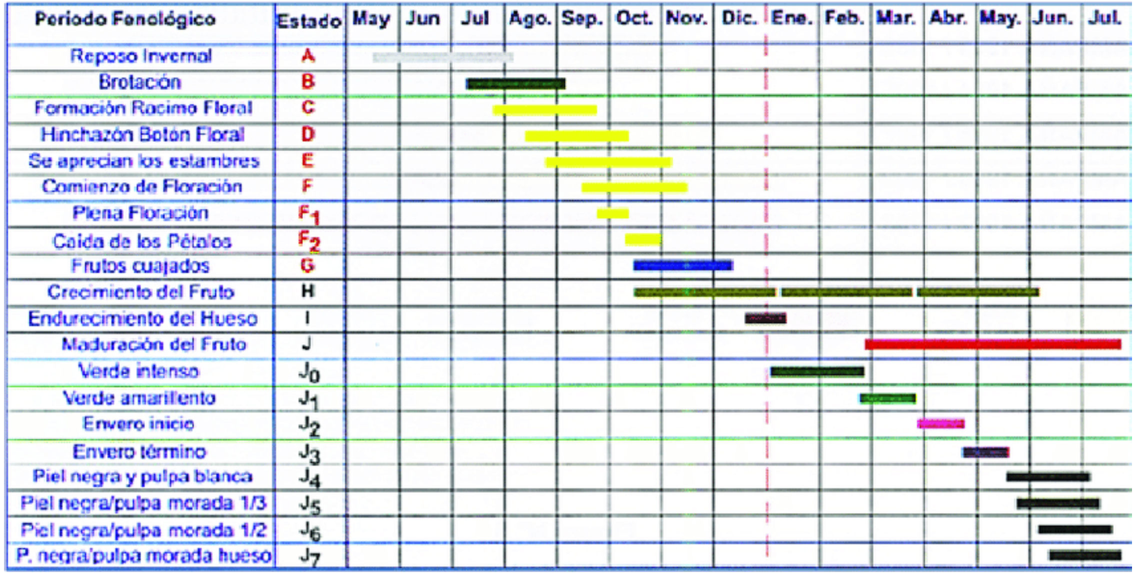
G – Caída de pétalos: los pétalos pardos se caen. Ellos pueden subsistir un cierto tiempo en la inflorescencia.

H – Cuajado de frutos: se distinguen los frutos jóvenes sobrepasando el cáliz.

I - Crecimiento del fruto: los frutos que persisten se agrandan para alcanzar el tamaño de un grano de trigo.

J – Endurecimiento del carozo: Cuando los frutos no pueden ser penetrados por su extremo pistilar.

- Un estado es tal, cuando mas del 50% de los órganos involucrados responden a esa definición.



Horas Frío (Chill-Hours)

- **<u>Menor acumulación de frío invernal</u>. No satisfacción de las necesidades de frío invernal de muchas de las variedades:**
  - **Deficiente brotación vegetativa**
  - **Desincronización de yemas florales y vegetativas**
  - **Caída de yemas**
  - **Floración escasa e irregular**
  - **Problemas de cuajado y producción**

Horas Frío (Chill-Hours)

2. Cálculo de Horas-Frío

Existen diferentes modelos que intentan predecir la ruptura del reposo; en la actualidad esos modelos contemplan rangos de temperatura con diferente eficiencia en la acumulación de frío.

Para salir del reposo, la planta requiere acumular frío. Para el cálculo de este requerimiento se emplean diversas fórmulas, de las cuales las más utilizadas son:

a. Modelo Weinberger: el término "horas de frío" (HF) se refiere a las horas transcurridas a temperaturas inferiores a 7,2 °C. En principio, el recuento de todas aquellas horas bajo 7,2 ºC, se realizaba en base a los datos de un termógrafo ubicado en la propia finca. Actualmente existen modelos de cálculo a partir de los datos diarios de temperaturas de las estaciones climáticas. Cada hora acumulada bajo dicho umbral equivale a una Unidad de Frío.

b. Modelo Utah, desarrollado por Richardson et al. (1974) para melocotonero, que considera un rango diferencial de acumulación de frío (***Tabla 1***).

   Cada hora acumulada bajo dicho umbral equivale a una Unidad de Frío.

c. Modelo Carolina del Norte, desarrollado por Shaltout y Unrath, 1983, para manzanos (***Tabla 2***).

El modelo de Utah, no se adapta a zonas con inviernos benignos, por lo que se han desarrollado modelos alternativos (Modelo dinámico, ***Tabla 3***).

Horas Frío (Chill-Hours)

Tabla 1. Eficiencia en unidades de frío de diferentes temperaturas en melocotonero (Richardson et al., 1974)

Rango de Temperatura (ºC)	Unidades de frío
1,4	0
1,5 - 2,4	0,5
2,5 - 9,1	1
9,2 - 12,4	0,5
12,5 - 15,9	0
16 - 18	-0,5
19,5	-1
21,5	-2

Tabla 2. Eficiencia en unidades de frío acumuladas a diferentes temperaturas en manzano "Starkrimson".

Temperatura (ºC)	Unidades de frío
-1,1	0
1,6	0,5
7,2	1
13,0	0,5
16,5	0
19,0	-0,5
20,7	-1
22,1	-1,5
23,3	-2

Horas Frío (Chill-Hours)

Tabla 3. Modelo dinámico para el cálculo de horas frío (Sudáfrica)

Rango de Temperatura (ºC)	Unidades de frío
<1,4	0
1,5 - 2,4	0,5
2,5 - 9,1	1
9,2 - 12,4	0,5
12,5 - 15,9	0
16 - 18	-0,5
>18	-1

Tabla 4: Requerimiento en frío de especies frutales de hoja caduca (n° horas <7,2°C)

Especie	Mínimo	Máximo
Almendro	100	500
Avellano	800	1600
Ciruelo europeo	700	1600
Ciruelo japonés	100-600	1000
Albaricoquero	200-500	900
Melocotonero**	100-400	1100
Cerezo	500-800	1500
Manzano	200-800	1700
Membrillero	100	500
Nogal*	400	1500
Peral	500	1500
Vid	100-500	1400

***Las variedades californianas tienen requerimientos de 300 HF*
** Las más difundidas entre 600-800 HF*

Horas Frío (Chill-Hours)

Horas frío en cerezo

Los siguientes datos han sido publicados por los obtentores de las variedades o bien por datos publicados por centros de investigación (IMIDA). Se encuentran ordenados de acuerdo a las necesidades de frío estimadas para diferentes variedades de cerezo.

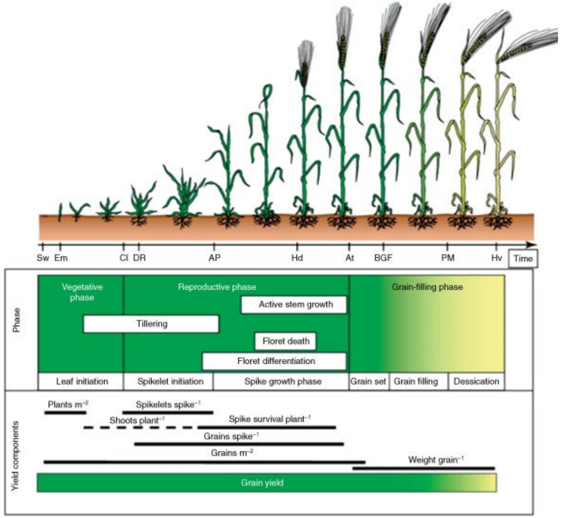
Variedad de cerezo	Horas frío < 7ºC	Unidades Frío (Utah)	Época de floración
Cristobalina	314	510	Extra-Temprana
Royal Tioga	500		Extra-Temprana
Royal Hazel	500		Temprana
Brooks	519	854	Temprana
Early Bigi	571	934	Temprana
Lapins	592	963	Temprana
Satin	600		Temprana
Burlat	**604**	**934**	**Media**
Ruby	610	968	Temprana
Bing	623	993	Media
Primulat	629	972	Temprana
Sweet Heart	649	1019	Media
New Star	654	1028	Temprana
Van	668	1036	Media
Santina	671	1039	Media
Utah Giant	800		Media
Sylvia	800		Tardía
Kordia	900-1.000		Tardía
Summit	1.100		Tardía
Regina	1.000-1.200		Tardía

Horas Frío (Chill-Hours)

Vernalization

Vernalization is the requirement for a period of exposure to low temperature before the plant apical meristem will transition from vegetative to reproductive development.

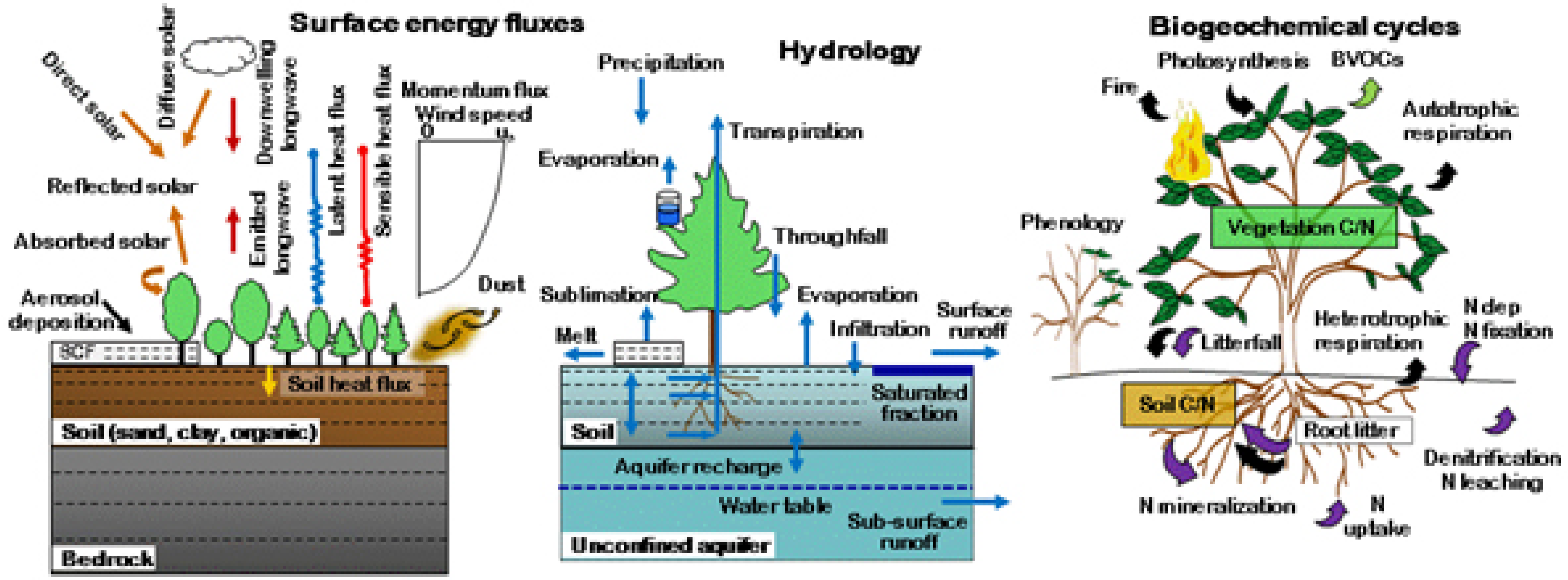
La duración del período de vernalización es muy variable ya que depende de la especie y variedad. Se suele medir en "días de frío" a los cuales tiene que estar sometida una planta para que pueda florecer de forma adecuada. La necesidad de vernalización puede ser absoluta, como en muchas plantas bienales que no pueden florecer sin ella, o relativa, como en muchas de las plantas anuales como el trigo o el centeno, entre otras, que responden cuantitativamente a la vernalización En estos cereales, la respuesta de floración es tanto más positiva cuanto mayor es el tiempo de vernalización. Así, la vernalización completa requiere unos 50 días de frío con temperaturas comprendidas entre –2 y 12º C (los óptimos de temperatura se sitúan entre 2 y 5 ºC). En general, la respuesta de floración ante la vernalización depende de la temperatura usada y de la duración del período de vernalización.



Índice

Otros Ciclos…

- **Ciclos**



Otros Ciclos…

- **Ciclos N-Materia Orgánica**

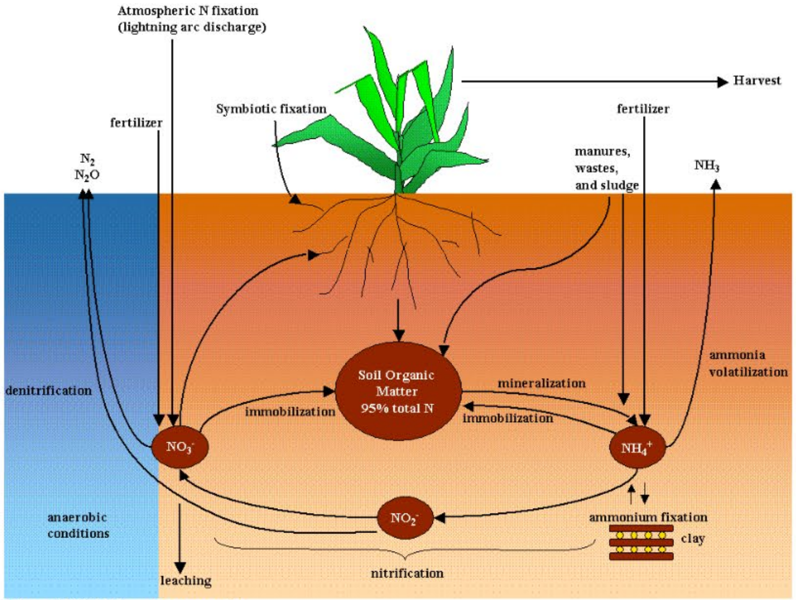
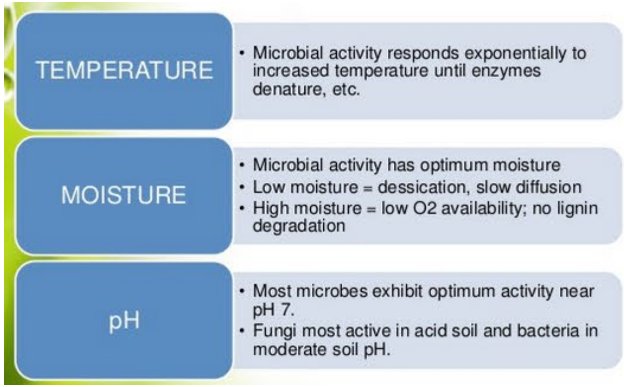


Figure 3:1-1: The nitrogen cycle



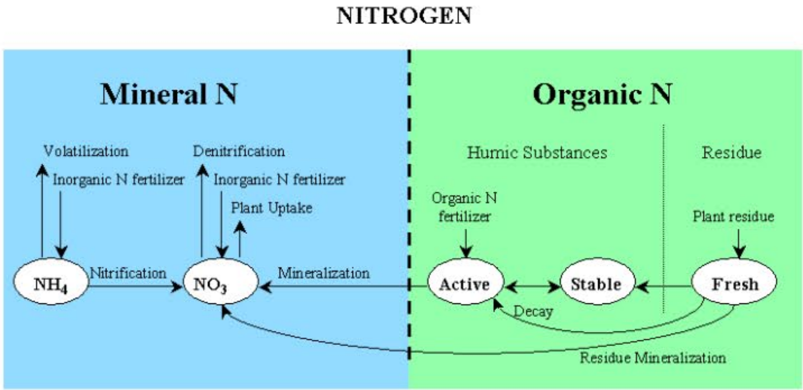


Figure 3:1-2: SWAT soil nitrogen pools and processes that move nitrogen in and out of pools.

- Ciclo Fósforo

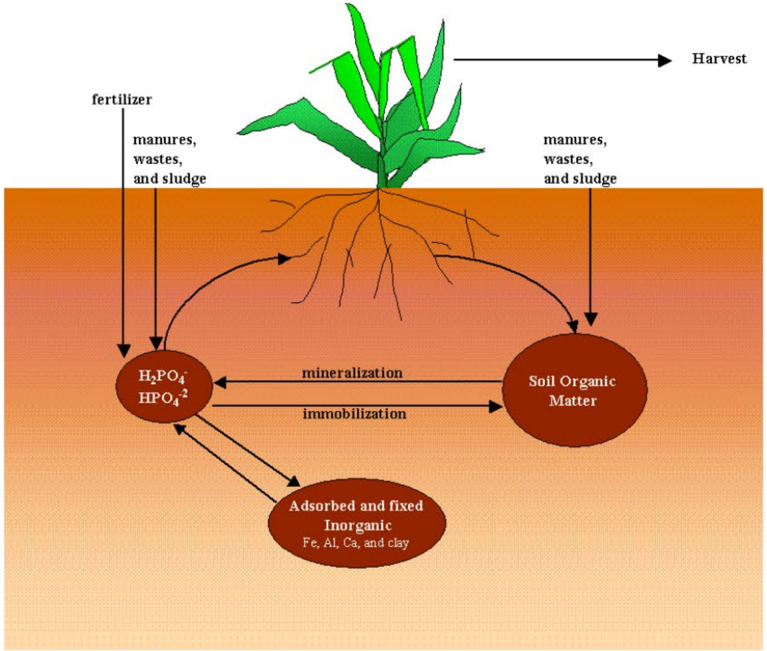


Figure 3:2-1: The phosphorus cycle

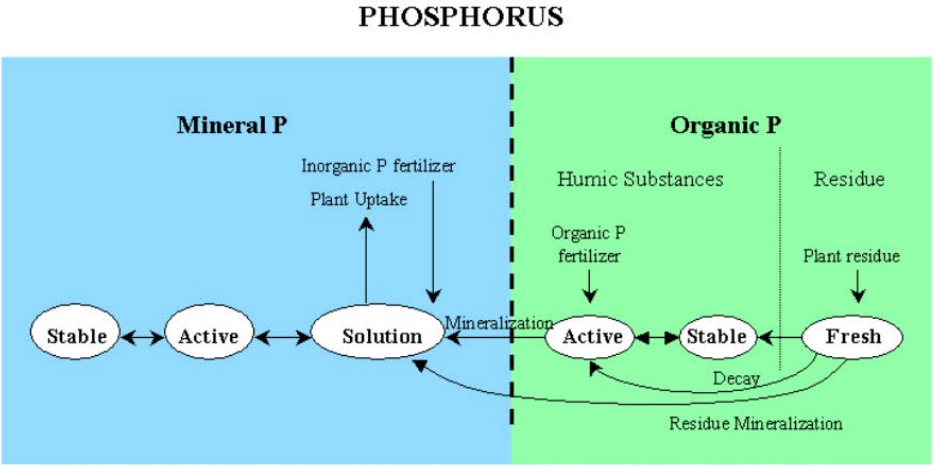
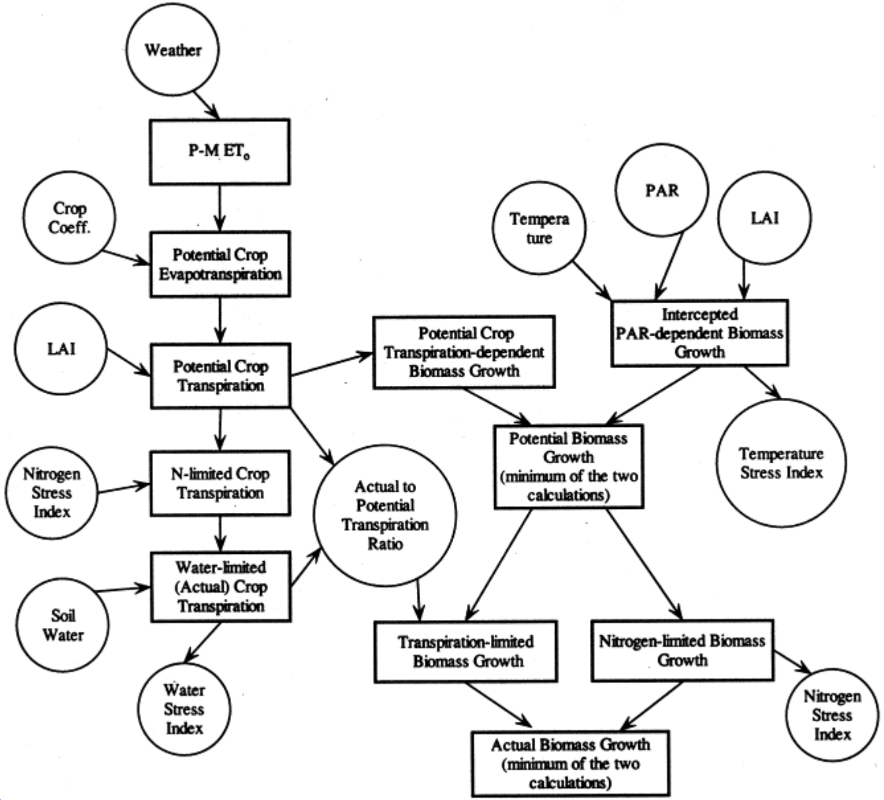


Figure 3:2-2: SWAT soil phosphorus pools and processes that move P in and out of pools.

[Índice]

Crop Modeling

- **Cropsyst**



4 CROP MODELS FOR CLIMATE CHANGE

Crop modeling is one of the approaches combining the complexity of climate change with the physiological functions and other biophysical aspects of soil–crop–atmosphere systems. The first crop simulation models were developed in the 1980s and were used to simulate wheat growth using conservative crop physiological functions. They include ARCWHEAT1 (Porter, 1984; Weir et al., 1984), five models from the ARS Wheat Yield Project of which CERES-Wheat (Ritchie et al., 1985a), and WINTER WHEAT (Baker et al., 1985), were the most prominent, and the Dutch models SUCROS (Laar et al., 1992) and SWHEAT (Van Keulen and Seligman, 1987). In the 1990s, models for various crops, were merged into crop modeling platforms, including DSSAT (Jones et al., 2003) (http://dssat.net/), APSIM (Keating et al., 2003) (http://www.apsim.info/Wiki/), CropSyst (Stöckle et al., 2003) (http://www.bsyse.wsu.edu/CS_Suite/CropSyst/), Wageningen crop models (Van Ittersum et al., 2003b), STICS (Brisson et al., 2003) (http://www7.avignon.inra.fr/agroclim_stics_eng/) and EPIC (Kiniry et al., 1995). In the 2000s, new models emerged including the SIRIUS model (Martre et al., 2006; Chapters 14 and 17), the WheatGrow model (Pan et al., 2006) which includes grain quality simulations, and the RiceGrow model considering plant architecture (Zhu et al., 2009). Over the last 10 years, researchers developed more crop models that vary in their approach and complexity, including SALUS (Basso et al., 2001), AquaCrop (Steduto et al., 2009) (http://www.fao.org/nr/water/aquacrop.html), HERMES (Kersebaum, 2007), MONICA (Nendel et al., 2011) and LPJmL

- Epic/Apex/SWAT…..

5:2.1.1 Biomass Production

The amount of daily solar radiation intercepted by the leaf area of the plant is calculated using Beer's law (Monsi and Saeki, 1953):

$$H_{phosyn} = 0.5 \cdot H_{day} \cdot (1 - \exp(-k_\ell \cdot LAI)) \quad 5:2.1.1$$

where H_{phosyn} is the amount of intercepted photosynthetically active radiation on a given day (MJ m^{-2}), H_{day} is the incident total solar (MJ m^{-2}), $0.5 \cdot H_{day}$ is the incident photosynthetically active radiation (MJ m^{-2}), k_ℓ is the light extinction coefficient, and LAI is the leaf area index.

Photosynthetically active radiation is radiation with a wavelength between 400 and 700 mm (McCree, 1972). Direct solar beam radiation contains roughly 45% photosynthetically active radiation while diffuse radiation contains around 60% photosynthetically active radiation (Monteith, 1972; Ross, 1975). The fraction of photosynthetically active radiation will vary from day to day with variation in overcast conditions but studies in Europe and Israel indicate that 50% is a representative mean value (Monteith, 1972; Szeicz, 1974; Stanhill and Fuchs, 1977).

Radiation-use efficiency is the amount of dry biomass produced per unit intercepted solar radiation. The radiation-use efficiency is defined in the plant growth database and is assumed to be independent of the plant's growth stage. The maximum increase in biomass on a given day that will result from the intercepted photosynthetically active radiation is estimated (Monteith, 1977):

$$\Delta bio = RUE \cdot H_{phosyn} \quad 5:2.1.2$$

where Δbio is the potential increase in total plant biomass on a given day (kg/ha), RUE is the radiation-use efficiency of the plant (kg/ha·(MJ/m^2)$^{-1}$ or 10^{-1} g/MJ), and H_{phosyn} is the amount of intercepted photosynthetically active radiation on a given day (MJ m^{-2}). Equation 5:2.1.2 assumes that the photosynthetic rate of a canopy is a linear function of radiant energy.

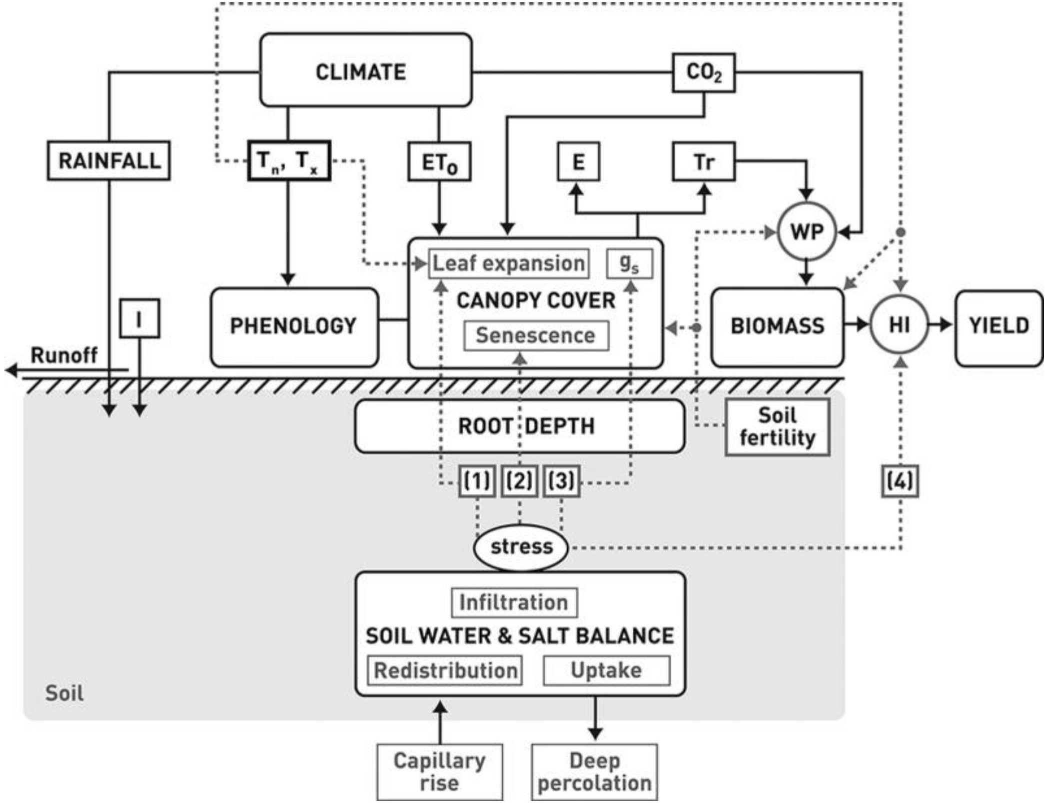
The total biomass on a given day, d, is calculated as:

$$bio = \sum_{i=1}^{d} \Delta bio_i \quad 5:2.1.3$$

where bio is the total plant biomass on a given day (kg ha^{-1}), and Δbio_i is the increase in total plant biomass on day i (kg/ha).

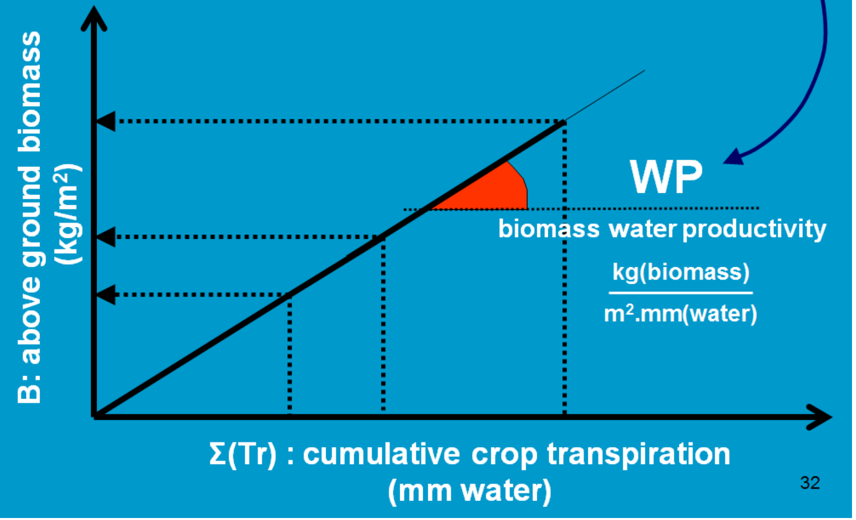
Crop Modeling

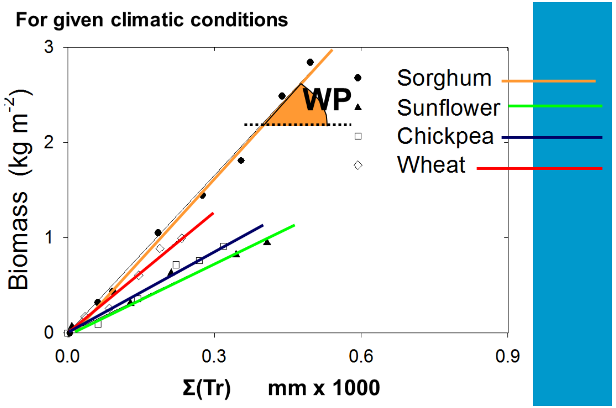
- **Aquacrop**



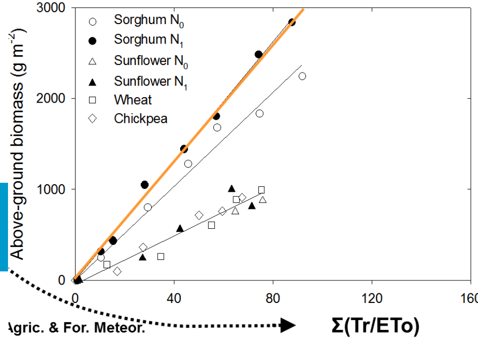
Aquacrop

There exists a stable & conservative nature between
- Biomass (B) and
- Cumulative transpiration (Σ(Tr))



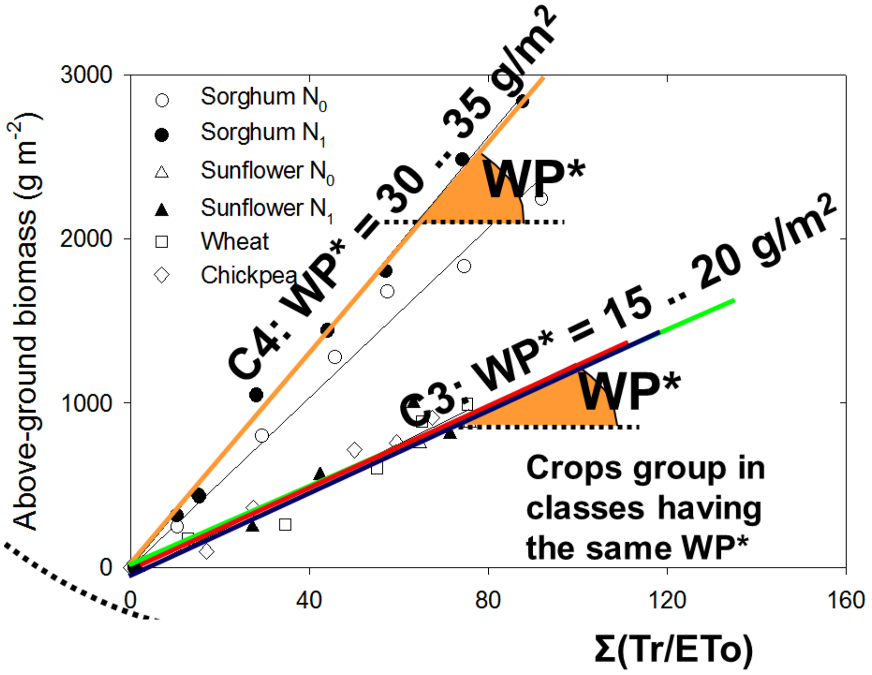


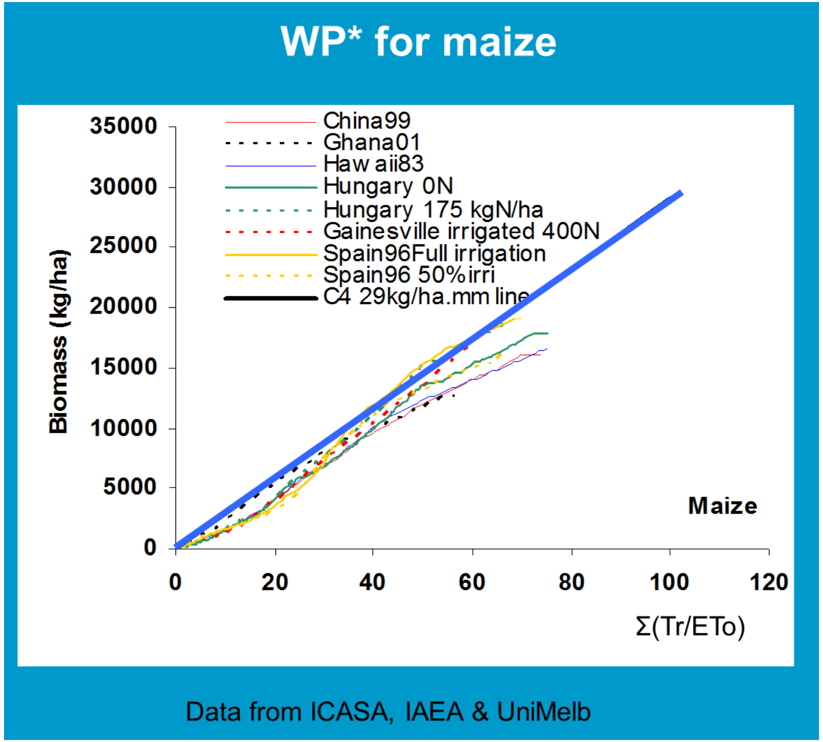
by dividing Tr by ETo
WP is normalized for climate



Crop Modeling

- **Aquacrop**

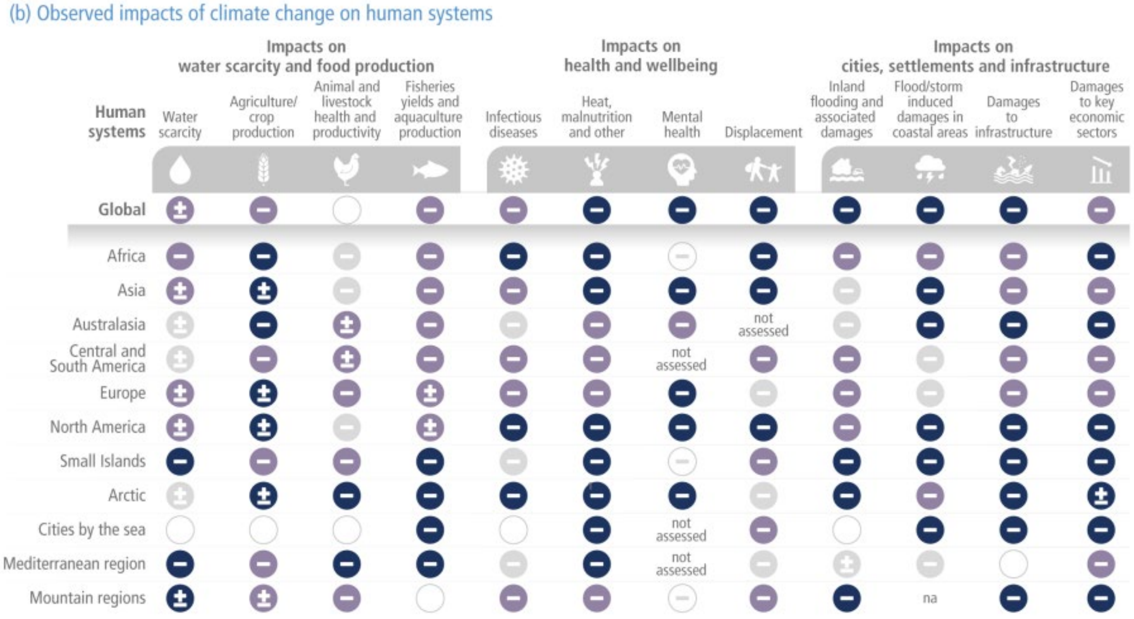




IPCC AR6.

- **Qué dicen los informes del IPCC AR5. WGII. Final Draft-Full Report**

  https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf



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IPCC AR5. Chapter 7.

CHAPTER

20

Crop modeling for climate change impact and adaptation

Senthold Asseng[1], *Yan Zhu*[2], *Enli Wang*[3], *Weijian Zhang*[4]

[1]University of Florida, Gainesville, USA
[2]Nanjing Agricultural University, China
[3]CSIRO, Australia
[4]Institute of Crop Sciences, Chinese Academy of Agricultural Sciences, Beijing, China

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TABLE 20.1 Summary of climate change factors and general impact on crops

Climate variables		Realized trends	Projected trends	General impacts on crop growth
CO_2		1.4 ppm/a (379 ppm in 2005)	1.9 ppm/a (450 ppm by 2050)	Increased net photosynthesis, plant biomass production and transpiration-use efficiency
				Reduced transpiration
				Increased canopy temperature
				Reduced crop nutrient concentration
Temperature	Min	0.56°C (2005) since 1906	0.02°C/a (1.3°C– 1.7°C in 2050)	Reduced frost risk
	Avg	0.74°C (2005) since 1906	1.8–4.0°C in 2100	Increased stomatal conductance, photosynthesis, respiration, and transpiration; faster growth and development, phenological shifts; reduced transpiration efficiency
	Max	0.92°C (2005) since 1906		Increased heat stress
Rainfall		0.11 mm/a	Variable changes across the globe, in general, increase at high latitude and decrease at low latitude	Positive or negative, depending on the direction and other factors
Solar radiation		Reduction in solar radiation and increased diffused light fraction (1365 W m^{-2} in 2005)	Reduction in solar radiation and increased diffused light fraction	Increase photosynthesis and growth due to increase diffused light fraction
Ozone	Troposphere	0.5–2.5%/a (50 ppb in 2000)	0.5–2.5%/a (60– 100 ppb by 2050)	Increased foliar injury, decreased growth and yield
	Stratosphere	0.6 %/a (265 DU in 2000)	0.1–0.2 %/a (275– 286 DU by 2050)	Reduce leaf expansion and biomass accumulation

After IPCC, 2013.

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Crop response to Climate Change

- **Temperature**
- In **cooler regions**, such as the northeast of China, an increase in annual mean temperature since the 1980s has contributed to the reported **increase in agriculture production**.
- An indirect effect of global warming can be **higher plant water demand** due to **increased stomatal conductance and transpiration** at higher temperatures.
- In **dryland** agriculture this can directly **limit plant growth**, while in irrigated systems increased temperatures could result in higher irrigation water demands in combination with increased losses through evaporation.
- Higher temperature can negatively impact plant production indirectly through **accelerated phenology** with **less time for accumulating biomass.**
- Temperature increase around **anthesis and grain filling can reduce grain yield** substantially.
- Temperature changes can also **affect yield quality** as shown for grain protein content and dough quality of wheat.

Crop response to Climate Change

- **Temperature**
- **Extreme temperature events will occur more often**. Extreme temperature events can have large negative impacts on plant growth and yield. Temperatures **below 9°C and above 31°C around anthesis** can reduce potential grain weight and therefore grain yield of wheat.
- Indirect effects of temperature may lead to the **paradox of increasing frost risk** in some systems. Shifting of flowering to ‘cooler’ parts of the season due to accelerated phenology with higher temperatures could potentially increase the risk of frost at flowering.

  - **Vine Case**: The projected trends for climate change throughout the entire 21st century (IPCC 2014) suggest major advances in vine phenology (10-20 days).
    - More water requirements
    - Yield is decreased in response to water stress
    - Ripening with higher temperatures
    - Higher temperatures also enhance vine respiration, and this increases carbon losses. This will decrease the amount of CO_2 assimilated per unit of water transpired, known as instantaneous water-use efficiency.
    - Grape and wine composition

Crop response to Climate Change

- **Rainfall**
- Not only the **total rainfall amount** but also the **rainfall distribution** plays an important role for determining crop yields.
- Rainfall around **anthesis ensuring water supply during grain filling is particularly critical** in annual crops
- Extreme events could include a **higher drought** frequency with long-term effects on farm viability which could reduce crop production and yields below what is expected based on the average climate change.
- Impact on soil infiltration depth, water balance, soil mineralization and crop water-use efficiency.

- **Solar radiation**
- Many studies have indicated a **reduction in the amount of solar radiation** reaching the earth's surface probably **caused by** a combination of increased **cloud cover and higher atmospheric concentrations of aerosols.**
- As total radiation has declined in recent decades, there is an accompanying effect of a **higher diffused light fraction**.
- While reduction in radiation can reduce crop photosynthesis, the increase in the fraction of diffused radiation can increase the crop radiation-use efficiency, **partially compensating** the impact of radiation decline.
- Lower solar radiation also **reduces potential evaporation**. In water-limited environments, this can increase plant available water and thus increase plant production.

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Crop response to Climate Change

- **Ozone O3**
- Ozone (O3) is a form of oxygen that is an **atmospheric pollutant at ground level**. Most of the O3 in the atmosphere (about 90%) is in the **stratosphere**, the remaining in the troposphere.
- The ozone in the troposphere and stratosphere has different effects on life on the earth depending on its location. **Stratospheric ozone plays a beneficial role by absorbing solar ultraviolet radiation** (Uv-B) from reaching the earth's surface.
- **Ozone is a strong oxidizer**, and therefore ozone closer to the earth's surface is potentially destructive to plants. in crops, ozone can **create reactive molecules that destroy Rubisco, an enzyme crucial for photosynthesis and accelerates leaf senescence**
- Increasing concentration of O3 at ambient CO2 **reduces yield of many crop species**.

Crop response to Climate Change

- **Elevated atmospheric CO_2 concentrations**
- Two main effects on crop growth. It increases the intercellular CO_2 concentration leading to **increased net photosynthesis** rate and, at the same time, **reduces stomatal conductance** resulting in reduced transpiration.
- Many **experimental studies** have shown that higher CO_2 increases plant biomass production and yield, and increases in crop yield are lower than the photosynthetic response:
  - C3 species (e.g. wheat, soybean, potatoes, sunflower) and C4 species (e.g. maize, sorghum, millet) have a different degree in response to elevated CO_2. **At 500–550 ppm of CO_2 concentration, grain yields of C3 crops increase by 10–20% while changes in C4 crop yields are less than 13%.**
  - On average, **doubling** CO_2 concentrations **increases photosynthesis by between 30 and 50%** in C3 species, and by **10–25%** in C4 species
- The impact of elevated CO_2 on plant production depends on water and nutrient availability.
  - The **highest response to elevated CO_2 is found under water-limiting conditions**, improving **WUE**.
- An important indirect effect of higher atmospheric CO_2, is **reduced plant nutrient concentrations**.
- Another indirect effect of atmospheric CO_2 **increase will be on canopy temperatures** via the reduction in stomatal conductance. Reduced stomatal conductance due to atmospheric CO_2 increase might therefore have additional effects on **crop growth and development similar to an increase in temperatures**.

Data Descriptor | Open Access | Published: 16 February 2022

A global dataset for the projected impacts of climate change on four major crops

Toshihiro Hasegawa, Hitomi Wakatsuki, Hui Ju, Shalika Vyas, Gerald C. Nelson, Aidan Farrell, Delphine Deryng, Francisco Meza & David Makowski

Scientific Data **9**, Article number: 58 (2022) | Cite this article

Abstract

Reliable estimates of the impacts of climate change on crop production are critical for assessing the sustainability of food systems. Global, regional, and site-specific crop simulation studies have been conducted for nearly four decades, representing valuable sources of information for climate change impact assessments. However, the wealth of data produced by these studies has not been made publicly available. Here, we develop a global dataset by consolidating previously published meta-analyses and data collected through a new literature search covering recent crop simulations. The new global dataset builds on 8703 simulations from 202 studies published between 1984 and 2020. It contains projected yields of four major crops (maize, rice, soybean, and wheat) in 91 countries under major emission scenarios for the 21st century, with and without adaptation measures, along with geographical coordinates, current temperature and precipitation levels, projected temperature and precipitation changes. This dataset provides a solid basis for a quantitative assessment of the impacts of climate change on crop production and will facilitate the rapidly developing data-driven machine learning applications.

Table 1 Summary statistics of climate change impacts on four major crops expresses as per decade impact and per degree impact without adaptation.

From: A global dataset for the projected impacts of climate change on four major crops

	Per decade impact (% decade^{-1})				Per degree impact (% °C^{-1})			
	Maize	Rice	Soybean	Wheat	Maize	Rice	Soybean	Wheat
Minimum	−40.0	−40.8	−30.0	−35.4	−158.7	−71.7	−112.6	−122.3
Maximum	14.2	26.2	13.8	21.2	70.8	120.7	58.3	153.7
Mean	−3.9	−1.4	−2.6	−1.8	−13.5	−2.6	−8.8	−5.6
1st quartile	−5.5	−2.5	−6.7	−3.5	−18.1	−7.1	−16.9	−10.9
Median	−2.1	−0.7	−1.2	−1.2	−7.1	−2.3	−4.0	−3.7
3rd quartile	−0.3	0.8	1.7	0.7	−1.1	2.7	6.3	2.3
Standard deviation	7.0	4.7	7.4	5.0	25.4	12.0	26.3	17.4
Skewness	−1.8	−2.6	−0.9	−1.7	−1.9	1.0	−1.1	−1.2
Kurtosis	8.6	21.9	4.7	10.8	8.6	24.4	5.2	17.4

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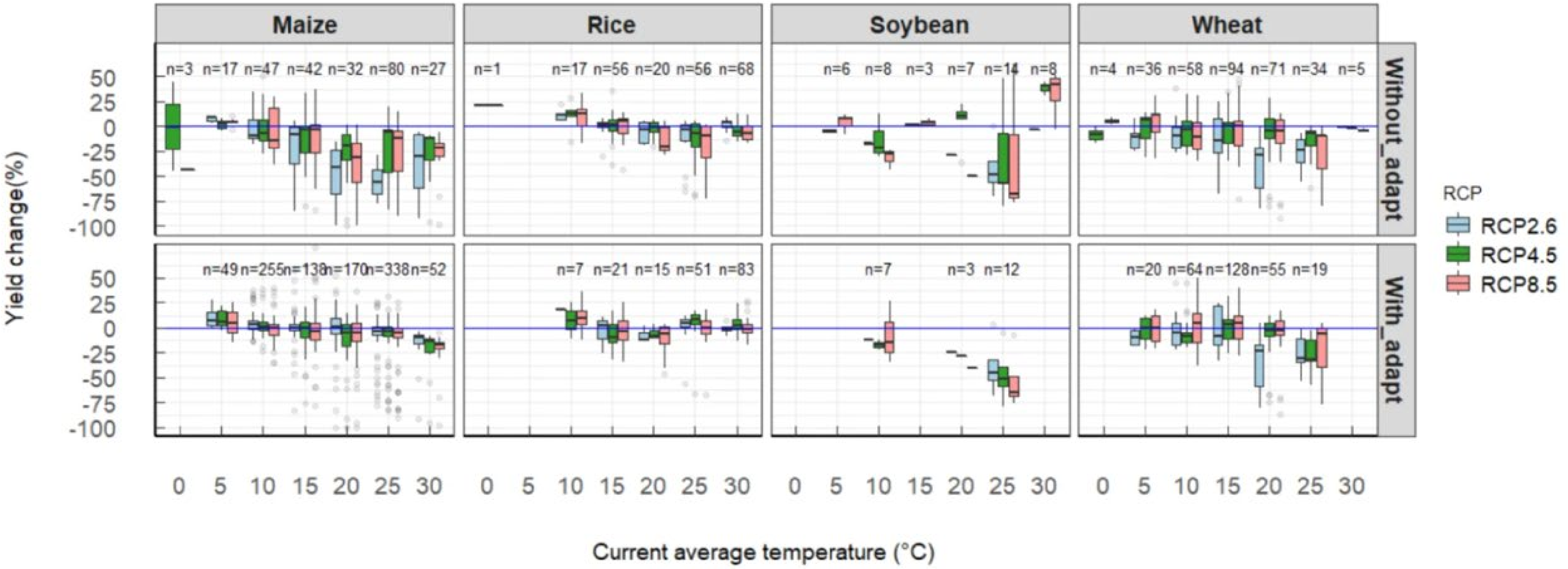
(a) Mid-Century



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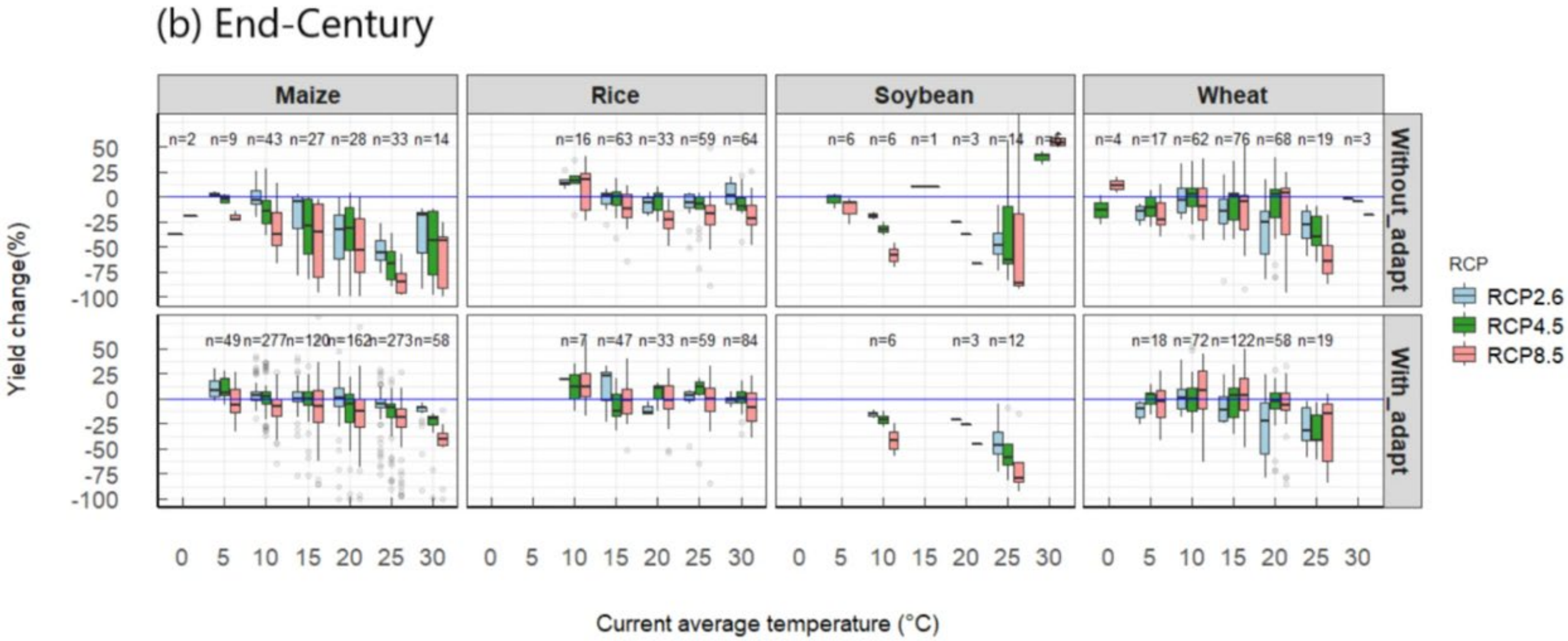
(b) End-Century
Maize
Rice
Soybean
Wheat
Without_adapt
With_adapt
Yield change(%)
Current average temperature (°C)
RCP
RCP2.6
RCP4.5
RCP8.5

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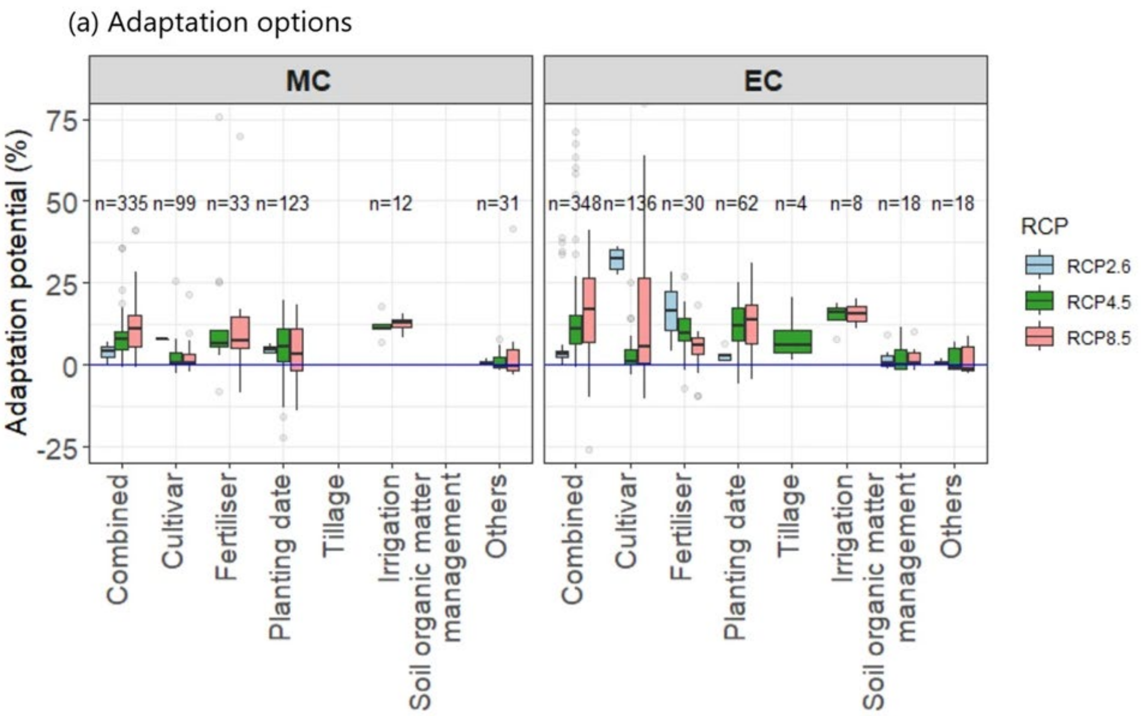

(a) Adaptation options
MC
EC
Adaptation potential (%)
75
50
25
0
-25
n=335 n=99 n=33 n=123 n=12 n=31
n=348 n=136 n=30 n=62 n=4 n=8 n=18 n=18
Combined
Cultivar
Fertiliser
Planting date
Tillage
Irrigation
Soil organic matter management
Others
RCP
RCP2.6
RCP4.5
RCP8.5

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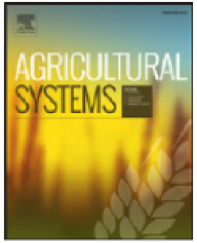

Adaptation response surfaces for managing wheat under perturbed climate and CO_2 in a Mediterranean environment

Check for updates

M. Ruiz-Ramos [a,*], R. Ferrise [b], A. Rodríguez [a], I.J. Lorite [c], M. Bindi [b], T.R. Carter [d], S. Fronzek [d], T. Palosuo [e], N. Pirttioja [d], P. Baranowski [f], S. Buis [g], D. Cammarano [h], Y. Chen [e], B. Dumont [i], F. Ewert [j], T. Gaiser [j], P. Hlavinka [k,l], H. Hoffmann [j], J.G. Höhn [e], F. Jurecka [k,l], K.C. Kersebaum [m], J. Krzyszczak [f], M. Lana [m], A. Mechiche-Alami [n], J. Minet [o], M. Montesino [p], C. Nendel [m], J.R. Porter [p], F. Ruget [h], M.A. Semenov [q], Z. Steinmetz [r], P. Stratonovitch [q], I. Supit [s], F. Tao [e], M. Trnka [k,l], A. de Wit [s], R.P. Rötter [t]

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Table 1. Adaptation options and climate/[CO_2] perturbations tested in the preliminary phase (normal font) and selected for the simulation phase (bold font). Simulations of the preliminary phase were run with CERES-wheat and SiriusQuality2 models.

Adaptation	Tested range	N preliminary phase	N simulation phase
Vernalization (V)	**Yes (WW, standard), No (SW)**	2	2
Phenology (Ph)	**−10%, 0%, +10%,** +20%	4	3
Sowing date (SD)	**−15, 0,** −15, **+30,** +45	5	3
Irrigation (I)	**Supplementary (40 mm at flowering), Full (only CERES), rainfed**	3	3
Combinations	V×Ph×SD×I	2*4*5*3=120	54
Perturbations (P, T, CO_2)		(0%, 0 °C, 360 ppm), (−15%, +2 °C, 447 ppm), (−30%, +4 °C, 521 ppm)	From −40 to +30% at 1 °C intervals, from −1 to +7 °C at 10% intervals, for 360, 447 and 521 ppm

Abbreviations: winter wheat (WW), spring wheat (SW), temperature (T), precipitation (P).

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ABSTRACT

Adaptation of crops to climate change has to be addressed locally due to the variability of soil, climate and the specific socio-economic settings influencing farm management decisions. Adaptation of rainfed cropping systems in the Mediterranean is especially challenging due to the projected decline in precipitation in the coming decades, which will increase the risk of droughts. Methods that can help explore uncertainties in climate projections and crop modelling, such as impact response surfaces (IRSs) and ensemble modelling, can then be valuable for identifying effective adaptations. Here, an ensemble of 17 crop models was used to simulate a total of 54 adaptation options for rainfed winter wheat (*Triticum aestivum*) at Lleida (NE Spain). To support the ensemble building, an *ex post* quality check of model simulations based on several criteria was performed. Those criteria were based on the "According to Our Current Knowledge" (AOCK) concept, which has been formalized here. Adaptations were based on changes in cultivars and management regarding phenology, vernalization, sowing date and irrigation. The effects of adaptation options under changed precipitation (P), temperature (T), [CO_2] and soil type were analysed by constructing response surfaces, which we termed, in accordance with their specific purpose, adaptation response surfaces (ARSs). These were created to assess the effect of adaptations through a range of plausible P, T and [CO_2] perturbations. The results indicated that impacts of altered climate were predominantly negative. No single adaptation was capable of overcoming the detrimental effect of the complex interactions imposed by the P, T and [CO_2] perturbations except for supplementary irrigation (sI), which reduced the potential impacts under most of the perturbations. Yet, a combination of adaptations for dealing with climate change demonstrated that effective adaptation is possible at Lleida. Combinations based on a cultivar without vernalization requirements showed good and wide adaptation potential. Few combined adaptation options performed well under rainfed conditions. However, a single sI was sufficient to develop a high adaptation potential, including options mainly based on spring wheat, current cycle duration and early sowing date. Depending on local environment (e.g. soil type), many of these adaptations can maintain current yield levels under moderate changes in T and P, and some also under strong changes. We conclude that ARSs can offer a useful tool for supporting planning of field level adaptation under conditions of high uncertainty.

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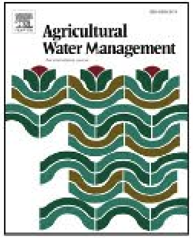

Evaluation of olive response and adaptation strategies to climate change under semi-arid conditions

Check for updates

I.J. Lorite[a,*], C. Gabaldón-Leal[a], M. Ruiz-Ramos[b], A. Belaj[a], R. de la Rosa[a], L. León[a], C. Santos[a]

[a] Andalusian Institute of Agricultural Research and Training (IFAPA), Centre "Alameda del Obispo", Córdoba, Spain
[b] Research Centre for the Management of Agricultural and Environmental Risks, Technical University of Madrid, Spain

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ABSTRACT

AdaptaOlive is a simplified physically-based model that has been developed to assess the behavior of olive under future climate conditions in Andalusia, southern Spain. The integration of different approaches based on experimental data from previous studies, combined with weather data from 11 climate models, is aimed at overcoming the high degree of uncertainty in the simulation of the response of agricultural systems under predicted climate conditions.

The AdaptaOlive model was applied in a representative olive orchard in the Baeza area, one of the main producer zone in Spain, with the cultivar 'Picual'. Simulations for the end of the 21st century showed olive oil yield increases of 7.1 and 28.9% under rainfed and full irrigated conditions, respectively, while irrigation requirements decreased between 0.5 and 6.2% for full irrigation and regulated deficit irrigation, respectively. These effects were caused by the positive impact of the increase in atmospheric CO_2 that counterbalanced the negative impacts of the reduction in rainfall. The high degree of uncertainty associated with climate projections translated into a high range of yield and irrigation requirement projections, confirming the need for an ensemble of climate models in climate change impact assessment.

The AdaptaOlive model also was applied for evaluating adaptation strategies related to cultivars, irrigation strategies and locations. The best performance was registered for cultivars with early flowering dates and regulated deficit irrigation. Thus, in the Baeza area full irrigation requirements were reduced by 12% and the yield in rainfed conditions increased by 7% compared with late flowering cultivars. Similarly, regulated deficit irrigation requirements and yield were reduced by 46% and 18%, respectively, compared with full irrigation. The results confirm the promise offered by these strategies as adaptation measures for managing an olive crop under semi-arid conditions in a changing climate.

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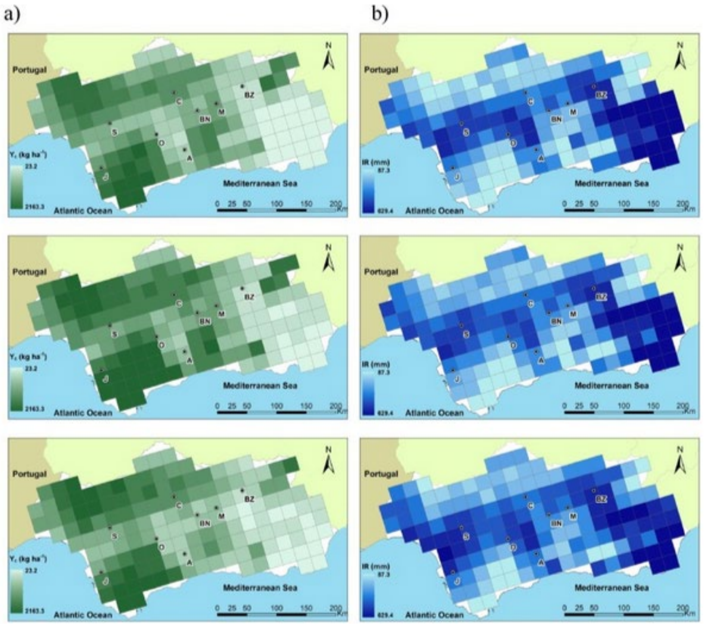

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Fig. 8. Maps of simulated yield under rainfed conditions (Y_C; a) and irrigation water requirements (IR) under full irrigation strategy (R2; b) for baseline (top map), near future (middle) and far future (bottom) for DMI-BCM climate projection with 'Picual' cultivar and agronomic scenario described in Section 2.3. J, S, O, A, C, BN, M and BZ indicate the locations of Jerez, Sevilla, Osuna, Antequera, Córdoba, Baena, Martos and Baeza, respectively.

Importante introducir la predicción meteorológica en el proceso productivo

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UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Gracias por tu atención

Alberto García-Prats (agprats@upv.es)
Instituto de Ingeniería del Agua y Medio Ambiente (IIAMA).
Universitat Politècnica de València (UPV). Spain.

DEPARTAMENTO DE INGENIERÍA HIDRÁULICA Y MEDIO AMBIENTE

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