

Which industrial crops to grow on marginal lands? Lessons learnt from MAGIC & MIDAS projects

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KAPES
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CENTRE FOR RENEWABLE
ENERGY SOURCES AND SAVING

Midas

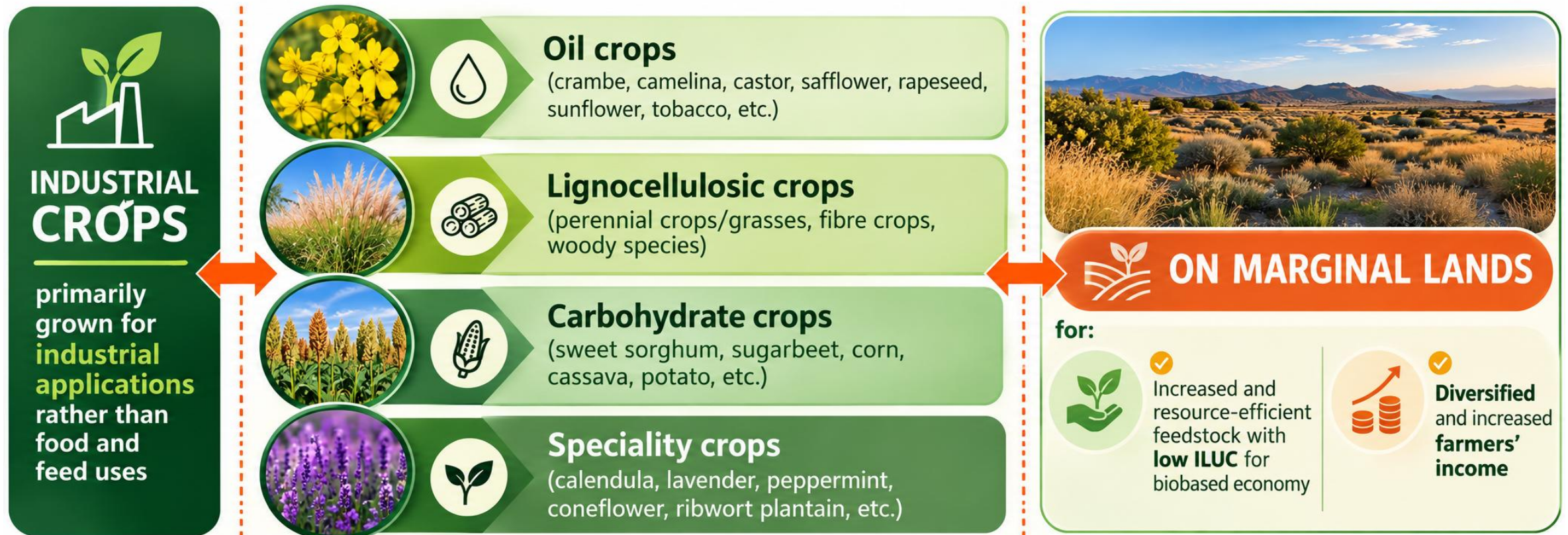
MARGINAL LANDS, INDUSTRIAL CROPS
AND INNOVATIVE BIO-BASED VALUE CHAINS

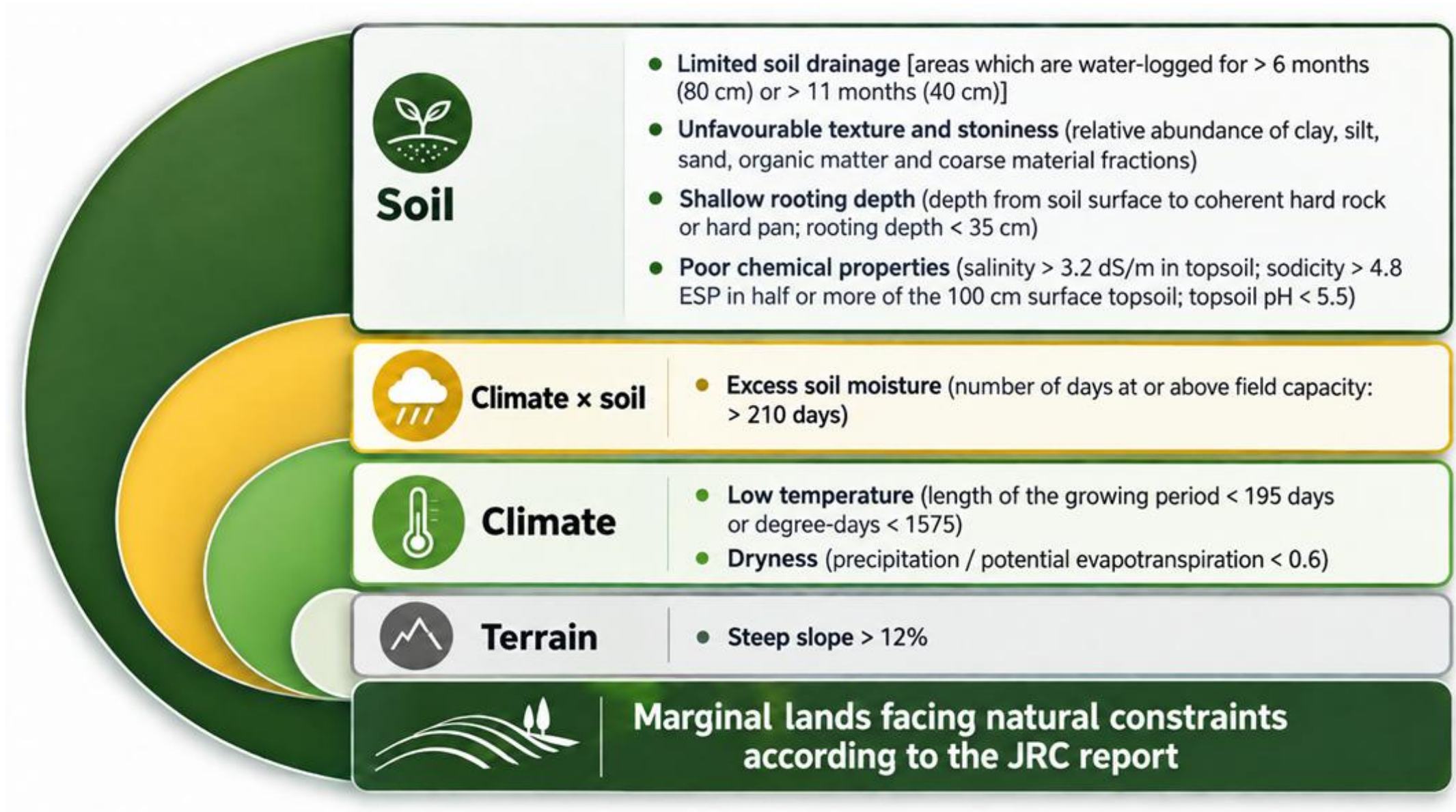


This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101082070.



- ➔ **Industrial Crops** provide **valuable biomass resource** for **high added value products** (such as bio-plastics, bio-lubricants, bio-chemicals, pharmaceuticals, bio-composites, biofuels etc.), **biofuels & bioenergy**.
- ➔ Based on **4CROPS** (www.cres.gr/4fcrops) & **Crops2Industry** (www.cres.gr/crops2industry) projects are categorized into four groups: **oil**, **lignocellulosic**, **carbohydrate** and **specialty crops**.
- ➔ In **MAGIC** project (www.magic-h2020.eu) **selected industrial crops** have been selected to be grown on **marginal lands facing natural constraints** (2017-2021).





Mapping the marginal lands in Europe

Marginal land in the EU-28

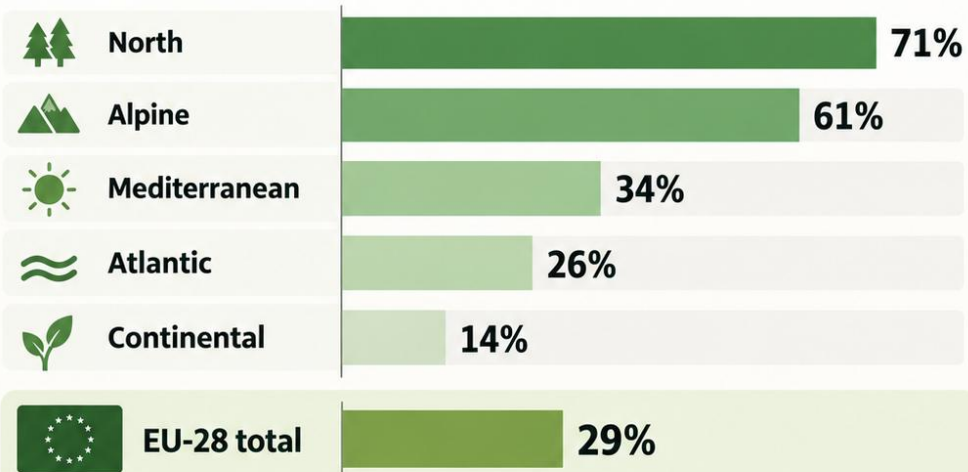
Mapping the marginal lands in the EU-28 based on biophysical constraints

29%

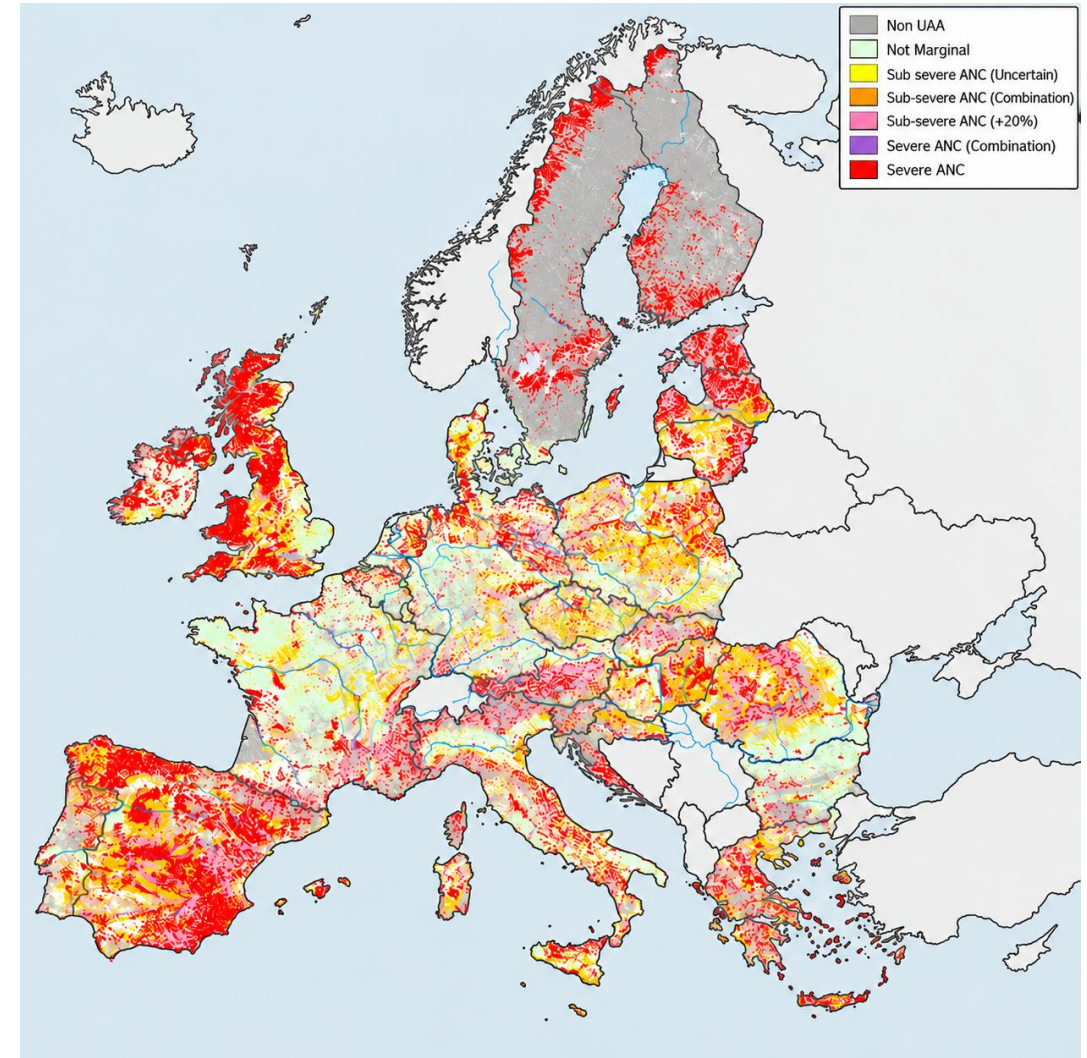
of total agricultural area in the EU-28 is **marginal land**

Marginal land by main climatic zone

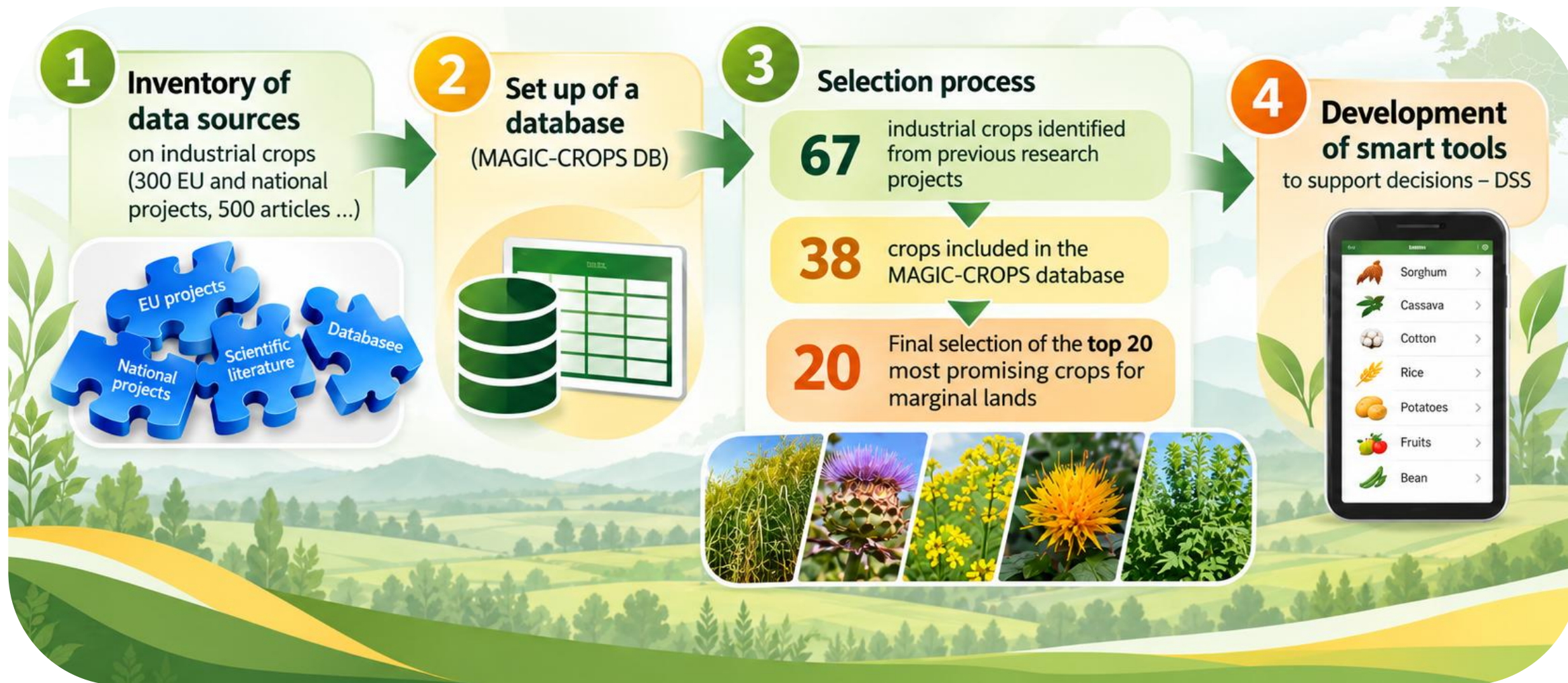
Marginal land (% of UAA)



Source: Elbersen et al. (2018), MAGIC project



Selection of the most promising industrial crops for marginal lands facing natural constraints for MAGIC project



Selection of the most promising industrial crops for marginal lands facing natural constraints for MIDAS project



How the selection of the most promising industrial crops to be grown on marginal lands facing natural constraints was carried out in the **MAGIC project**

1

67

industrial crops identified from previous research projects



2

38

crops included in the MAGIC-CROPS database



3

20

most promising crops selected for cultivation on marginal lands



Oilseed and specialty crops

- Camelina, crambe, castor bean
- Ethiopian mustard, safflower
- Lupin, hemp, cardoon, pennycress

7 crops



Lignocellulosic crops

- Perennial grasses (e.g. switchgrass, miscanthus, giant reed, reed canary grass)
- Woody species (e.g. willow, poplar)
- Other (e.g. cardoon, tall wheatgrass, wild sugarcane)

9 crops



Carbohydrate crops

- Sweet sorghum
- Lupin

4 crops



MAGIC project: selected crops and field-trial sites across Europe

Crops that can be cultivated across Europe*

- 1 **Camelina** 
- 2 **Crambe** 
- 3 **Pennycress** 
- 4 **Switchgrass** 
- 5 **Miscanthus** 
- 6 **Black locust** 
- 7 **Siberian elm** 
- 8 **Industrial hemp** 

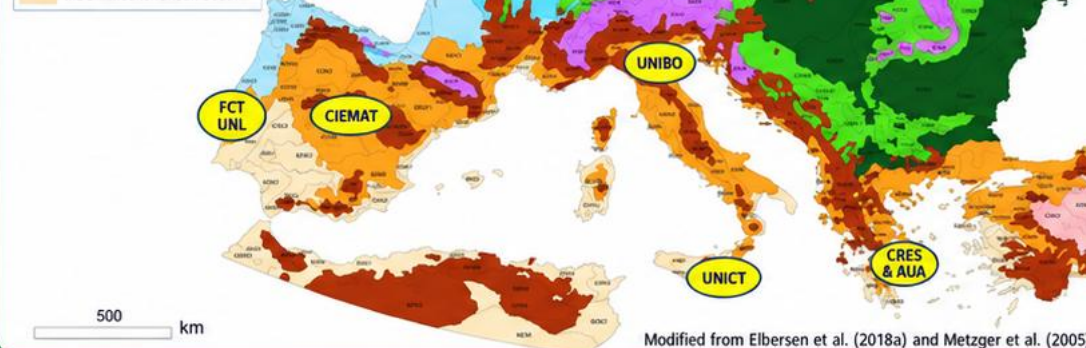
*Selected crops suitable for cultivation across Europe.

Environmental Zone (Metzger et al. (2005))	Agro-ecological Zone (AEZ)	Consortium partners with new or existing field trials
MDM - Mediterranean Mountains MDN - Mediterranean North MDS - Mediterranean South	1	AUA, CIEMAT, CRES, FCT UNL, UNIBO, UNICT
ATN - Atlantic North ATC - Atlantic Central LUS - Lusitanian	2	DLO, INRA, NOVABIOM
BOR - Boreal CON - Continental NEM - Nemoral PAN - Pannonian	3	3B, IBC, INF & MP, SILAVA, UHOH

 = Consortium partners

Environmental Zone

- ALN - Alpine North
- BOR - Boreal
- NEM - Nemoral
- ATN - Atlantic North
- ALS - Alpine South
- CON - Continental
- ATC - Atlantic Central
- PAN - Pannonian
- LUS - Lusitanian
- ANO - Anatolian
- MDM - Mediterranean Mountains
- MDN - Mediterranean North
- MDS - Mediterranean South



Modified from Elbersen et al. (2018a) and Metzger et al. (2005).

MAGIC field-trial sites

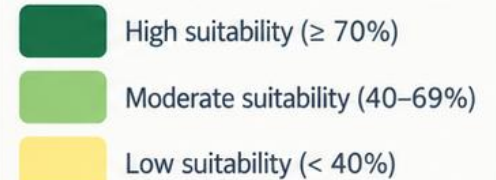
- FCT UNL** Universidade Nova de Lisboa
- CIEMAT** Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
- UNIBO** Università di Bologna
- CRES & AUA** Centre for Renewable Energy Sources & Activities (AUA)
- UNICT** Università di Catania
- DLO** Wageningen University & Research (DLO)
- NOVABIOM** NOVABIOM
- INRA** INRAE
- UHOH** University of Hohenheim
- INF & MP** Institute of Natural Fibres and Medicinal Plants
- 3B** 3B – Research Institute
- SILAVA** Latvian State Forest Research Institute
- IBC** Institute of Bioeconomy and Circular Economy

Suitability of selected MAGIC industrial crops across European agro-ecological zones

Share of marginal land potentially suitable for cultivation (%)

Crop group	Crop	Mediterranean (AEZ 1)	Atlantic (AEZ 2)	Continental & Boreal (AEZ 3)
Lignocellulosic / perennial grasses 	Tall wheatgrass	96	79	86
	Switchgrass	73	10	13
	Miscanthus	60	44	44
	Giant reed	59	1	1
	Wild sugarcane	21	0	0
	Reed canary grass	21	65	74
Herbaceous / multipurpose crops 	Lupin	92	19	19
	Biomass sorghum	88	16	3
	Cardoon	79	37	42
	Hemp	74	42	9
Oilseed and specialty crops 	Crambe	99	91	66
	Camelina	96	97	92
	Pennycress	95	34	38
	Ethiopian mustard	84	23	5
	Castor bean	74	6	2
	Safflower	7	76	100
Woody crops 	Siberian elm	82	11	14
	Willow	26	86	60
	Poplar	22	83	75

Suitability level (share of marginal land)



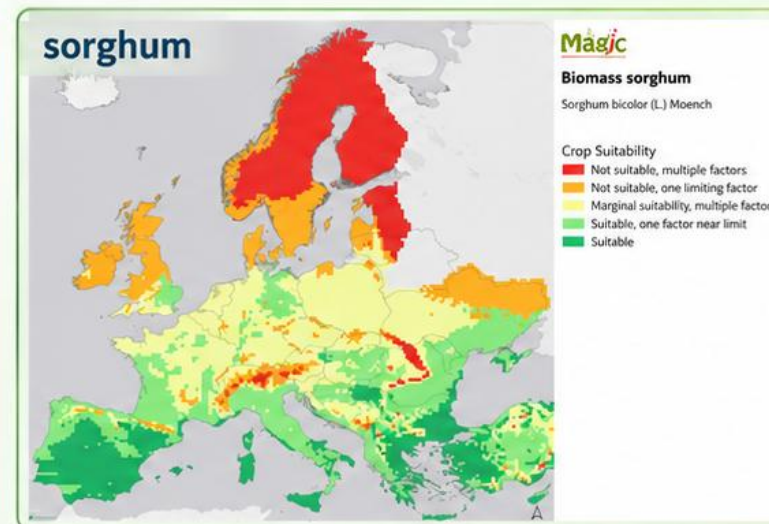
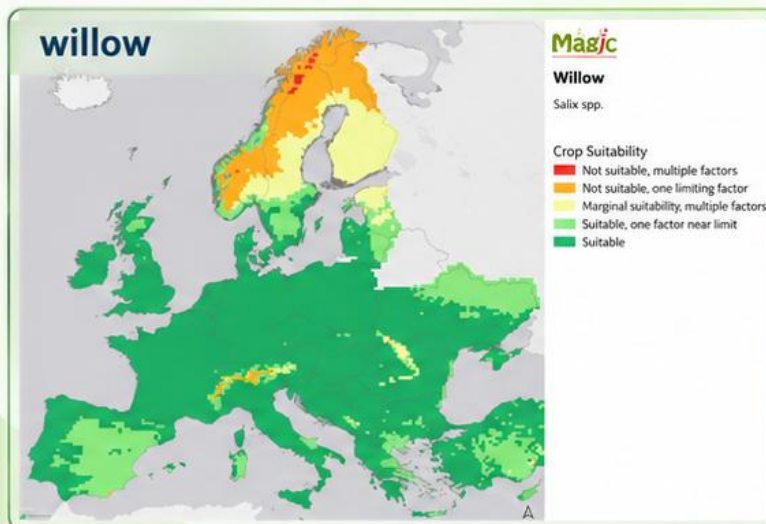
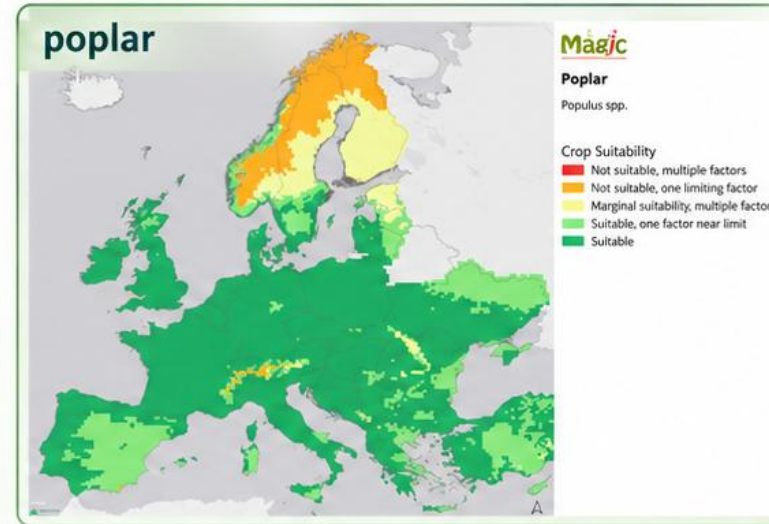
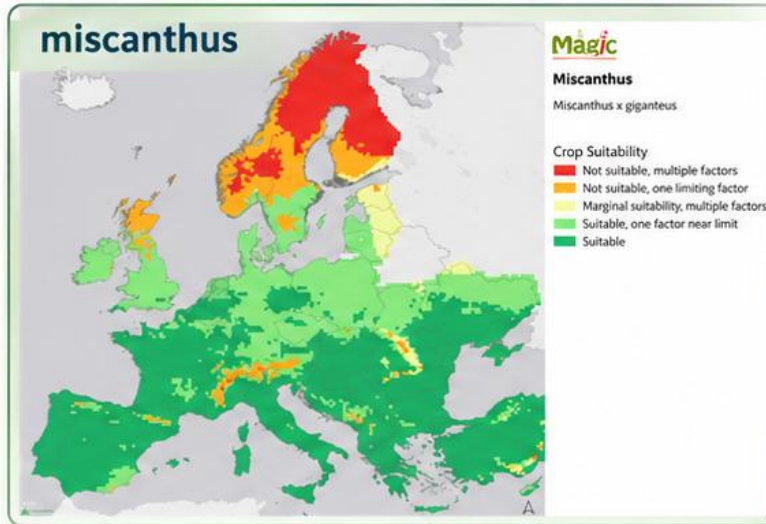
Key messages

- Camelina and crambe** perform strongly across all three AEZs.
- Tall wheatgrass** is consistently suitable across Europe.
- Safflower** is especially suited to Continental & Boreal conditions.
- Willow and poplar** are particularly strong in Atlantic and Continental & Boreal zones.

Values simplified from the MAGIC project suitability table; percentages indicate the share of marginal land potentially suitable for cultivation.

MAGIC project: suitability maps for selected industrial crops on marginal lands

Illustrative examples: miscanthus, poplar, willow and biomass sorghum



Key messages



Suitability maps were developed for selected industrial crops in the MAGIC project.



The examples shown here illustrate contrasting suitability patterns across European marginal lands.



These maps support crop screening, regional targeting and decision-support tools.

Miscanthus (perennial grass)



Tested in EU projects



Selected as a promising crop to be grown on marginal lands (<https://www.optima.fp7.eu>)



Selected as a promising crop to be grown on marginal lands (<https://optimisc.uni-hohenheim.de/en>)



Currently included to be grown on marginal and/or contaminated lands (www.grace-bbi.eu)



Recently had been also tested on long-term field trials across Europe on marginal and contaminated lands.

Key results from MAGIC field trials



Adaptation & establishment

Successful establishment under dry conditions and on unfavorable soil textures (shallow soil depth, acidity, heavy clay soils).



Marginal & contaminated lands

Good performance on marginal and contaminated lands, confirming its suitability for low-input systems.



Long-term performance

Stable productivity over multiple years with low input requirements.



Socio-economic potential

Provides biomass for bioenergy and a range of bio-based products while contributing to land rehabilitation and climate mitigation.



MAGIC long-term field trials



Established in Greece, Italy, Portugal, France, Netherlands and Germany.



Lifetime 2 to 14 years.

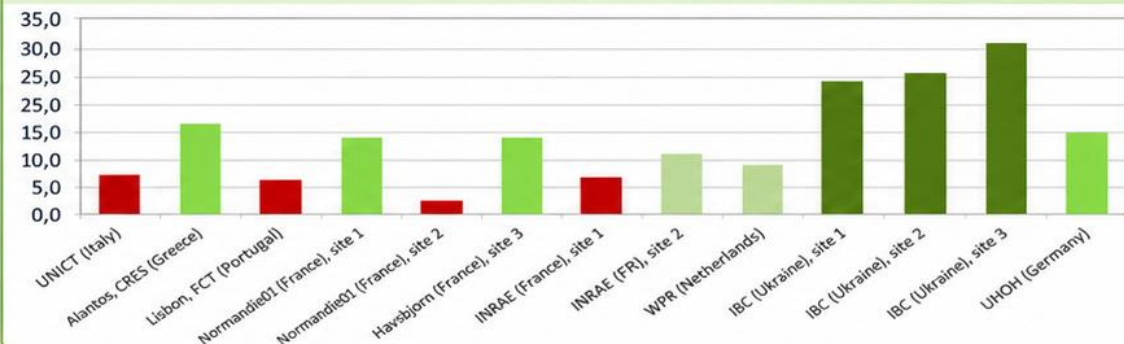


Tested under dryness, unfavorable soil textures, contaminated and marginal lands for socio-economic reasons.



Additional new field trials also established in France and Germany within MAGIC.

Dry matter yields (t/ha)



Switchgrass (perennial grass)

*A promising biomass crop
for marginal lands in Europe*



Switchgrass in the 2nd and 15th years
(source: CRES)



Selected in previous EU projects

- ✓ Switchgrass was selected in the **OPTIMA** project (www.optimaafp7.eu) as a promising crop for cultivation on marginal lands.
- ✓ A **large variety of cultivars** can be successfully cultivated across Europe.
- ✓ Long-term trials in Europe have shown mean dry matter yields of about **10 t/ha** on marginal lands.



Tested in MAGIC under challenging conditions

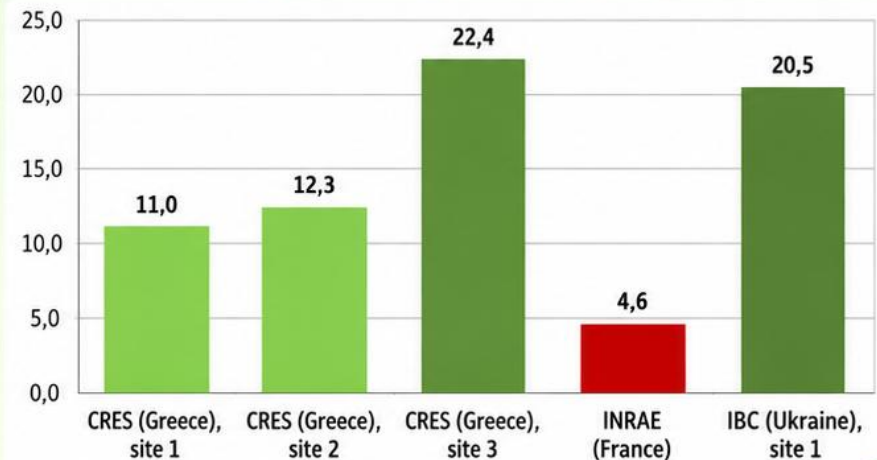
- ✓ In MAGIC, long-term switchgrass field trials were established under **dry conditions**, on **unfavourable soil textures** (shallow soils, heavy clay soils), and on **marginal lands** for socio-economic reasons.
- ✓ Long-term field trials were established in **Greece, Italy, the Netherlands and Ukraine**, with lifetimes ranging from **2 to 20 years**.
- ✓ **Additional field trials** were also established within MAGIC.
- ✓ Switchgrass was tested in five sites in MAGIC. **High yields were recorded in Ukraine and Greece.**



Key results from MAGIC field trials

In **MAGIC**, long-term switchgrass field trials have been established under dryness, unfavourable soil texture (shallow soil depth, heavy clay soils) and marginal lands for socio-economic reasons.

Dry matter yields (t/ha)



Willow (*Salix spp.*) Salicaceae family

A woody crop for marginal and waterlogged lands



Key characteristics



Grows in a **variety of soils** with pH 5–7.5.



Roots tolerate **highly anoxic conditions**.



Can be planted in **waterlogged conditions**.



High tolerance to soils with **heavy metals**.



Suitable for **phytoremediation**.



Tested in MAGIC under challenging conditions



In MAGIC, willow was tested in long-term field trials established under a) **excess soil moisture** and b) **unfavorable soil texture**.



Long-term field trials were established in **Poland, Ukraine and Latvia**.



Trial lifetime ranged from **5 to 13 years**.

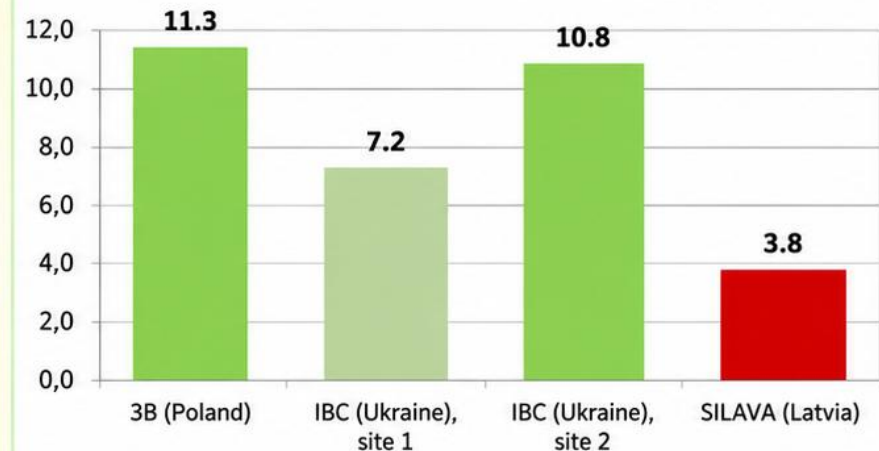


New field trials were also established in **2017 and 2018** in **Latvia and Ukraine** on marginal lands with **unfavorable texture and stoniness soil (clay)**.



Key results from MAGIC field trials

Dry matter yields (t/ha)



Willow was grown in three European countries (Poland, Ukraine and Latvia) in MAGIC. High biomass yields were recorded in Poland and Ukraine, while yields in Latvia were less than 4 t/ha.

Camelina cultivated in MAGIC: field trial examples from Poland and Italy

Illustrative examples from selected marginal-land trials



Camelina was among the selected industrial crops cultivated and evaluated in the MAGIC project.



Key findings



Camelina yield was strongly affected by slope.

- At 15% slope, seed yield reached **2 t/ha**.
- At 25% slope, seed yield was **below 0.5 t/ha**.

These examples highlight both the cultivation potential of camelina and the strong influence of site conditions on performance.



Italy (UNIBO): camelina trials on sloping land

Slope 15%



Slope 25%



View of camelina trials in Italy by UNIBO.

Poland (3B): camelina trial on sandy soil



1.06.2019



03.07.2019



13.07.2019



03.07.2019

View of camelina trials in Poland by 3B.



Germany trials (UHOH, 2018–2021)



In Germany, hemp trials were carried out for MAGIC by UHOH from 2018 to 2021.



Two row spacings were applied: 15 cm and 45 cm.



Two nitrogen rates were tested: 40 and 120 kg N/ha.

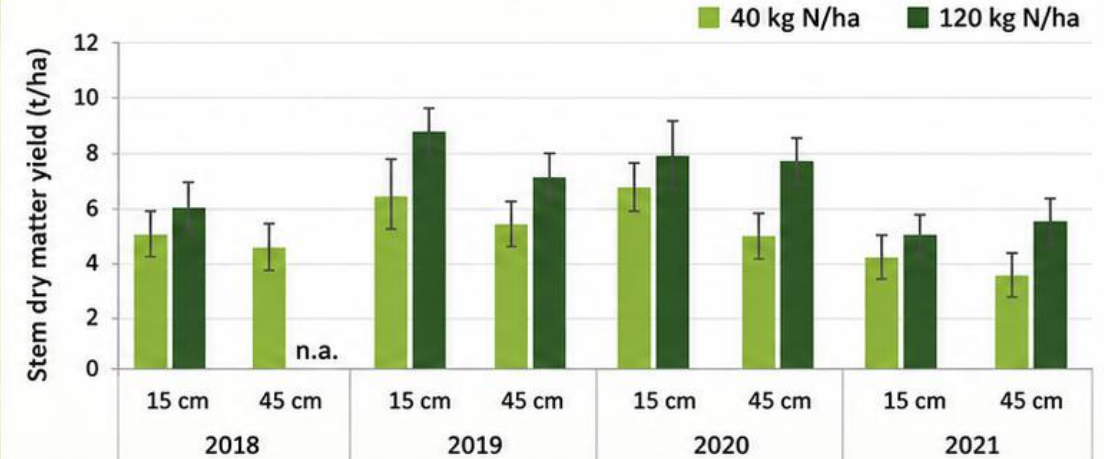


Stem dry matter yield generally increased at the higher nitrogen rate and was often higher at 15 cm spacing.



The highest recorded stem dry matter yield was about 8.8 t/ha.

Germany: stem dry matter yield (t/ha)



Greece trials



In Greece, two varieties (Futura 75 and Futura 83) were cultivated under three irrigation rates: 25%, 50% and 100% of PET.

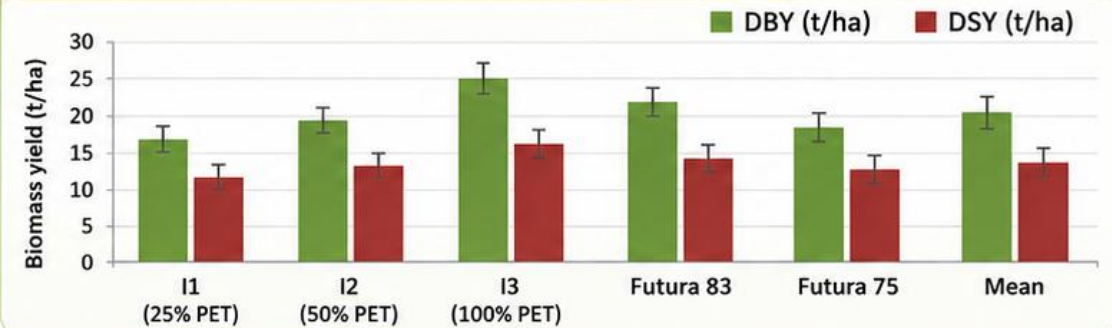


Futura 83 was more productive than Futura 75.



Crop performance improved as irrigation increased from 25% to 100% of PET.

Greece: biomass response to irrigation and variety



Key messages



Industrial hemp showed good productivity in MAGIC trials under different management conditions.



In Germany, row spacing and nitrogen application influenced stem dry matter yield.



In Greece, irrigation level and variety strongly affected biomass production.

Castor bean harvesting activities in MAGIC

Central Greece case study by CREA, UTH and CRES



About this activity

This slide presents harvesting-related field activities for castor bean in Central Greece within the MAGIC project.



View of the castor bean field trial in Greece after herbicide application to stop growth.



Harvesting equipment and headers



Cereal header



Cutting bar

Sunflower header



Cutting bar

View of the castor bean field trial in Greece and harvesting headers.



Key points

1

Harvesting activities were demonstrated in Central Greece within the MAGIC project.

2

Different combine harvester headers were examined for castor bean harvesting.

3

The field images illustrate crop condition before/after growth termination and during harvest evaluation.

Additional harvesting activities in MAGIC Camelina and cardoon harvesting trials in Italy

Apart from castor bean, additional harvesting activities were also carried out for camelina and cardoon.

Camelina harvesting trial



View of camelina harvesting trial in Italy (June 2021).

-  **Location:**
Ozzano, Italy
-  **Collaboration:**
CREA & UNIBO
-  **Slope:**
15%
-  **Crop:**
Camelina cultivar Alba
-  **Average seed yield:**
1.52 Mg DM ha⁻¹

 **Camelina was successfully harvested on sloping land under MAGIC conditions.**

Cardoon harvesting trial



View of cardoon harvesting in Italy (August 2020).

-  **Location:**
Maccarese, central Italy
-  **Trial size:**
18.32 ha
-  **Site conditions:**
clay soil with frequent water stagnation
-  **Harvester used:**
FiatAgri L624 combine harvester
-  **Effective seed yield (ESY):** 0.9 t/ha
-  **Working speed:** 4.9 km/h
-  **Theoretical field capacity (TFC):** 2.36 ha/h
-  **Effective field capacity (EFC):** 2.0 ha/h
-  **Field efficiency (FE):** 87.24%
-  **Material capacity (MC):** 1.8 Mg/h

 **Cardoon harvesting was demonstrated under wet clayey field conditions.**

Key messages

- 1** MAGIC evaluated harvesting feasibility not only for castor bean, but also for camelina and cardoon.
- 2** The trials demonstrated the use of conventional combine harvesting systems under contrasting field conditions.
- 3** Operational performance and yield data help assess the practical suitability of industrial crops on marginal lands.

Selected value chains analysed in MAGIC

Industrial crops, conversion pathways and target products



Lignocellulosic crops



Crop	Conversion pathway	Main product(s)	Type
 Miscanthus	Pyrolysis	Energy (industrial heat)	 Energy
 Poplar	Gasification	Energy (SNG)	 Energy
 Switchgrass	Fermentation	Ethanol	 Fuel
 Willow	Pyrolysis	Biochemicals (biobitumen)	 Biochemical



Oil crops



Crop	Conversion pathway	Main product(s)	Type
 Safflower	Oxidative cleavage	Azelaic and pelargonic acid	 Biochemical
 Camelina	Metathesis	Methyl decenoate	 Biochemical
 Castor	Several oleochemical processes	Diacids	 Biochemical



Carbohydrate / multipurpose crops



Crop	Conversion pathway	Main product(s)	Type
 Industrial hemp	Mechanical processing	Insulation material	 Material
 Sorghum	Anaerobic digestion	a) heat & power b) biomethane	 Energy
 Lupin	Extraction	Adhesives	 Material

Crop group colours:

 Lignocellulosic crops |  Oil crops |  Carbohydrate / multipurpose crops

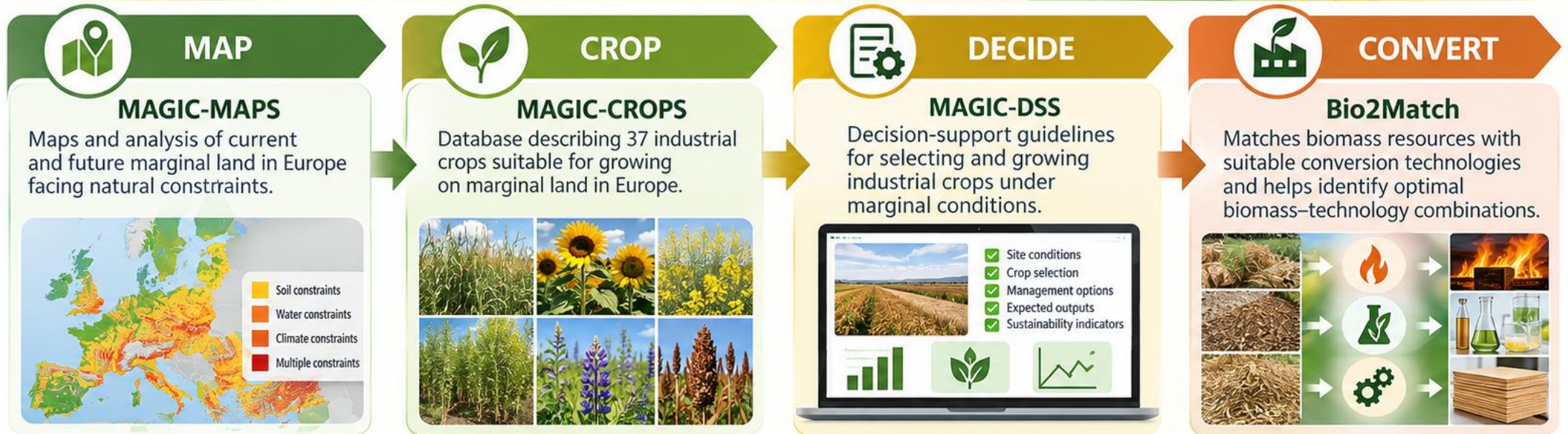
Output type icons:

 **Energy** |  **Fuel** |  **Biochemical** |  **Material**

Value chains selected in MAGIC for further analysis.

What can you find on the MAGIC website?

Tools, data and practical knowledge for industrial crops on marginal lands



Further resources available on the website

 **Public deliverables & reports**
Mapping, crop selection breeding, agronomy, harvesting, logistics.



 **Farmers' guidance & good practices**
Low-input cultivation and profitable crop guidance.



 **Value chains & sustainability**
Environmental, economic and social assessments and policy recommendations.



 **Publications & training**
Peer-reviewed papers, webinars, training and demonstration videos.



 **Practice abstracts & dissemination**
Farmer/end-user practice abstracts, events and outreach materials.



www.magic-h2020.eu

Building on MAGIC knowledge to demonstrate and upscale sustainable value chains of industrial crops on marginal lands

Magic

Marginal lands for growing Industrial Crops



Pillar 1 Crop & cropping systems optimization

Optimize climate-resilient and biodiversity-friendly industrial crops and cropping systems for marginal lands through breeding and agronomy.



Pillar 2 Value chains & biomass use

Improve the functional performance of specific value chains and products and increase resource use efficiency for non-edible biomass in a biorefinery concept.

Key outputs from MAGIC

- ✓ Identification and characterization of marginal lands in Europe
- ✓ Selection and evaluation of industrial crops
- ✓ Agronomic and environmental performance
- ✓ Initial value-chain options and conversion routes
- ✓ Data, tools and guidance

MAGIC
provides the scientific and technical foundation for MIDAS



Mapping of marginal lands



Selection of promising industrial crops and varieties



Agronomic know-how (cultivation & harvesting)



Preliminary value-chain concepts and conversion pathways



Data, tools and decision support (e.g. MAGIC-DSS)



MIDAS

Marginal Lands for Industrial Crops

MIDAS demonstrates and upscales sustainable value chains of industrial crops on marginal and severely degraded lands in Europe.



Miscanthus
Lignocellulosic (energy)



Poplar
Lignocellulosic (biochemicals)



Safflower
Oil crop (biobased products)



Camelina
Oil crop (biobased products)



Industrial hemp
Multipurpose (insulation, composites)

From trials to sustainable value chains



Field trials on marginal lands
Multi-location demonstrations

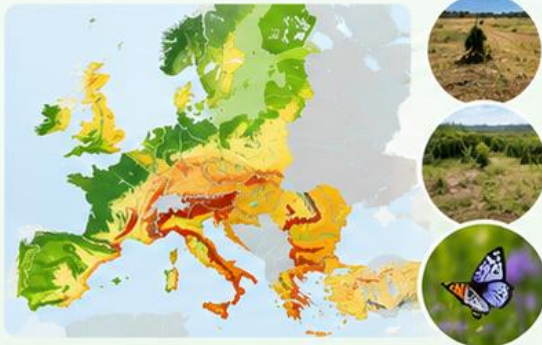
Sustainable production
Optimized agronomy and harvesting

Biorefinery conversion
Multiple products and co-products

Market & scaling
Business models, policy outputs, replication

1

Understand marginal land potential and ecosystem services



- Improve understanding of current and future marginal land for low-ILUC biomass production
- Assess biodiversity and ecosystem service challenges and co-benefits
- Upscale results in spatial and socio-economic terms

WP1, WP5, WP6

2

Optimise industrial crops and cropping systems



- Optimize selected industrial crops for marginal lands
- Use modern biotechnologies and tailored agronomic practices
- Develop low-ILUC cropping systems (e.g. intercropping, agroforestry)

WP2, WP3

3

Develop and demonstrate case studies on marginal land



- Develop case studies of low-ILUC cropping systems
- Test intercropping and agroforestry on marginal agricultural land
- Demonstrate results at farm level for present and future systems

WP3

4

Develop innovative bio-based products and value chains



- Develop innovative bio-based products (biochemicals, composites, elastomers)
- Follow a biorefinery concept
- Enable circular use of biomass and sustainable value chains

WP4



MARGINAL LAND
POTENTIAL



OPTIMISED
CROPS & SYSTEMS



DEMONSTRATION
IN THE FIELD

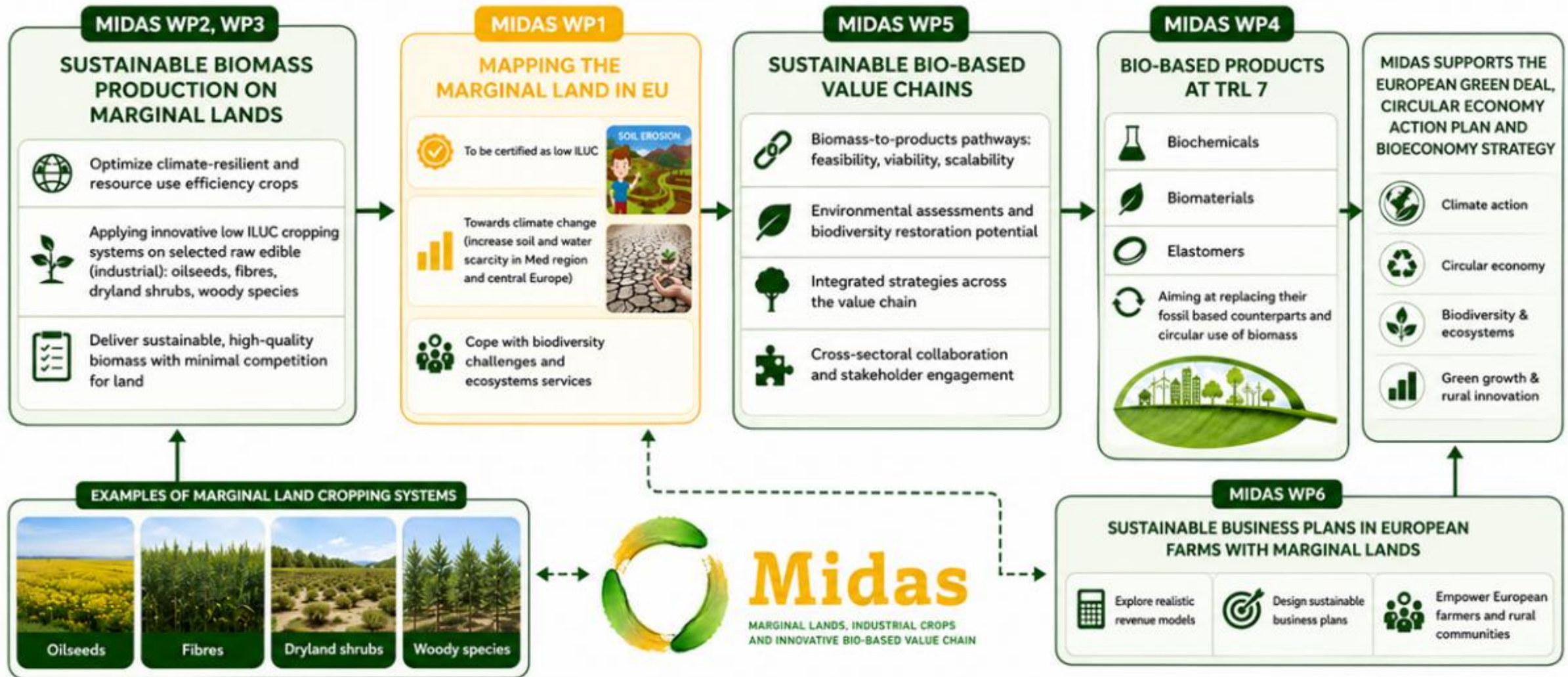


BIO-BASED PRODUCTS
& VALUE CHAINS



SUSTAINABLE
AND CIRCULAR
BIOECONOMY

Key elements of MIDAS



Mapping of
marginal lands

Innovative Cropping Systems
in 9 countries (13 sites).

11 innovative bio-based products
following a circular use of biomass.

3 innovative sustainable
value chains.

3 sustainable
business plans

Key industrial crops for MIDAS



Castor bean

Oilseeds

(crambe, castor, safflower, carinata)

Annual crops (winter/spring) providing seeds (oil and seed meal) and residual biomass

Biochemicals

(oleogels, biolubricants, biostimulants, mulch films) and **bioenergy**



Miscanthus

Lignocellulosic crops

(fibres, perennial grasses and woody species)

Hemp and sorghum (annual), miscanthus (perennial grass), willow, poplar and Siberian elm (woody species)

Biomaterials

(MDF panels, insulation materials, nanocarbons, biochar) and **bioenergy**



Guayule

Dryland shrubs

(guayule, lavender)

Perennial crops; guayule is better suited to southern Europe, while lavender has wider coverage

Elastomers (latex for gloves, rubber for tyres) and **biochemicals** (resins, plant protection products)

What new MIDAS brings to marginal land mapping in the EU27

Building on the MAGIC foundation

Starting point from MAGIC



Initial marginal land mapping framework



Future projections and additional regions



Project website StoryMap and first comparative mapping results



MIDAS advances

1

Updated EU27 marginal-land mapping

Refined and expanded mapping beyond the original MAGIC approach.



2

Detection of abandoned marginal arable land

Identification of land at risk of abandonment and underuse.



3

Biodiversity and ecosystem services integration

A framework to include ecological value in the land-classification system.



4

Crop-yield simulation with AquaCrop

Linking land suitability with yield performance.



5

Upscaling with field case-study data

Using crop yields from project field trials to improve regional mapping.



6

Socio-economic KPIs at NUTS3 level

Adding territorial indicators to support decision-making.



Key message: MIDAS moves from static mapping toward an **integrated EU27 system** that combines biophysical constraints, biodiversity, ecosystem services, crop performance and socio-economic indicators.



Preliminary insight: around **30% of Europe's arable land** may be characterized as marginal, with lower shares expected in central and northern Europe and higher shares in the south.

Key breeding activities in MIDAS for selected industrial crops

Optimization through breeding

Two optimization pathways in MIDAS: breeding and agronomy.



Activity

1

Miscanthus hybrids developed by WU in collaboration with VanDinterSemo BV within the GRACE project.

Selection and evaluation of promising miscanthus breeding material.



GRC-1



GRC-7

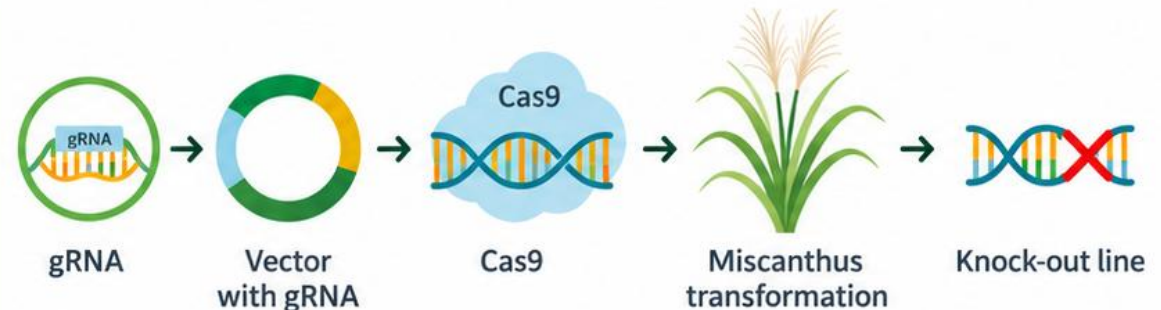


Activity

2

Development of molecular breeding tools for industrial orphan crops.

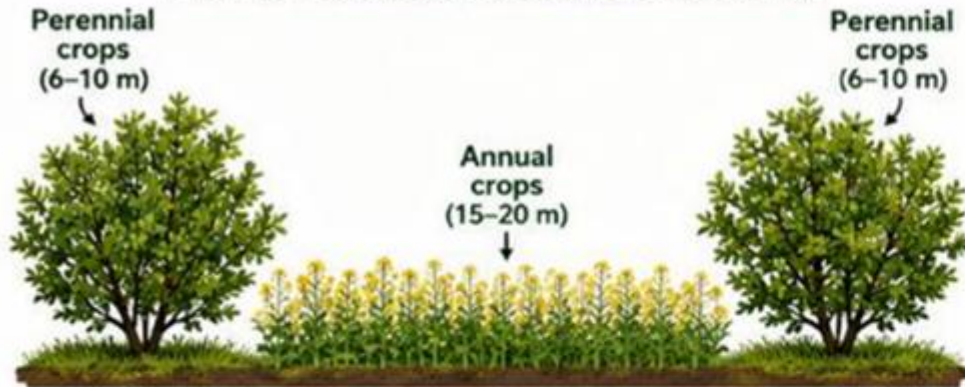
Including transformation and gene-editing approaches for miscanthus improvement.



Innovative cropping systems for MIDAS industrial crops

Agroforestry system

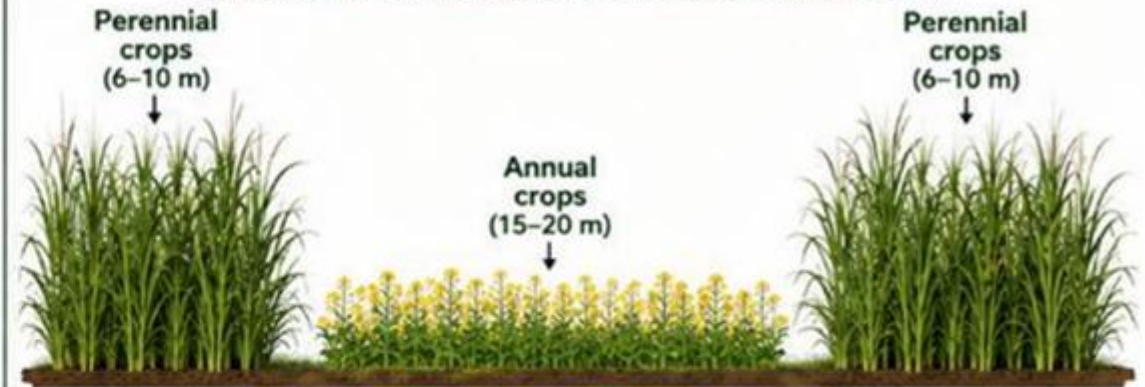
Perennial component: willow, poplar or Siberian elm



Mixed system: woody perennials + annual crops

Intercropping system

Perennial component (tall grasses) varies depending on location



Annual crops can be safflower, castor, crambe, sorghum, hemp or carinata

Case study partners

Intercropping

- UNIBO (IT)
- UNICT (IT)
- NOVAMONT (IT)
- CIEMAT (ES)
- ITAP (ES)
- CRES/AUA (GR)
- GUATECS (FR)
- UHOH (DE)
- IFVC (RS)
- HempCzech (CZ)

Agroforestry

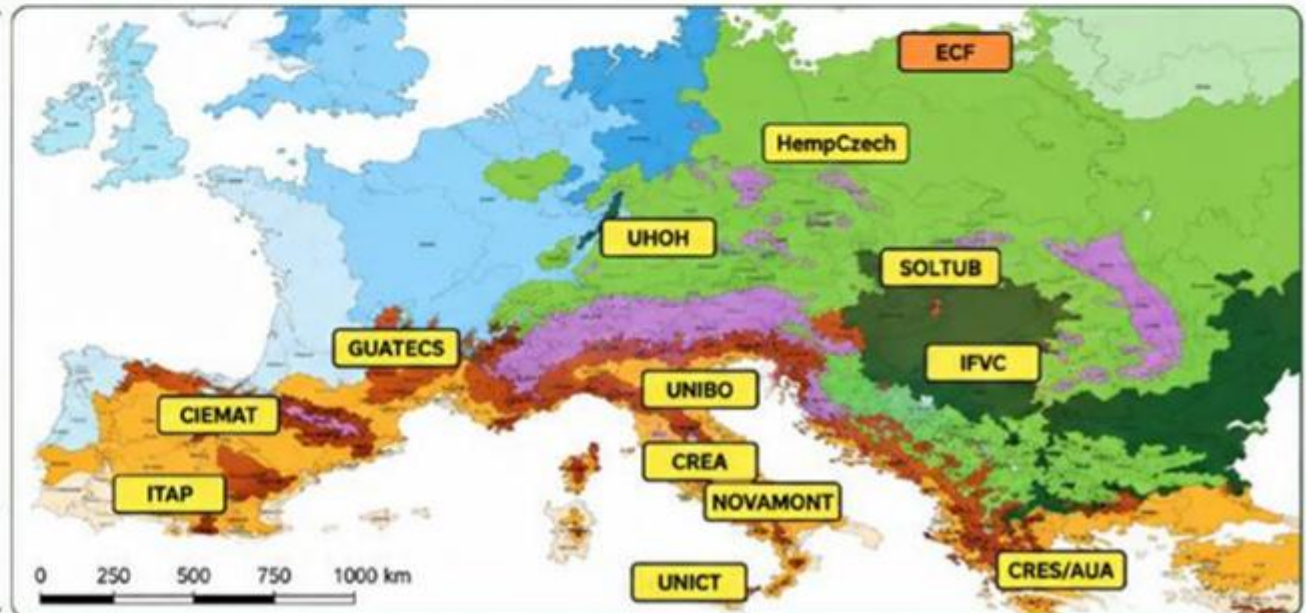
- CIEMAT (ES)
- CRES/AUA (GR)
- CREA (IT)
- SOLTUB (HU)
- FCF (PL)

Environmental Zone (Spötl et al., 2002)

MDM – Mediterranean Mountains	1
MDN – Mediterranean North	
MDS – Mediterranean South	
ATN – Atlantic North	2
ATC – Atlantic Central	
LUS – Lusitanian	
BOR – Boreal	3
CON – Continental	
NEM – Nemoral	
PAN – Pannonian	

 Partners responsible for the case studies

 Partner responsible for a replication case



Two innovative cropping systems; intercropping and agroforestry

Strip intercropping – Sicily



Marginality conditions: steep slope (>15%) and sandy clay soil (46% sand).



Crops: cardoon (perennial), safflower, crambe and industrial hemp (annual crops).



Adaptive change: castor bean was initially established, but it was replaced by safflower in the following year.



Seed yields (2nd year): cardoon 1.6 t/ha; crambe 0.6 t/ha; safflower 1.0 t/ha; hemp 0.1 t/ha.

Agroforestry – Rome



Agroforestry case study in Rome, where innovative cropping systems are being developed and applied within MIDAS.



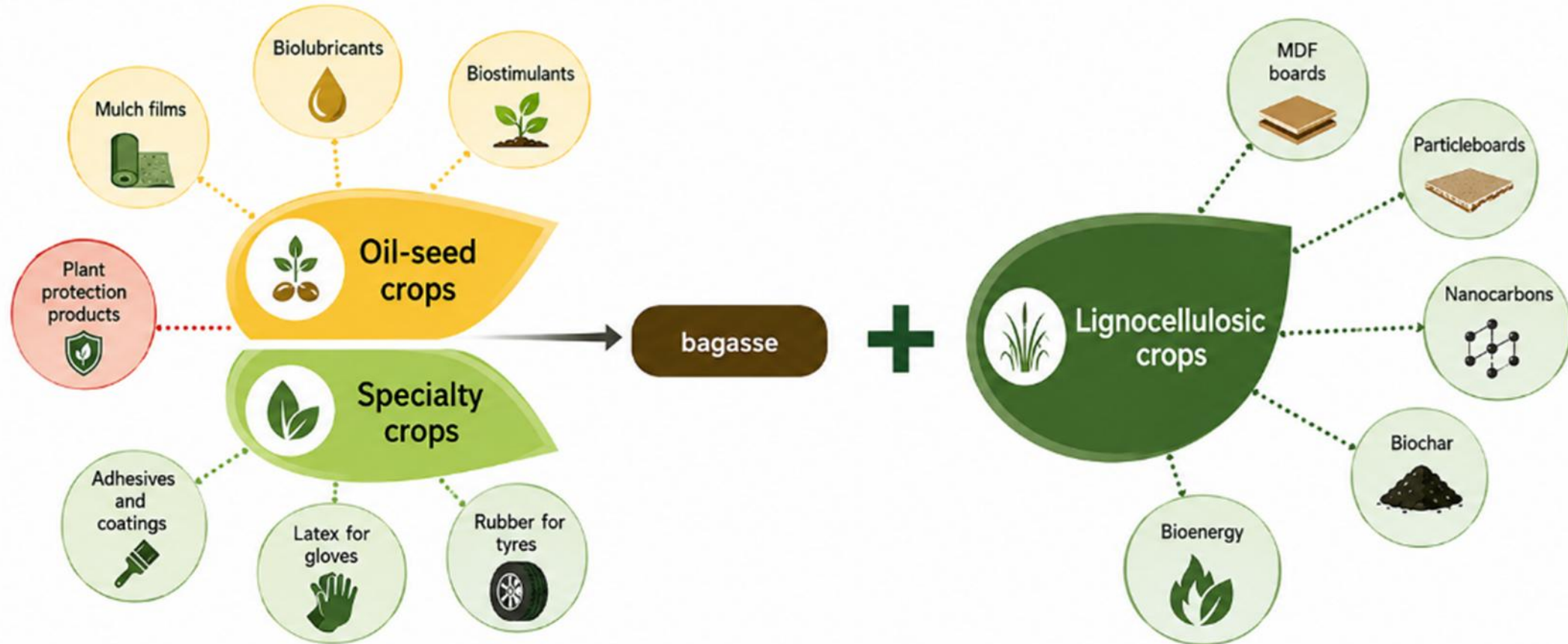
Example of diversified land use integrating woody vegetation and crop production.



MIDAS explores innovative low-ILUC cropping systems adapted to marginal lands.



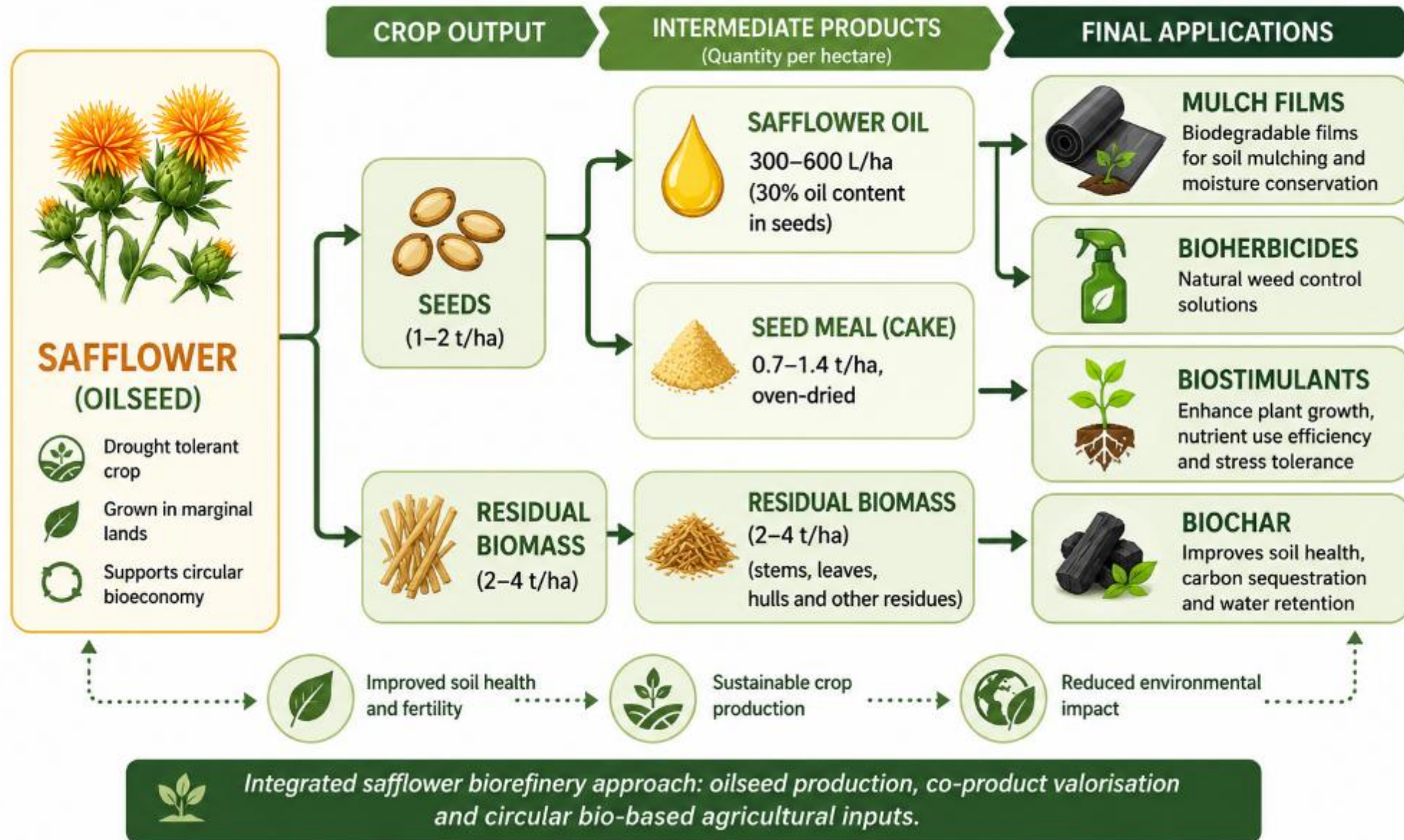
The MIDAS value added bio-products from the MIDAS industrial crops



11 bio-based products (mulch films, biolubricants, biostimulants, plant protection products, latex for gloves, rubber for tyres, MDF boards, particleboards, nanocarbons, biochar, adhesives and coatings) produced at TRL 7.

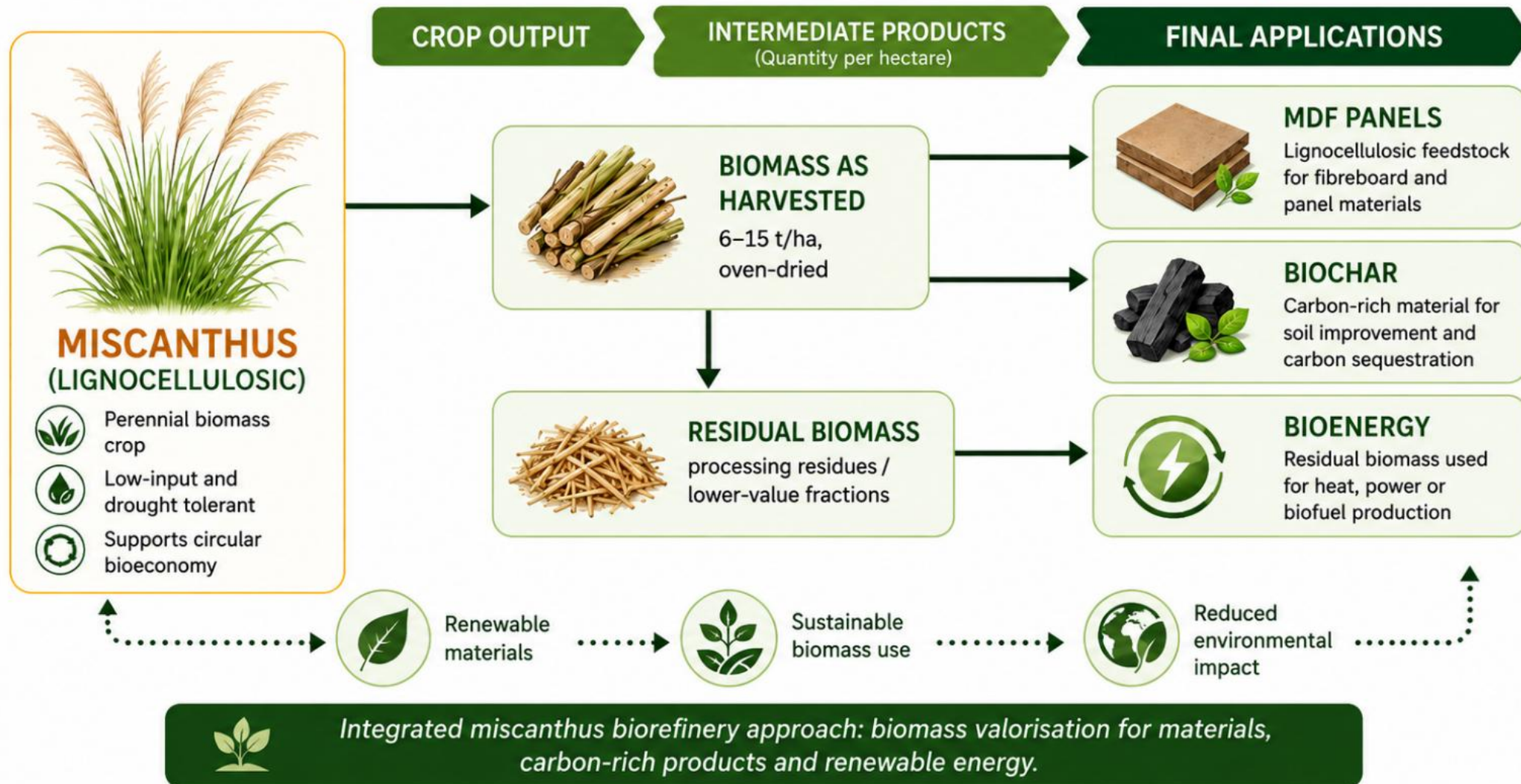
The valorization pathways for safflower

From oilseed to bio-based products for sustainable agriculture



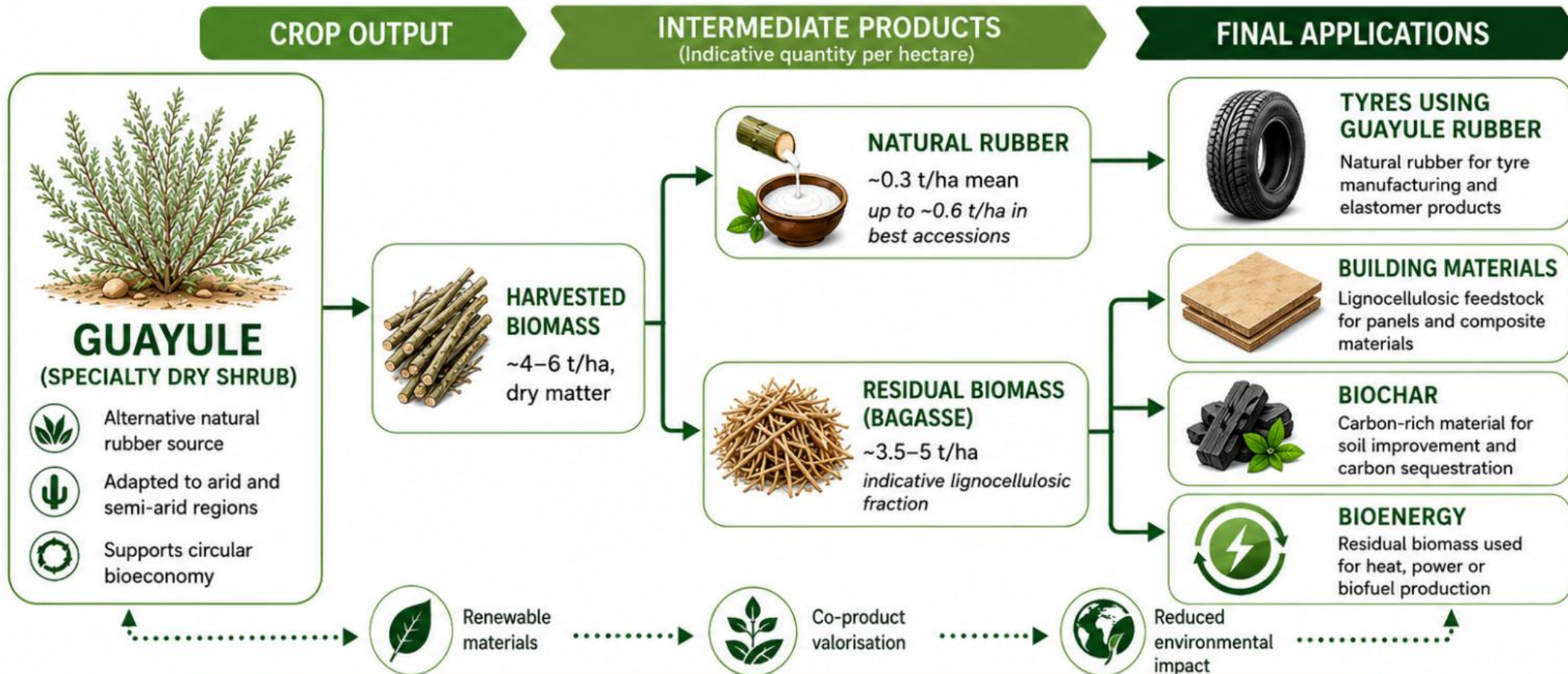
The valorization pathways for miscanthus

From lignocellulosic biomass to bio-based products and renewable energy



The valorization pathways for guayule

From arid-land shrub biomass to natural rubber and bio-based co-products



Integrated guayule biorefinery approach: natural rubber production and valorisation of lignocellulosic co-products for materials, biochar and renewable energy.

Indicative values based on University of Castilla-La Mancha field trials; yields vary with accession, crop age, irrigation and harvest cycle.

Midas

MARGINAL LANDS, INDUSTRIAL CROPS
AND INNOVATIVE BIO-BASED VALUE CHAINS



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Thank you



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Funded by
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This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101082070. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them.