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New challenges for sunflower ideotyping in changing environments and more ecological cropping systems

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Sunflower : a major component of the rainfed cropping systems worldwide

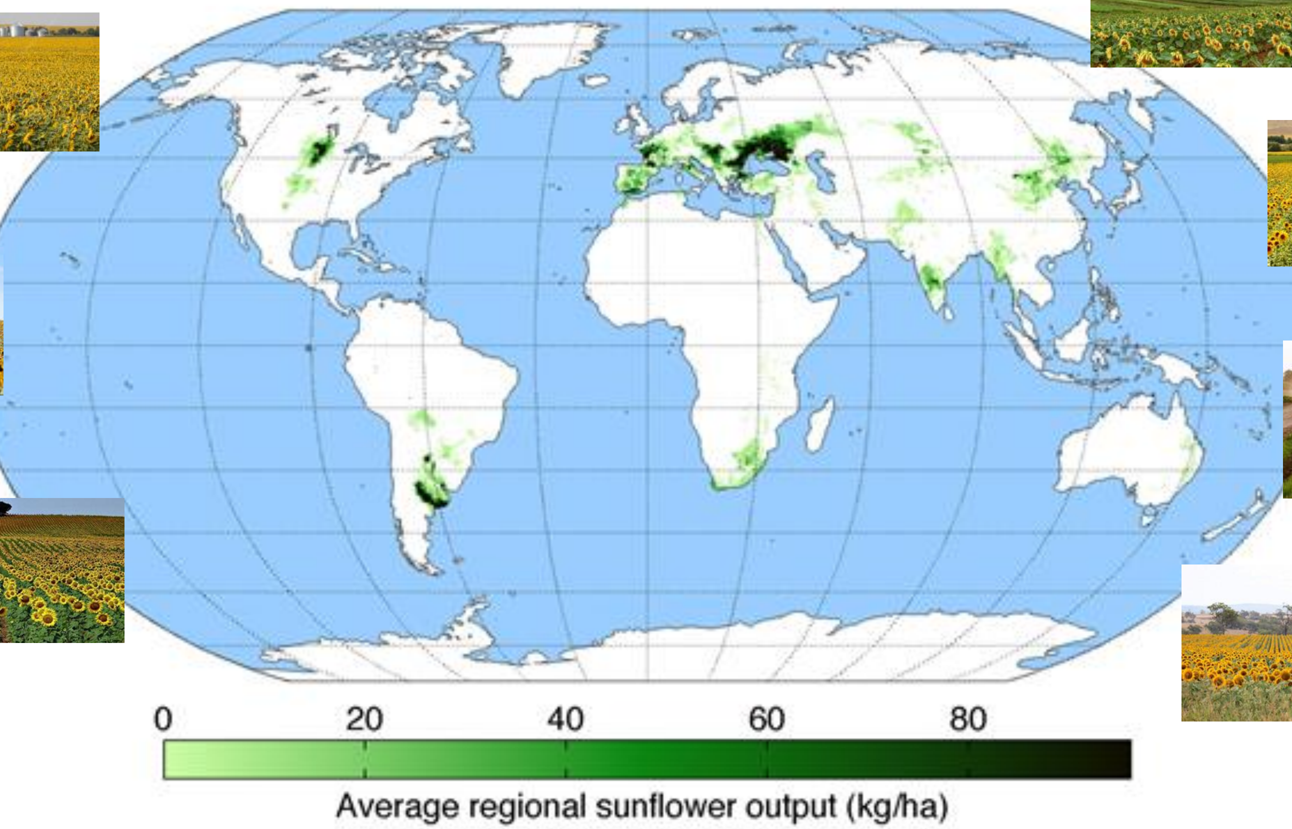












Cf. E.Pilorgé (this conference)



Oil → Protein
Confectionary

Sunflower crop has to address 4 new challenges

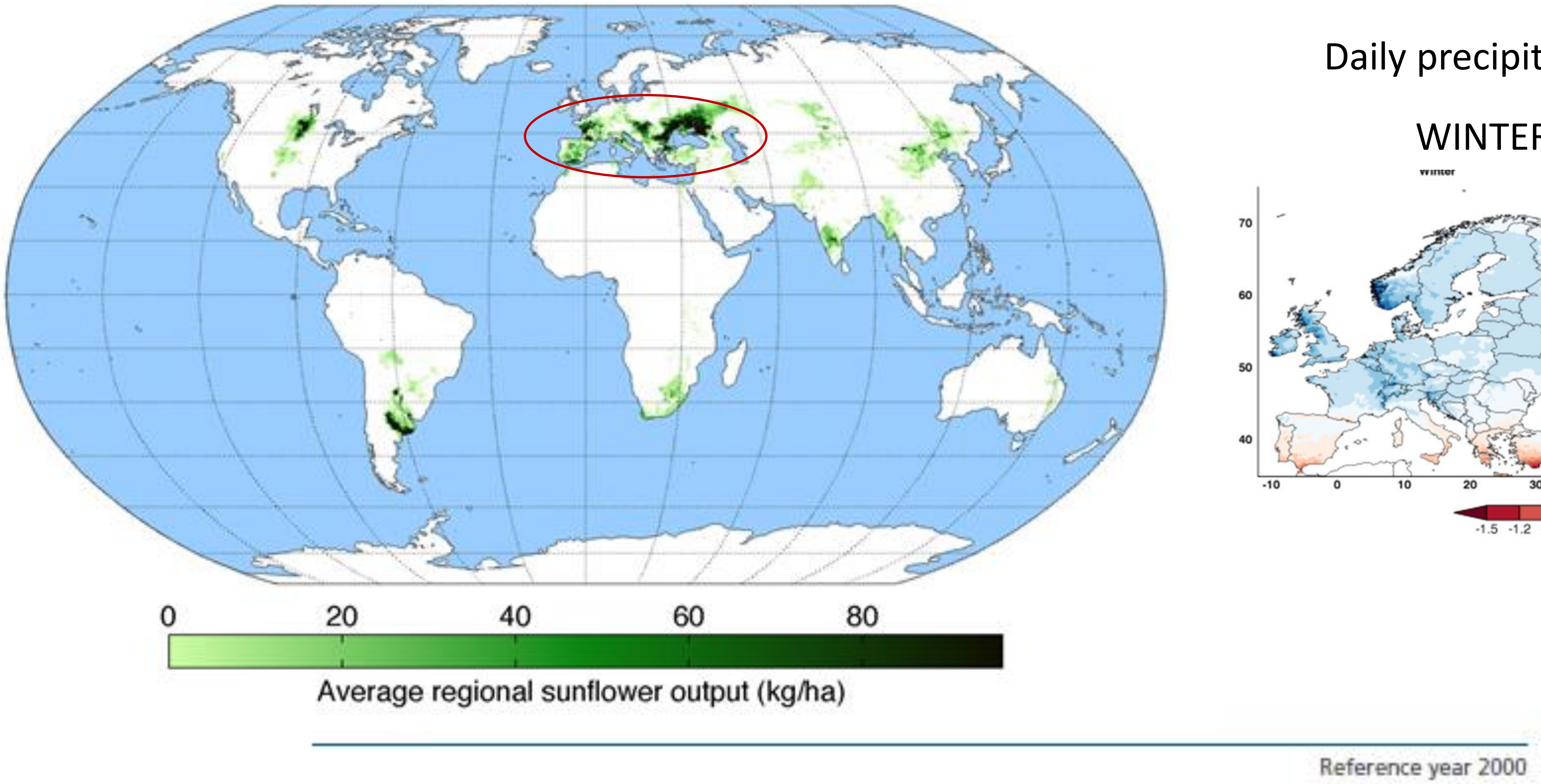
1) How to mitigate the detrimental impacts of **climate change** on production and benefit from some growing opportunities ?

2) How to contribute to **more ecological agrosystems** ?

3) How to increase the provision of **ecosystem services** by the crop ? (and their visibility)

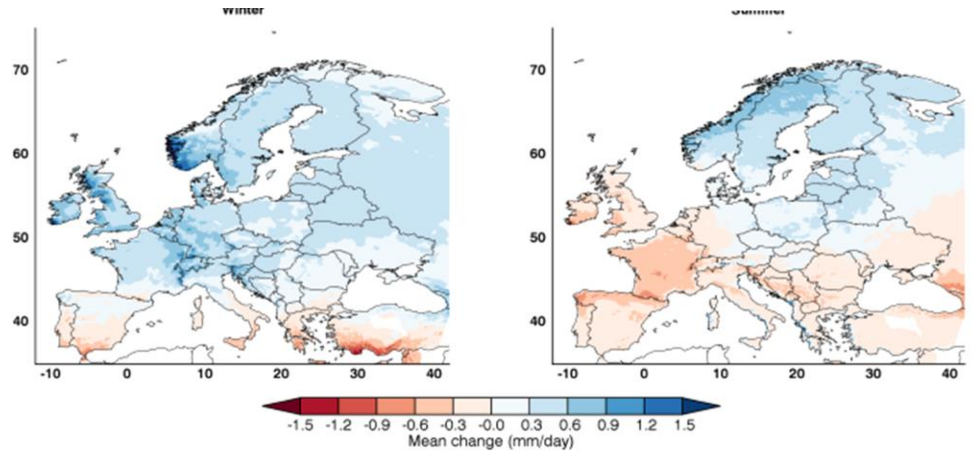
4) How to improve our capacities of **ideotyping** (and breeding) for these new challenges ?

Sunflower production regions will be markedly exposed to climate change (and especially to drought)



Daily precipitation (2071-2100) – RCP8.5

WINTER SUMMER



Ciscar *et al*. (2018)

~ 70 % of sunflower production comes from Europe (Russia, Ukraine, UE-27)
→ reduction of precipitation whatever the RCP scenario

Sunflower and climate change : vulnerability

OCL 2017, 24(1) D102

DOI: 10.1051/ocl/2016052

OCL
Oilseeds & fats Crops and Lipids

Topical issue on:
OIL- AND PROTEIN-CROPS AND CLIMATE CHANGE
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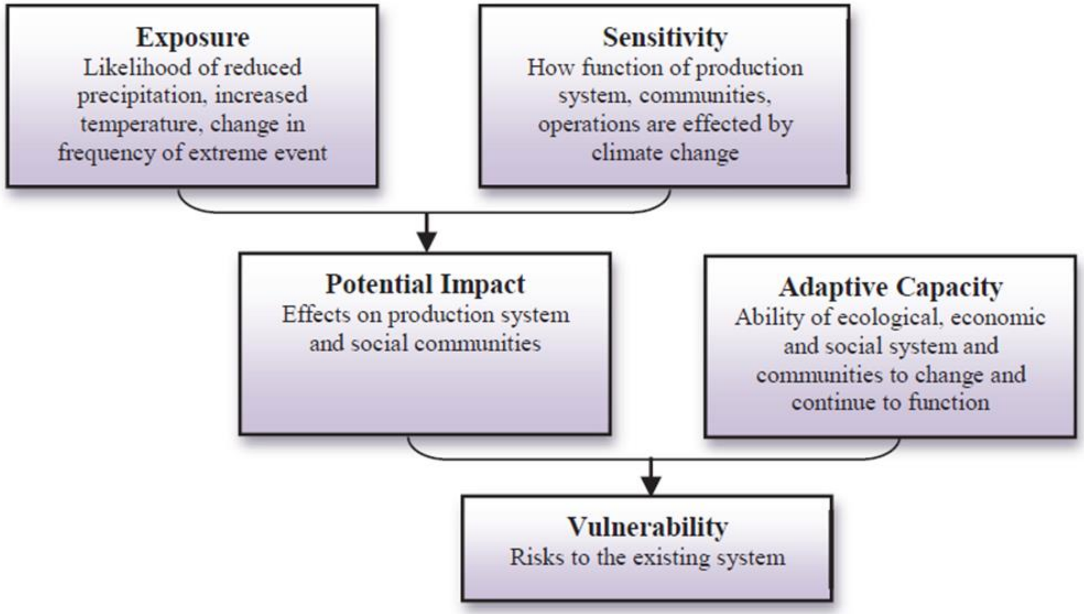
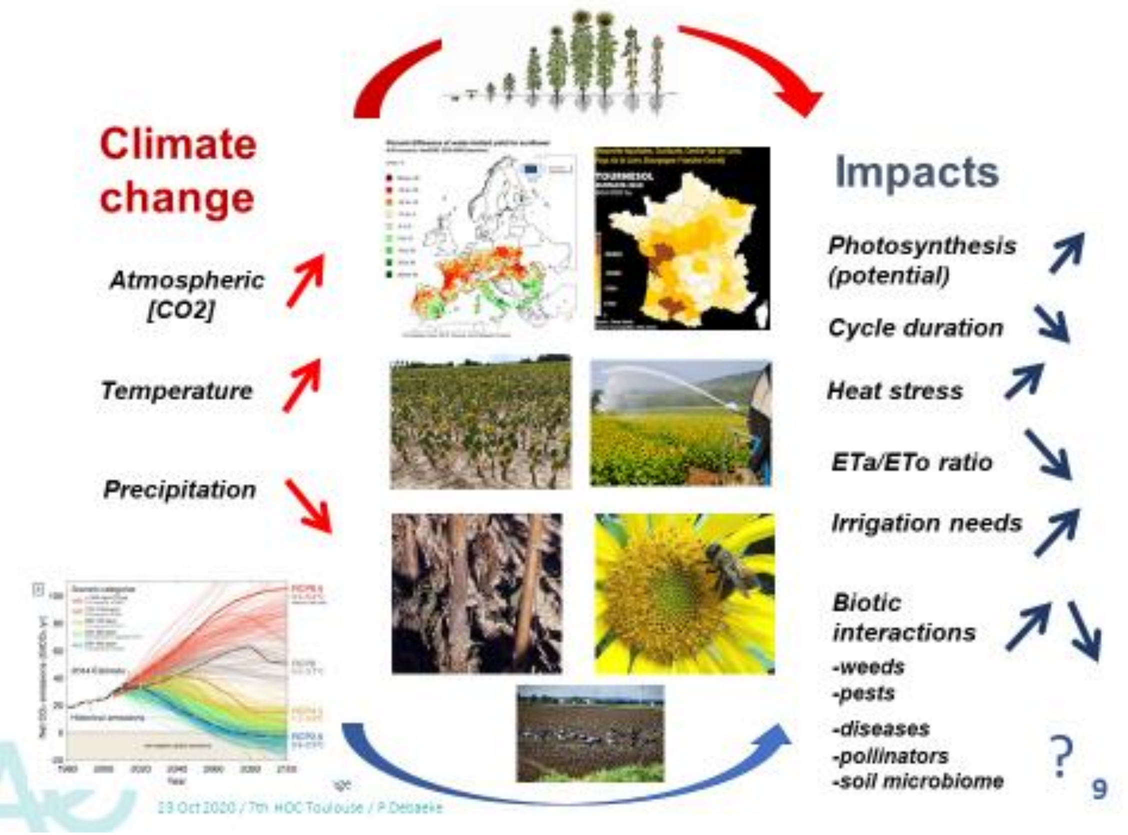
Sunflower crop and climate change: vulnerability, adaptation, and mitigation potential from case-studies in Europe

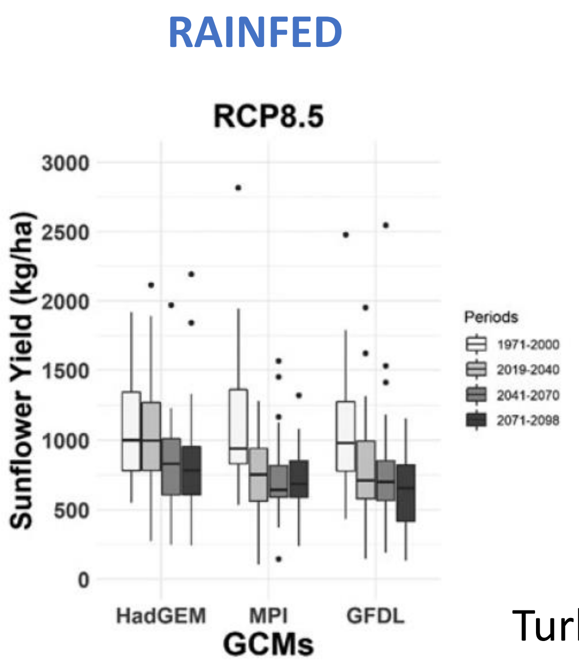
Philippe Debaeke[1,*], Pierre Casadebaig[1], Francis Flenet[2] and Nicolas Langlade[3]



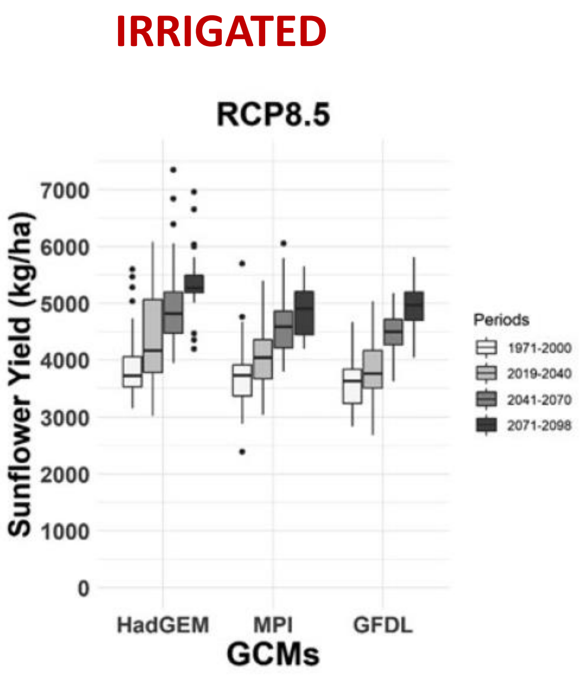
IPCC (2001)



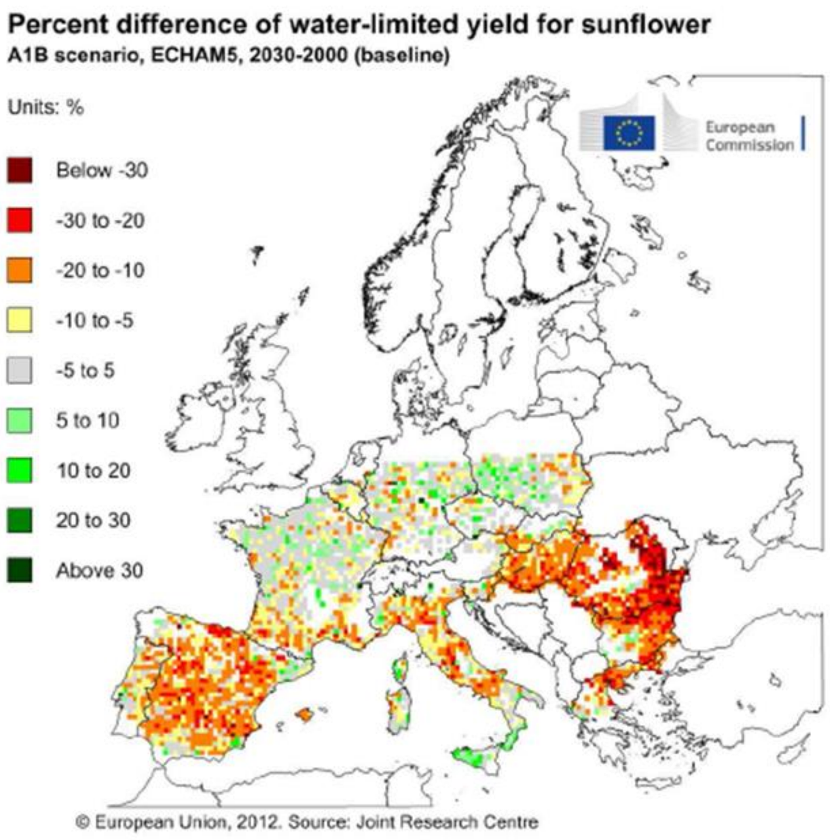
Sunflower and climate change : yield impacts



Turkey



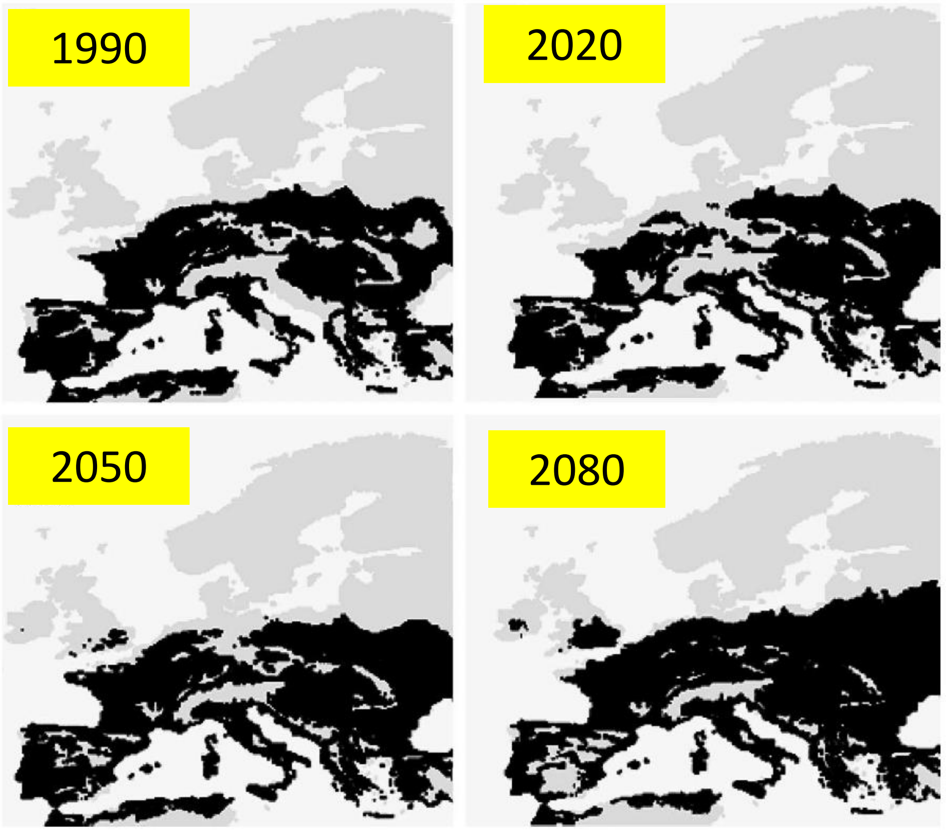
Gurkan *et al* (2021), *JAS*
CSM-CropGro-Sunflower



Donatelli *et al* (2012)
CropSyst model

Sunflower yields will be deeply impacted in rainfed systems with no adaptation (southern countries, shallow soils, no irrigation) ; positive effect of [CO2]atm

Sunflower and climate change : new opportunities in septentrional Europe



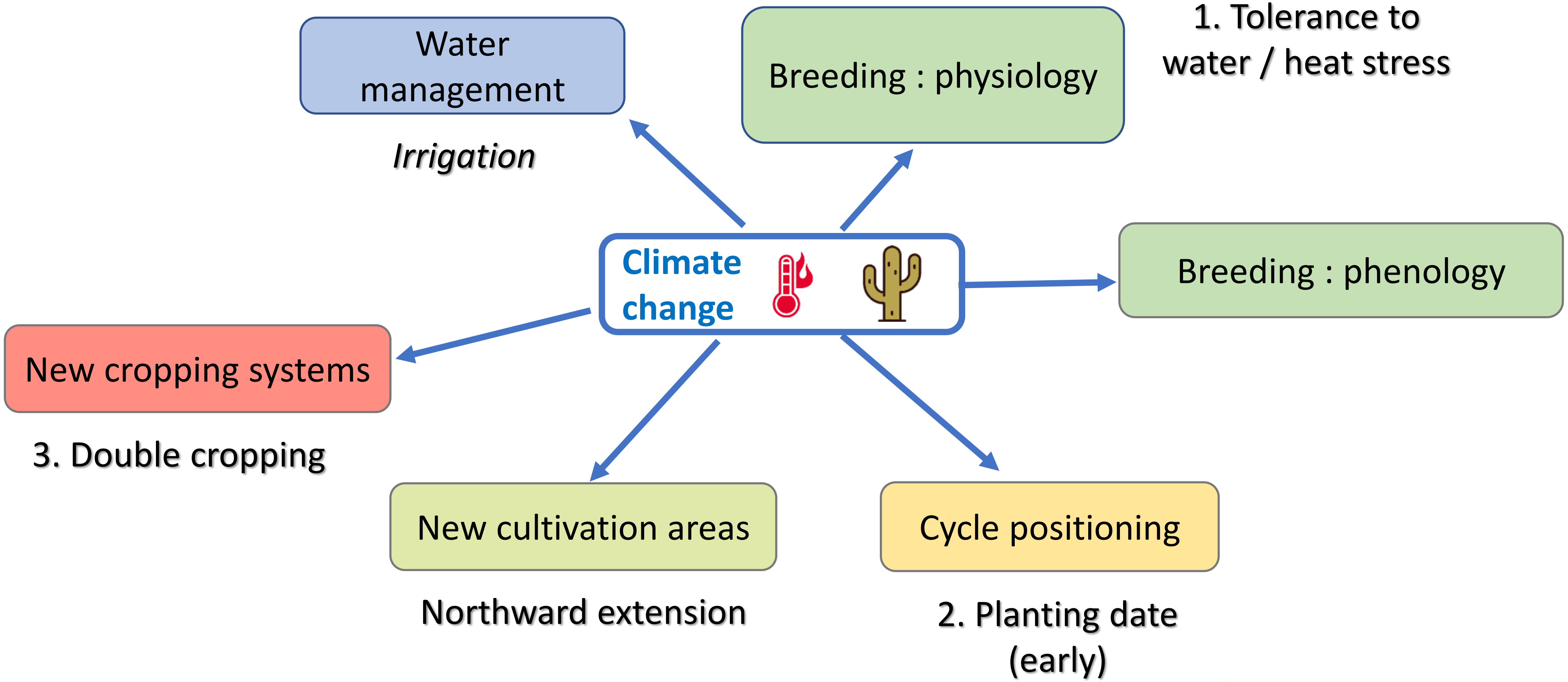
HadCM3 climatic model - A2 scenario

Tuck *et al.* (2006)
Biomass & Bioenergy

- New set of climatic constraints (water stress, high T°C)
- Higher $[CO_2]$ atm
- New biotic stresses (pathogens)
- New production environments
- New cropping systems adapted to climate change

Which traits & ideotypes ?
Which regional distribution ?
for a sunflower crop adapted to climate change

Sunflower and climate change : adaptation options



Sunflower is a (moderately) drought-tolerant crop
→ 1. breeding for genotypes more tolerant to water stress

- High capacity to extract water from the subsoil
- Plasticity of the crop, in terms of adapting leaf area development to available water
- Genotypic variability : “conservative” vs “productive” strategies (Casadebaig *et al*., 2008)

SUNRISE

(cf N Langlade et al. – this conference)

Potential traits for screening sunflower genotypes for drought tolerance.

Trait	Correlation with yield	Reference
Stomatal conductance	Yes	Rauf and Sadaqat (2008b)
Osmotic adjustment	Yes	Rauf and Sadaqat (2008a)
Shoot and root length	Yes	Manivannan et al. (2007)
Photosynthetic rate	–	Kiani et al. (2007b)
Malondialdehyde contents	–	Soleimanzadeh et al. (2010)
Seedling traits	Yes	Rauf (2008)
Harvest index	Yes	
Drought susceptibility index	–	
Root system	Yes	
Leaf hydraulics	–	
Chlorophyll fluorescence	Yes	Kiani et al. (2008)
Leaf hydraulics	–	Rauf et al. (2009)
Canopy temperature, stem diameter	Yes	Alza and Fernandez-Martinez (1997)
Osmotic adjustment	Yes	Chimenti et al. (2002)
Head diameter, number of achene and chlorophyll content	Yes	Darvishzadeh et al. (2011)

Hussain *et al* (2018), *Agric Water Manag*

2. Breeding for early sowing (as an escape strategy)

- By anticipating the timing of critical growth stages, the exposure of sunflower crop to heat and drought can be minimized

→Sowing in early spring in temperate regions (Allinne *et al*., 2009); sowing in autumn or winter in Mediterranean countries (Houmanat *et al.,* 2016)

→ **Target traits (related to chilling tolerance)**: lower base temperature, early vigor (seed, shoot & root growth at low temperature), recovery after cold stress, resistance to soilborne diseases (e.g. downy mildew).

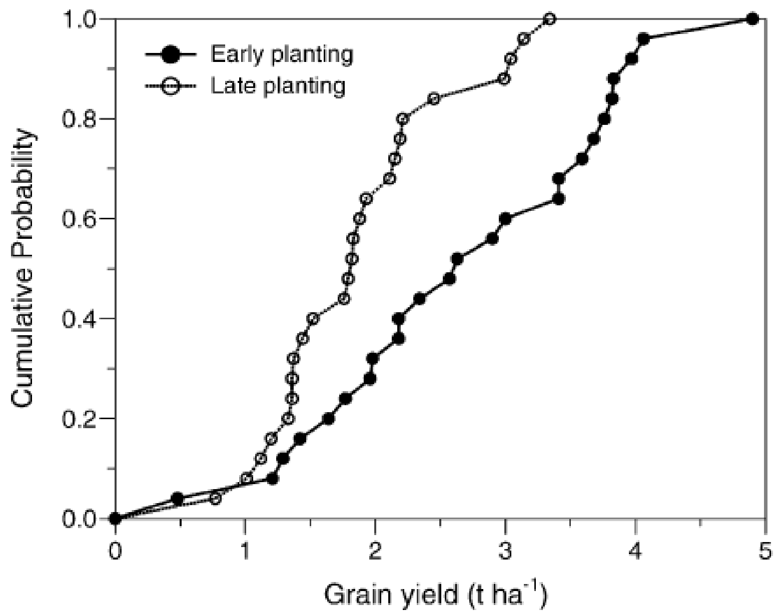


Fig. 2. Cumulative probability of sunflower yields for 1st January (closed circles) and 15th March (open circles) plantings, simulated with OILCROP-SUN for 25 years at Cordoba, Spain.

Soriano *et al* (2004), *EJA*

3. Breeding for late sowing (for double cropping or second crop)

- Sunflower is an attractive option for double cropping (grain, energy) following the early harvest of winter crops
- Best crop management : sowing soon after harvest, minimum tillage, no additional inputs, supplemental irrigation (establishment, flowering)
- Variety traits to select :
  - Very early maturity (1300 to 1400 °C.days, 100-120 days) : early flowering, low grain moisture
  - Low susceptibility to sclerotinia head rot (irrigation around flowering, risk of wet and cold conditions during ripening)
  - Linoleic instead of oleic types (lower temperatures during grain filling)
- In Europe, these hybrids often come for the selection of very early materials intended for main sunflower cropping in the northern regions.
- Trials where cultivars are tested for their response to late sowing under double cropping conditions are not widespread

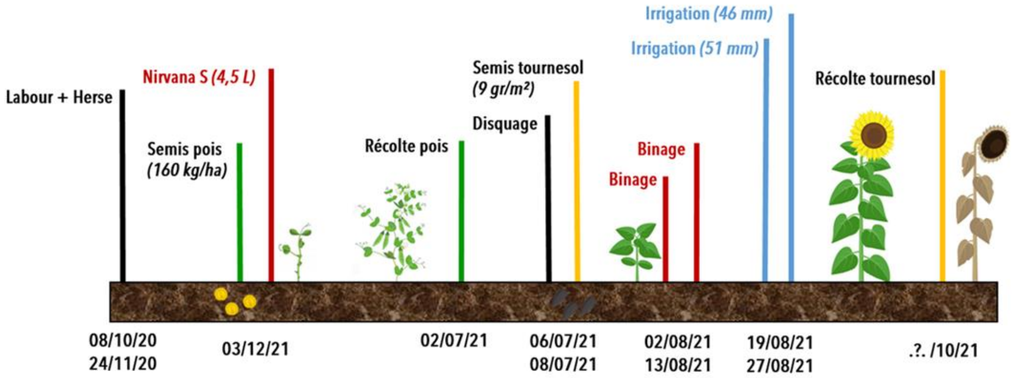
24/08/2021

06/09/2021

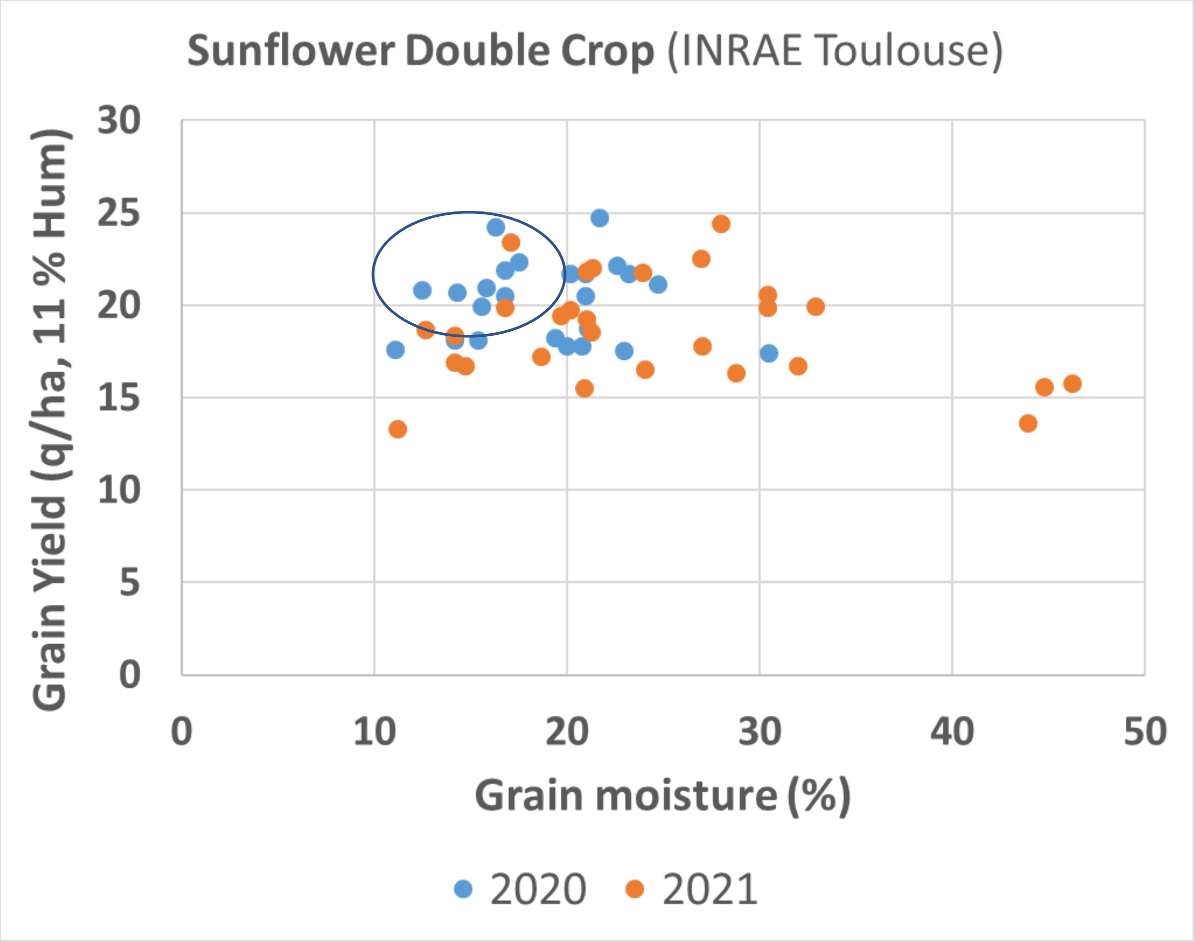
29/09/2021

Sunflower double cropping in Toulouse (SW France): sown on 08/07/2021

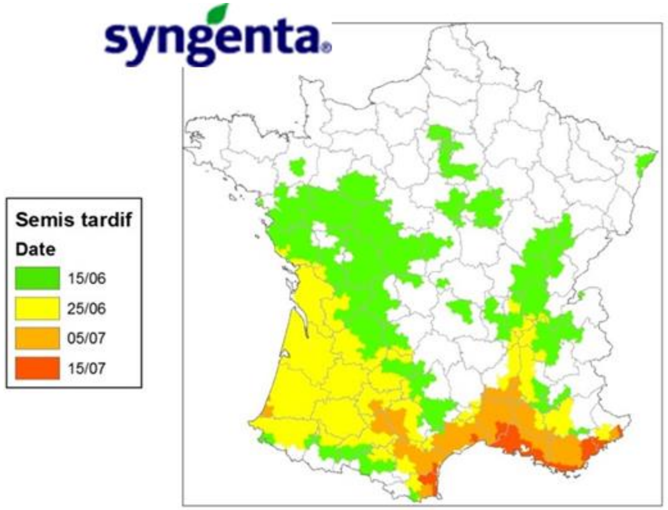
1. BILAN 2021



From C Lemouzy & G.Tison (INRAE)



Tradeoff between potential productivity and possibility to harvest at a minimum grain moisture

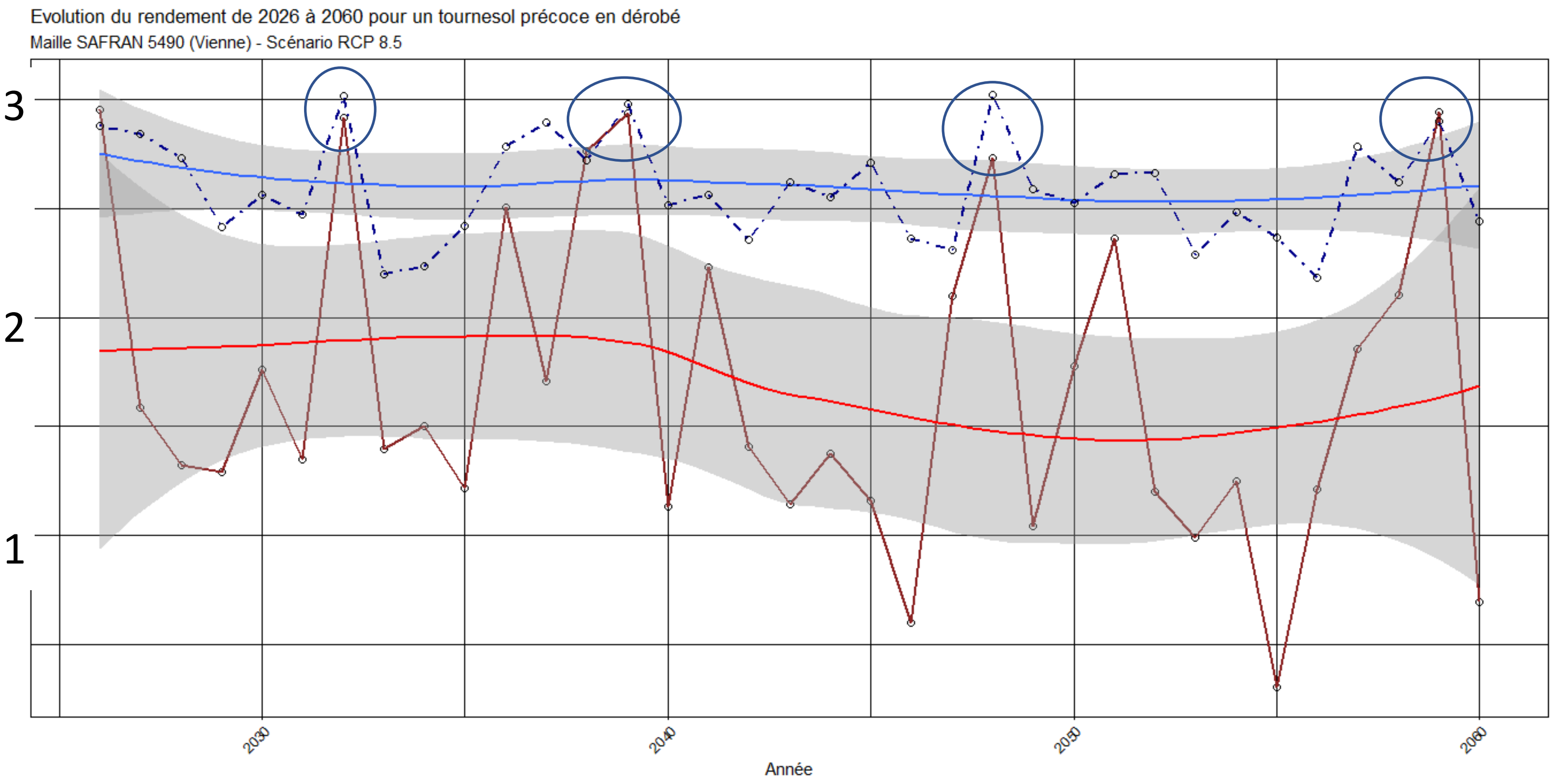


Sowing deadline (15/06 to 15/07) for harvesting at 13 % moisture

University of Nebraska-Lincoln

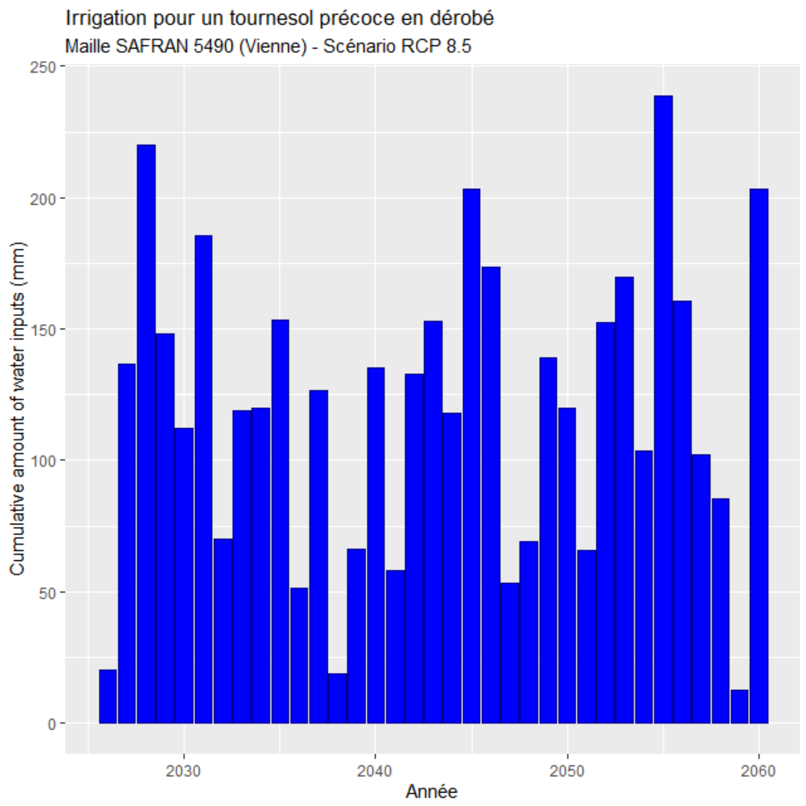
Yield potential and irrigation requirements

GY (t/ha) 2026-2060 for DC sunflower – RCP 8.5 (Center West of France)



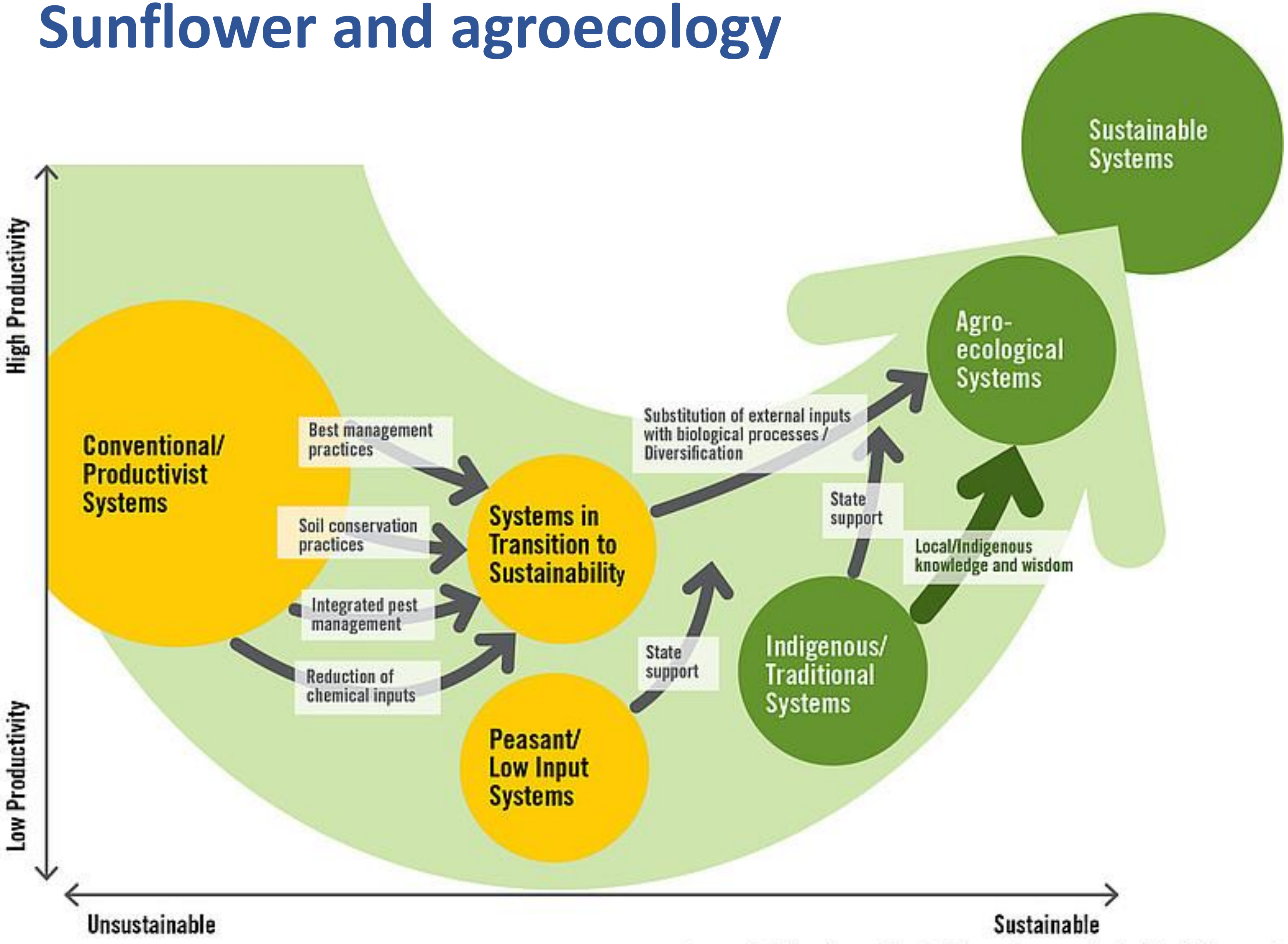
---- rainfed ---- irrigated

Irrigation (mm) for a full irrigation (potential)



Simulations with **STICS** (A.Duchalais, 3C2A)

Sunflower and agroecology



Source: Latin America and the Caribbean, Summary for Decision Makers, p. 9

IAASTD (2008)

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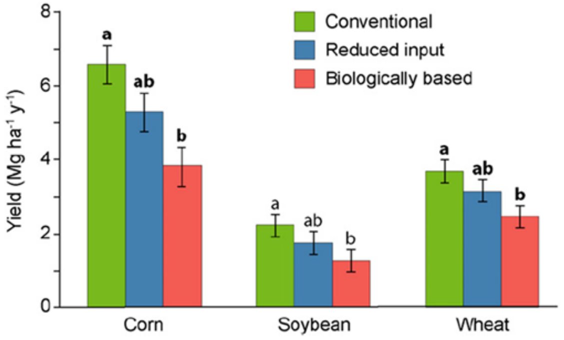
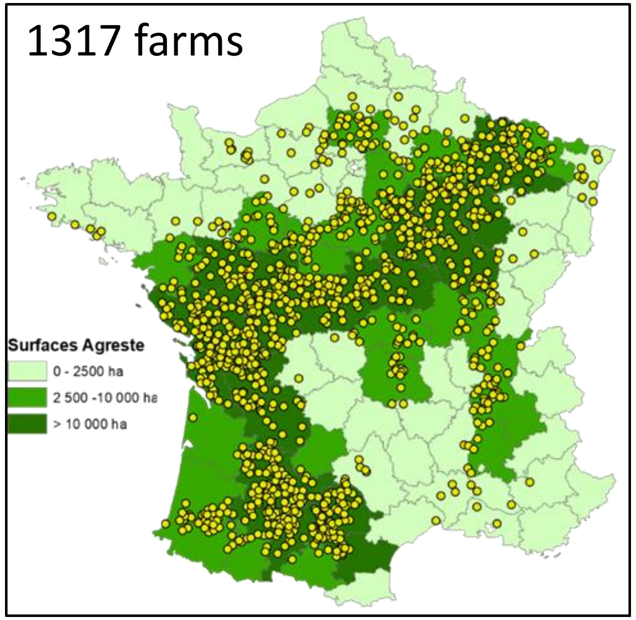
Sunflower crop: environmental-friendly and agroecological

Philippe Debaeke[1,*], Laurent Bedoussac[2], Catherine Bonnet[1], Emmanuelle Bret-Mestries[3], Célia Seassau[4], André Gavaland[5], Didier Raffaillac[1], Hélène Tribouillois[1], Grégory Véricel[1] and Eric Justes[1]



Kravchenko *et al.* (2017), *PNAS*

Sunflower in France : some predominant crop practices



~ 700 000 ha (2021)

Irrigation : < 5% irrigated ; < 20 % in deep soils (> 80 cm)
N fertilization : no application (25 %) – 57 kg $N.ha^{-1}$ on average

Soil tillage : 52 % ploughing in 2021 (83 % in 2002)

Treatment Frequency Index : 1.8 (2017) without seed treatment (vs 4.2 for wheat ; 5.7 for oilseed rape) (Agreste, 2019)

Mechanical weed control : 24 % (46 % in 2011) → 25 % **herbicide-tolerant** varieties

Cover crop before sunflower : from 10 % (2006) to 41 % (2021)
% sunflower grown under organic farming: 4 % (2017) –> ~10 % (2021)

→ A rainfed low-input crop ; less tillage, more cover crops

From Wagner, Lecomte, Martin-Monjaret (2022)

Terres Inovia
l'agronomie en mouvement

INRAE

Breeding for low-input management and organic farming

Limiting factors		Breeding goals		Traits
Weed infestation	→	Competitiveness against weeds	→	Rapid growth and development (early stages): emergence rate, seed vigor, root growth, leaf rate, shoot biomass, canopy closure, plant height….
Nutrient stress	→	Nutrient uptake efficiency	→	Root system….
Disease attacks	→	Disease tolerance and resistance Genetic and agronomic control	→	A lot of efforts have been done (cf Vear, in this conference)

Terres Inovia

→ Little is known on this genetic variability

Breeding for multiple cropping systems ?

Sunflower/Faba Bean/Crimson Clover. Triple Crop.
Western Canada
https://lamb-farms.com/cover_crops.php

Sunflower/Soybean (Toulouse)

©Agroof

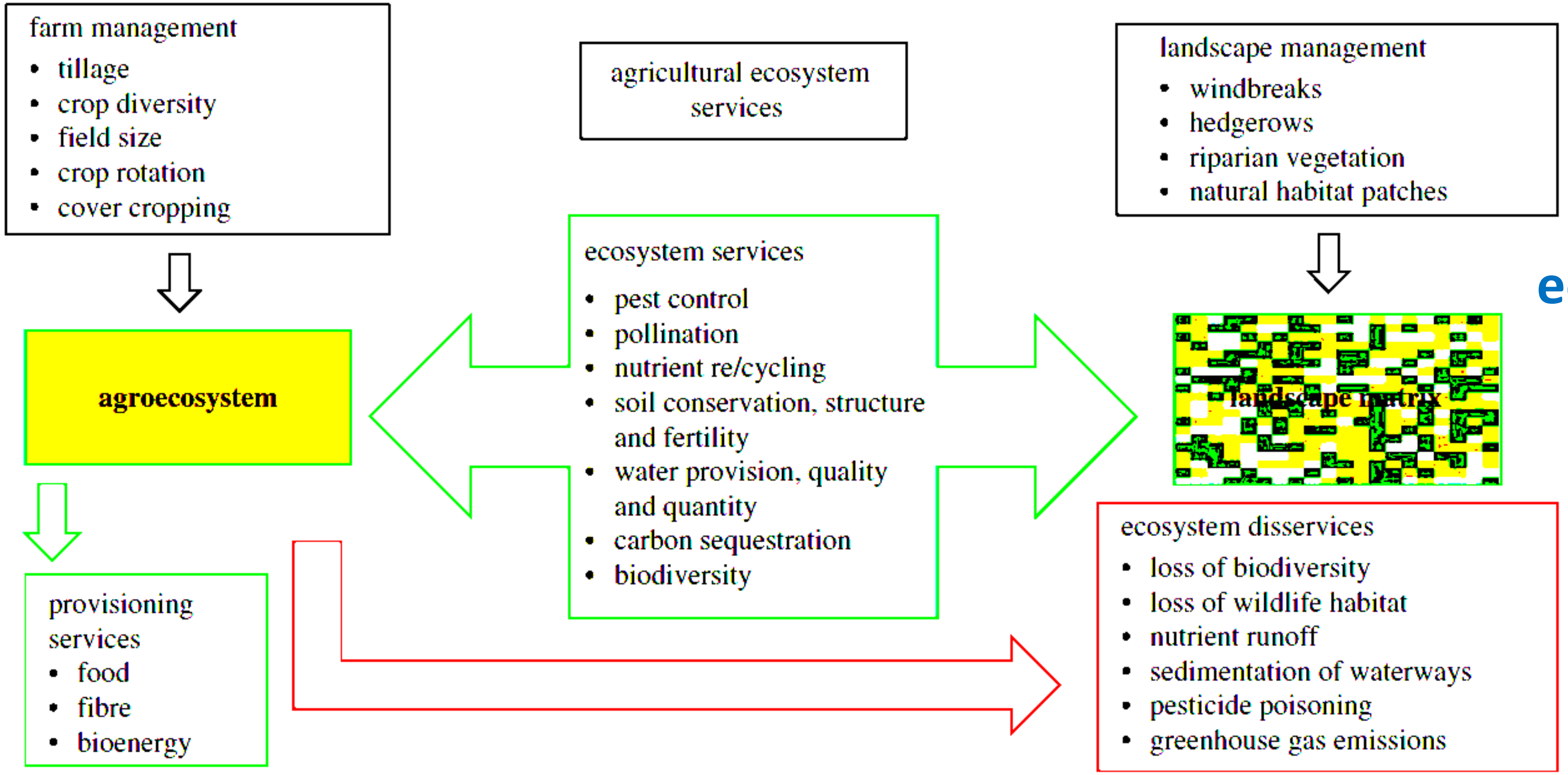
Intercropping - Variety mixtures - Agroforestry

➡ No varietal recommendation

Soil conservation agriculture (no tillage, cover crops, rotation) ; Relay cropping ➡ Sunflower not well adapted

RMT Agroforesterie

Ecosystem services and agriculture



How to increase the ecosystem services delivered by sunflower crop ?

Which traits & ideotypes?

Power (2010), *PNAS*

Ecosystem services other than production delivered by sunflower crop

(i) *sustainment of biodiversity*, by **providing nutritional resources (pollen, nectar) in early summer to pollinators (bees)**

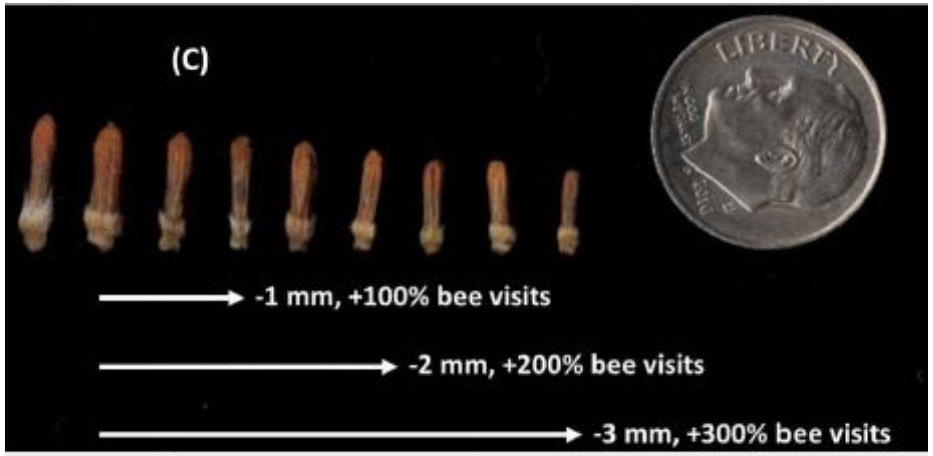
(ii) *environment protection* by a contribution to **phytoremediation** in heavy-metal polluted soils

(iii) *pest regulation* by a **break effect** in cereal rotations and by contributing to *weed control* in succeeding crops through **allelopathy.**

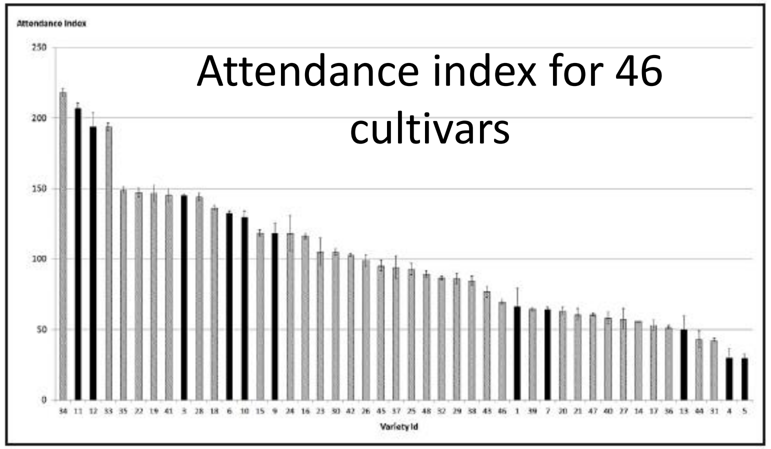
Sunflower and pollinators: desirable plant traits

- **Nectar sugar** amount increases bee visits
- **Corolla length** decreases bee visits
- Nectar sugar composition is less important
- Honey bees and wild bees respond similarly

From R. Mallinger and J. Prasifka USDA-ARS



Using nectar-related traits to enhance crop-pollinator interactions (Prasifka et al, 2018) - *FPS*

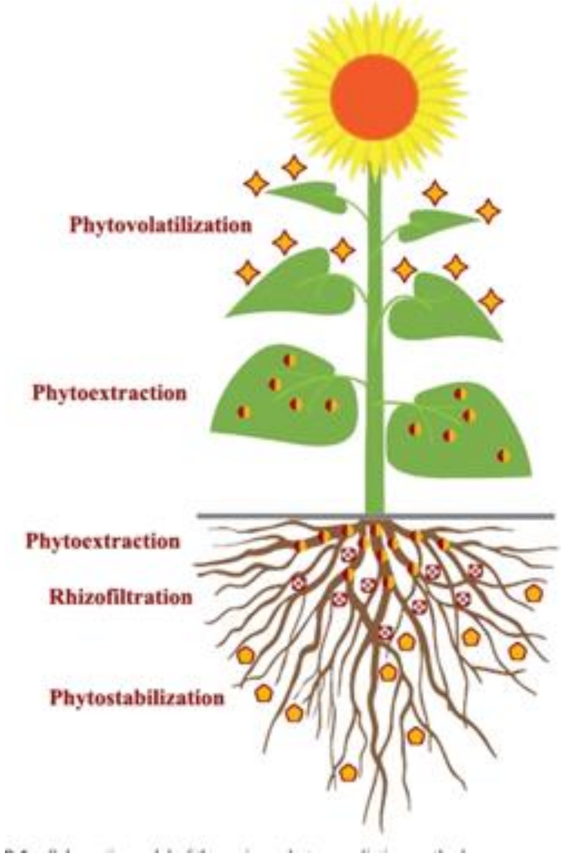


Cerrutti and Pontet (2016), *OCL*

→ production of inbreds and hybrids with smaller florets could enhance sunflower pollination

Phytoremediation of soils contaminated with HMs

- Sunflower can be used efficiently for phytoextraction of heavy metals (HM) thanks to its high biomass production, its capacity for metal accumulation and because its oil can be used for non-food purpose (Angelova *et al.*, 2016).
- Differences for HM accumulation and extraction efficiency among cultivars grown on metal-contaminated soil (Nehnevajova *et al*. (2005).
- Prior to any breeding attempt, a careful screening of various genotypes should be done to select the cultivars with the naturally highest HM uptake.
- This hyperaccumulation activity could also be used to extract and concentrate essential elements (e.g selenium) through biofortification in order to improve human nutrition (Garoussi *et al.*, 2018).



Allelopathic potential of sunflower

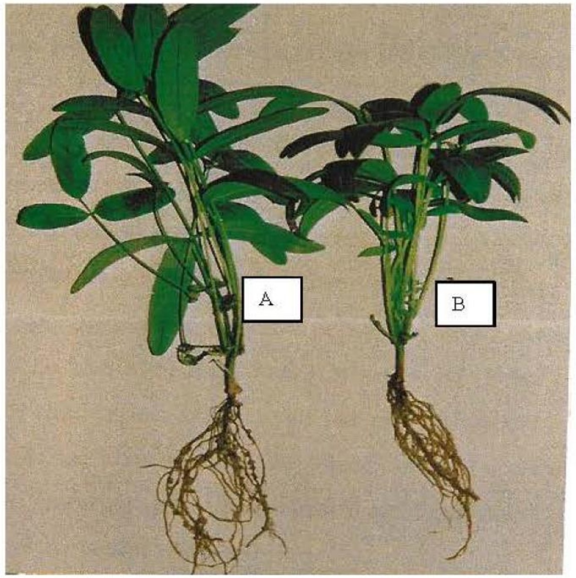
- Numerous papers reported the allelopathic potential of sunflower plants and tissues in controlling weeds in sunflower and next crops with possible unwanted effects on subsequent crop species (e.g. Gawronska *et al*., 2007; Albuquerque *et al*., 2011; Jabran, 2017)

- Sunflower contains bioactive allelochemicals, especially phenolics and terpenoids, which would be involved in this suppressing effect

- Allelopathy could be exploited for biocontrol in several ways as biologically active mulch either scattered over the soil surface or mixed into the soil

- Different allelopathic activities were observed among a small set of sunflower hybrids (Anjum and Bajwa, 2008; Silva *et al*., 2009; Alsaadawi *et al*., 2012; Ullah *et al*., 2018)

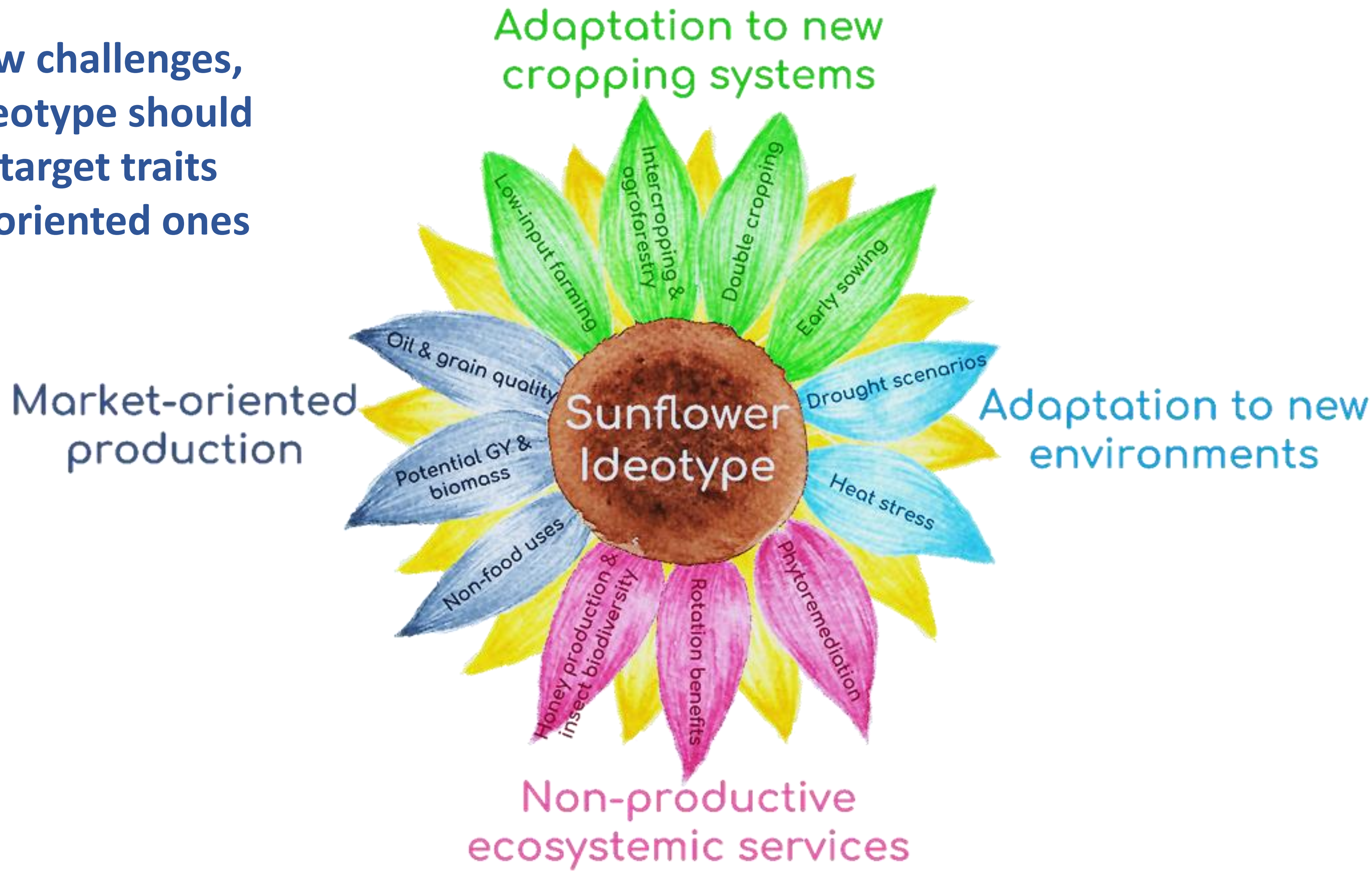
Vigna subterranea



Effect of sunflower plant residues on the growth and nodulation of bambara groundnut. (A) control and (B) plants grown in soil with residues. Note presence of nodules in the control and their absence in treated plants

Batlang and Shishu (2007)

To face these new challenges, the sunflower ideotype should consider other target traits that the market-oriented ones



Debaeke et al. (2021), *OCL*

Information provided by advisory systems after registration and post-registration assessment (e.g France)

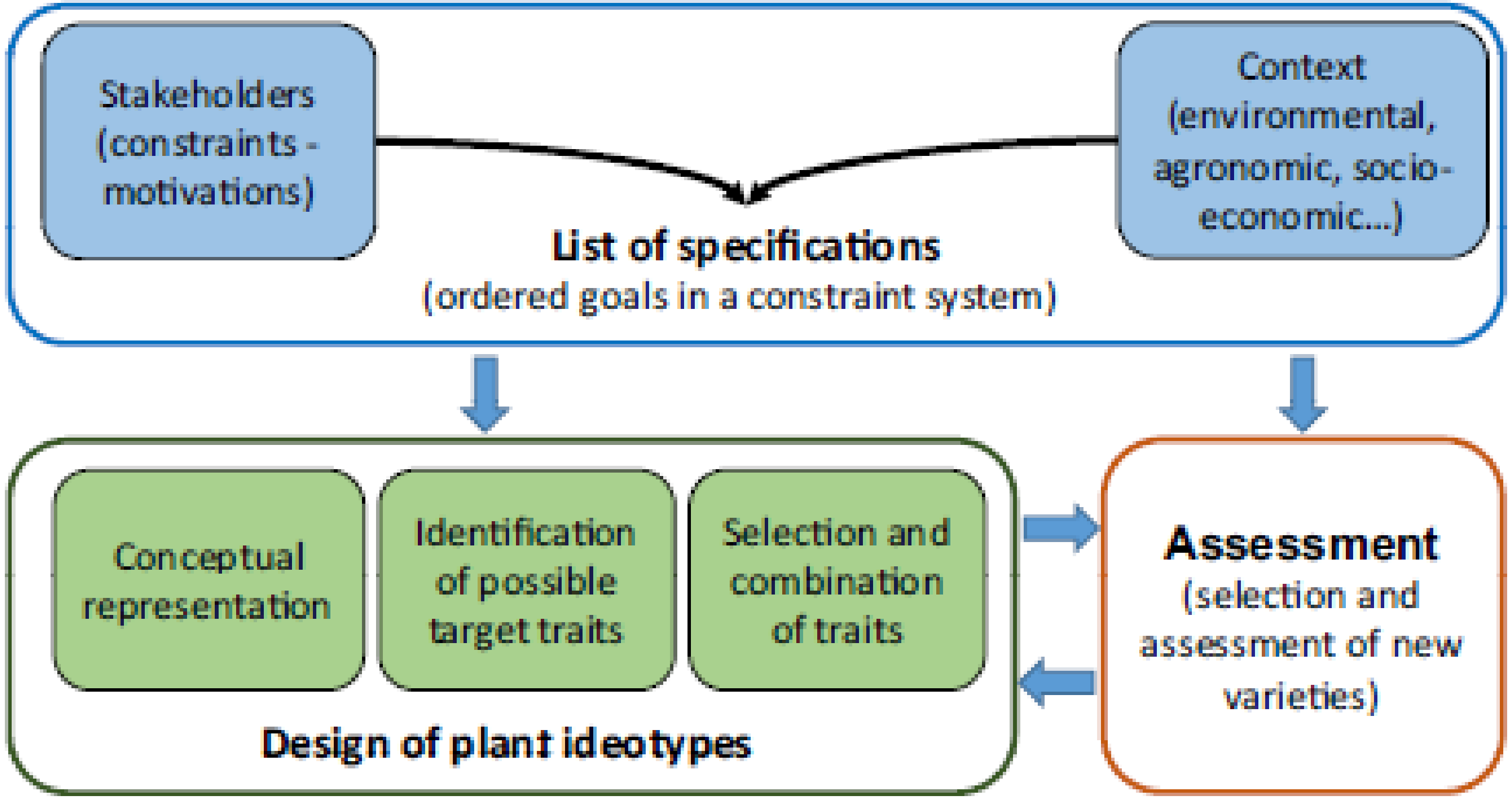
→ A reduced number of varietal characteristics

→ Not sufficient for variety choice in such diversified systems

Plant phenology	Anthesis **earliness** : 5 levels (very early to late) Maturity earliness : 5 levels (very early to late)
Plant morphology	Plant **height** : 3 levels (short; medium; tall)
Disease tolerance	Phomopsis stem canker: 5 levels Sclerotinia head rot: 4 levels Sclerotinia basal stalk rot: 3 levels Verticillium wilt: 4 levels
Mildew resistance	3 levels (RM9 ; RM8 ; other RMs)
Herbicide tolerance	3 levels (no ; Clearfield ; Express Sun)
Seed characteristics	Thousand seed weight : 3 levels (low ; medium ; high)
Oil characteristics	Oil concentration : 4 levels (low ; medium ; high ; very high) Oil quality : high oleic vs linoleic (mid-oleic)
Yield performance	5 levels according to multi-location field trials

(http://www.myvar.fr)

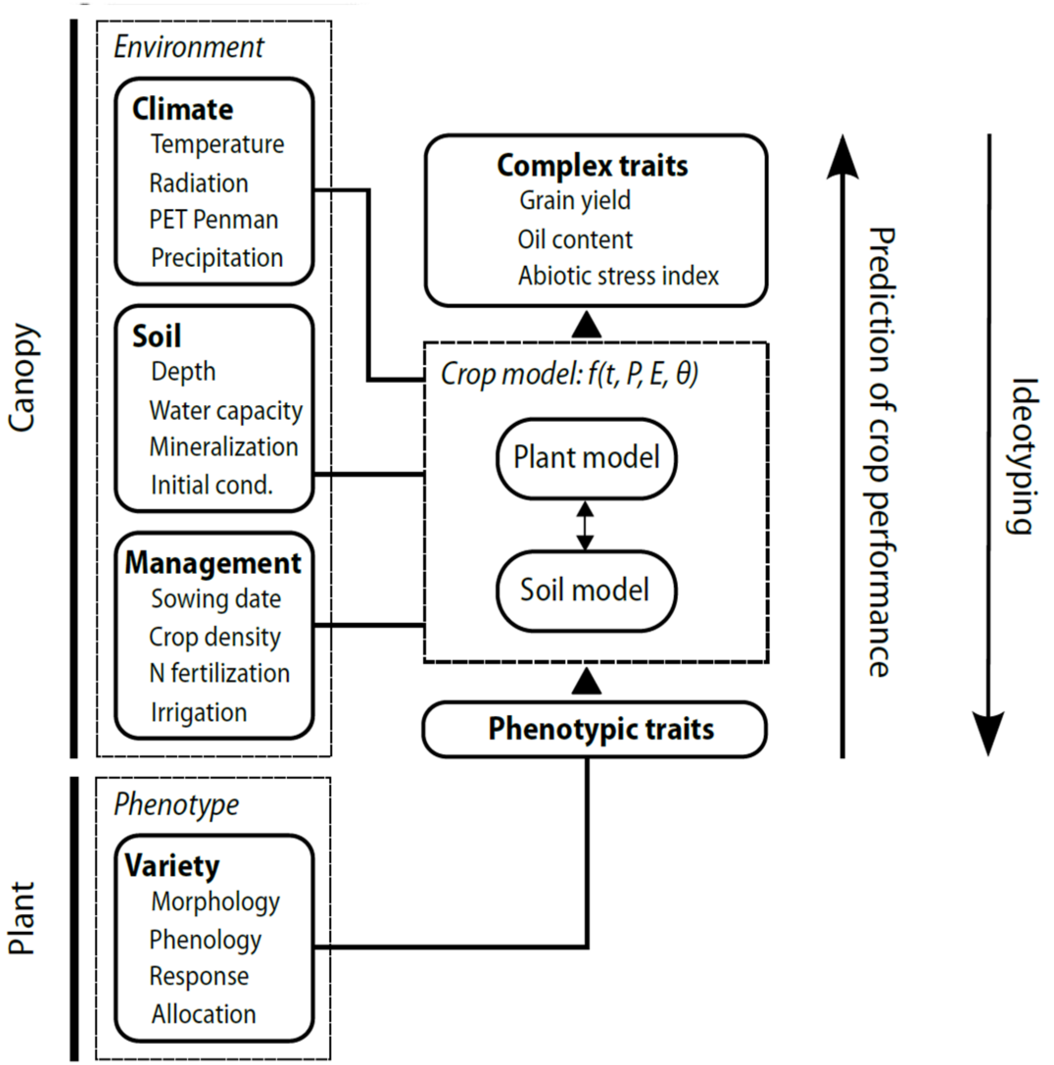
How to design ideotypes for these new contexts ?



A. Gauffreteau (2018), *OCL*

Process-based models as an efficient tool for testing ideotypes

- knowledge integration
- complex interactions between soil-plant-atmosphere & crop practices (incl. variety)
- simulation of future and unexplored conditions

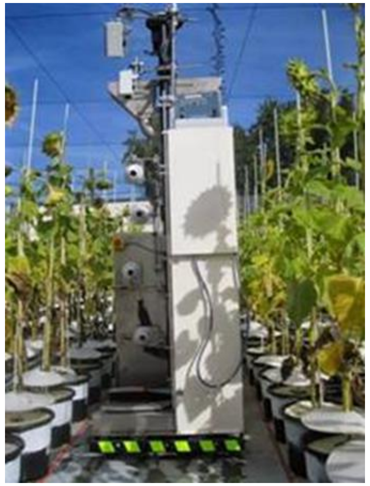


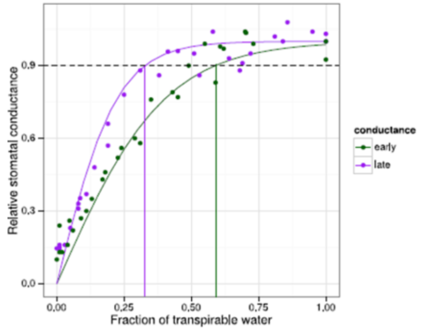
e.g SUNFLO model

Casadebaig *et al.* (2011, 2016)

Advanced phenotyping : easy and high-throughput access to new traits

Outdoor pot platform
(HELIAPHEN Platform, INRAE Toulouse)





Field phenotyping
(AGROPHEN Platform, INRAE Toulouse)

Fcover → canopy closure

Response of transpiration and leaf expansion to soil water deficit → model parameters, plant indicators

Evaluation of varieties in new cropping systems : *e.g* organic farming

Terres Inovia

Crop management

→ Late sowing date (May)
→Mechanical weed control
→Legume as previous crop

Early vigor is an additional criteria for variety evaluation (UAV evaluation)

- Dedicated OF network in post-registration
- Varieties developed for organic farming

Conclusions : implications for sunflower agronomy and physiology

- Screening of a wider range of genetic resources and traits (field, platforms)
- Fine tuning of ecophysiological indicators and methods of phenotyping (sensors)
- Set up new experimental designs for G x E x M applied to sustainable cropping systems
- Representation of this diversity in crop growth models
- Decision support systems for choosing varieties using multi-criteria approach and coupled with crop models (cf on-going INVITE EU-project)

invite

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New challenges for sunflower ideotyping in changing environments and more ecological cropping systems☆

Philippe Debaeke[1,*], Pierre Casadebaig[1] and Nicolas B. Langlade[2]

Thank you for your attention

Thanks to the colleagues of INRAE Toulouse (UMR AGIR, LEPSE, UE), GEVES, and Terres Inovia for exchanging ideas and data during collaborative projects at the interface of agronomy, crop physiology and genetics (SUNRISE, CASDARs, PROMOSOL, Plant2Pro, h2020-INVITE)

Sunrise project – INRAE Toulouse