Climate Change AI

Evaluating Digital Tools for Sustainable Agriculture using Causal Inference

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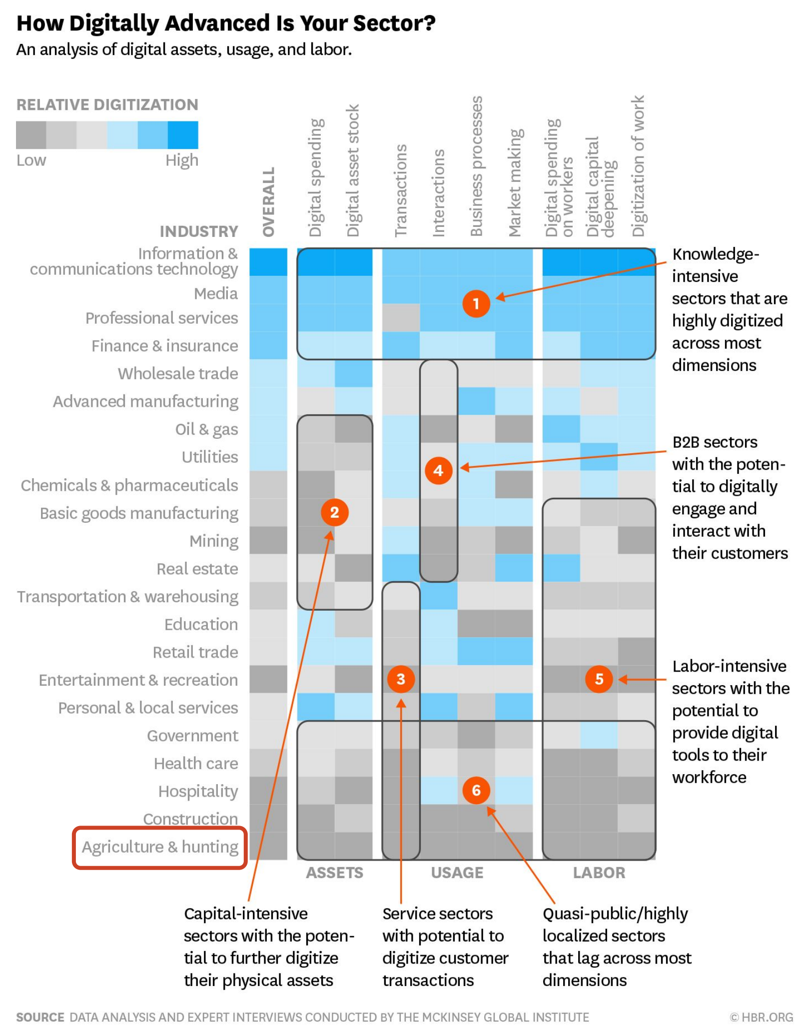
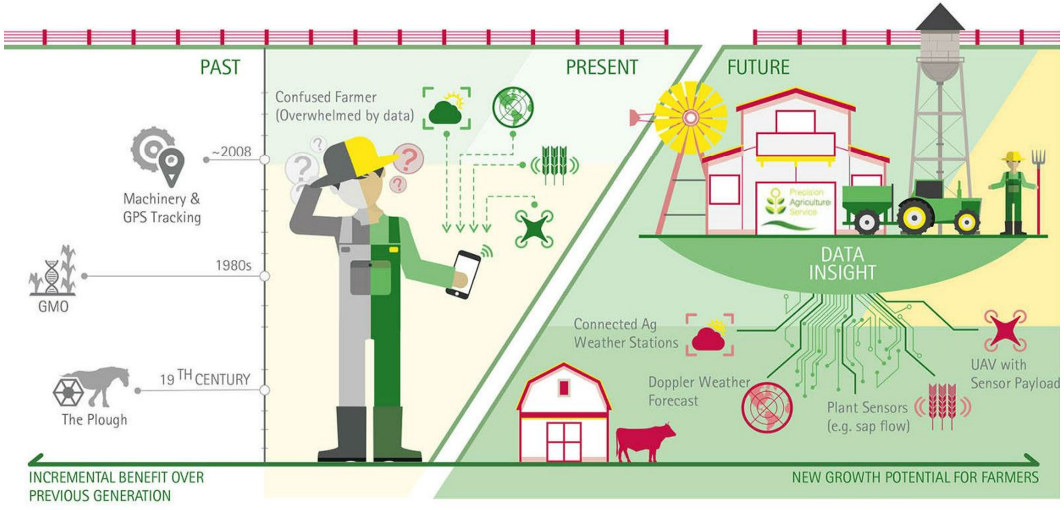
Motivation





smart farming technologies could drive to the application of required sustainable agriculture practices

but limited adoption

Farmer needs:

- ↦ **actionable advices**
- ↦ **evidence about effectiveness & benefits**

The case of a knowledge-based recommendation system for optimal cotton sowing

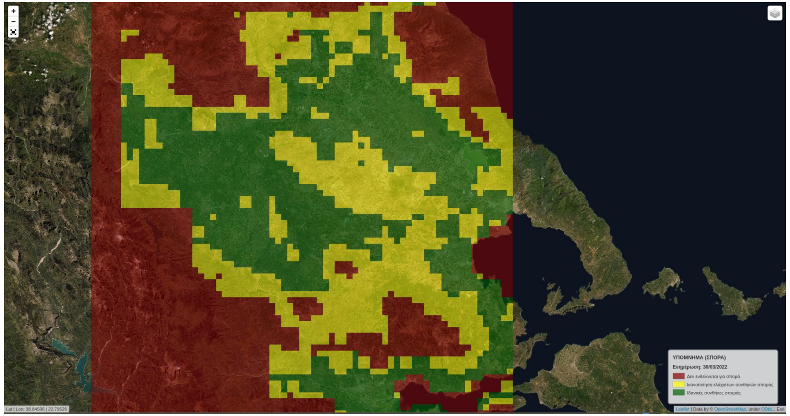
Answering on a real need of cotton farmers.
Is today a good day to sow?

Collaboration with a farmer's cooperative (171 cotton fields) in Orchomenos, Viotia-Greece

Cooperative have consolidated routines for interacting with their crops (e.g. common practices, homogeneous fertilizer application, jointly owned machinery)

ΑΓΡΟΤΙΚΟΣ ΣΥΝΕΤΑΙΡΙΣΜΟΣ ΟΡΧΟΜΕΝΟΥ

pilot of sowing map for cotton for cultivation period of 2021 in Orchomenos, GR



Knowledge-based Recommendation System

Artificial 10-day at 2km forecast blending WRF & GFS

$$a_i = \frac{GFS_{day=i}}{GFS_{day=1}}, i \in \{3, ..., 10\} \tag{1}$$

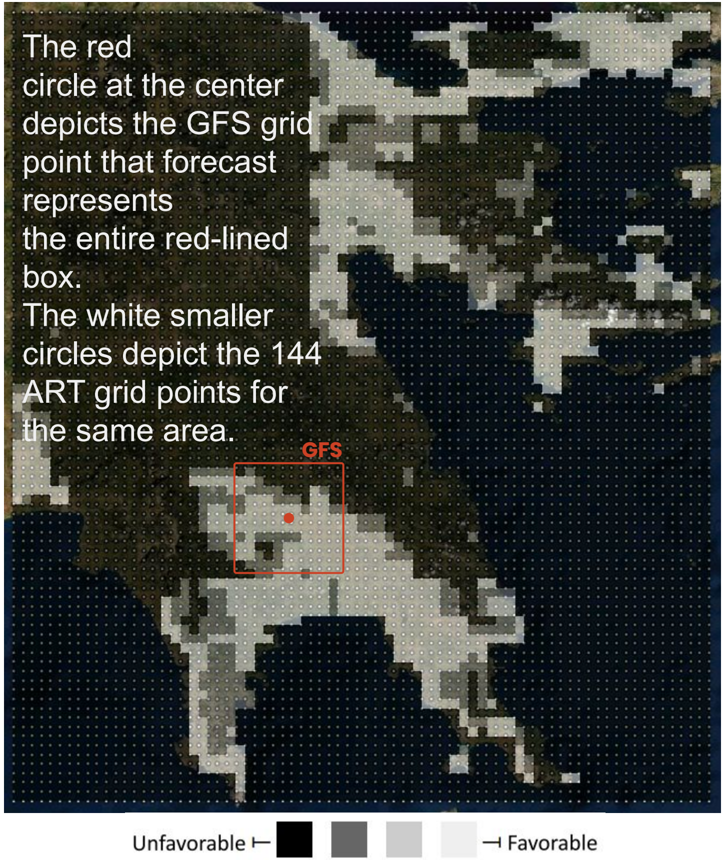
$$ART_j = \begin{cases} WRF_{day=j} & , j \in \{1, 2\} \\ WRF_{day=1} \cdot a_j & , j \in \{3, ..., 10\} \end{cases} \tag{2}$$

Knowledge-based rules

Type of Temperature	Statistic	Condition	Condition Priority
soil (0-10 cm)	mean	>18°C	optimum
ambient (2 m)	max	>26°C	optimum
soil (0-10 cm)	mean	>15.56°C	mandatory
soil (0-10 cm)	min	>10°C	mandatory
ambient (2 m)	min	>10°C	mandatory

All conditions refer to a time window between 5 to 10 days

Nearest neighbor



actionable advices ✅

evidence about effectiveness & benefits ❓

Hmm,
but what is the
actual impact of
our recommended
actions?

[BOOK] Evaluating decision support and expert systems

L Adelman - 1992 - dl.acm.org

Three approaches to evaluating decision support and expert systems are presented: subjective, technical, and empirical. Subjective evaluation assesses the decision support or expert system from the perspective of the system's users and sponsors. For subjective evaluation, the author presents several techniques including multiattribute utility technology, cost-benefit analysis, and decision analysis. Technical evaluation determines whether the delivered system is a good technical product. Technical evaluation techniques include …

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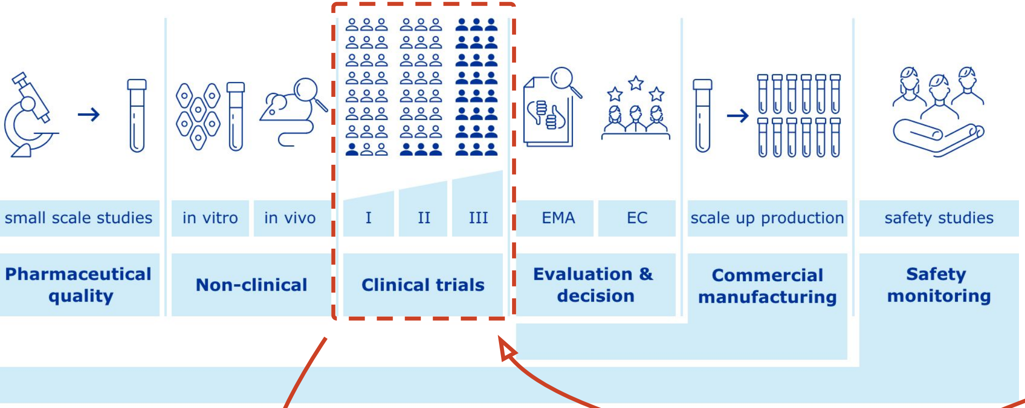


Table 1. *Evaluation methods overviewed herein*

Subjective evaluation methods for requirements validation and to obtain system performance and usability judgments
- Multi-Attribute Utility Assessment (MAUA)
- Task analysis
- Interviews and questionnaires
- Observation
- Human factors checklists
- User diaries

Technical evaluation methods
- Static and dynamic analysis to assess the logical consistency and completeness of the knowledge base
- Domain experts and the use of test cases to assess the functional completeness and predictive accuracy of the knowledge base
- Software testing methods to assess "service requirements"

Empirical evaluation methods to obtain objective measures of system performance
- Experiments
- Quasi-experiments
- Case studies (i.e., field tests)

Ok, lets run our experiments! But if there is no capacity for RCTs?

Evaluating agricultural recommendations using **causal inference**

Our approach

Model the farm system using a causal graph, and identify the effect of sowing on a recommended day on the yield the farmer observed.

Unit	Field
Treatment (T)	The field was sown on a recommended day
Outcome (Y)	Yield observed at the end of season

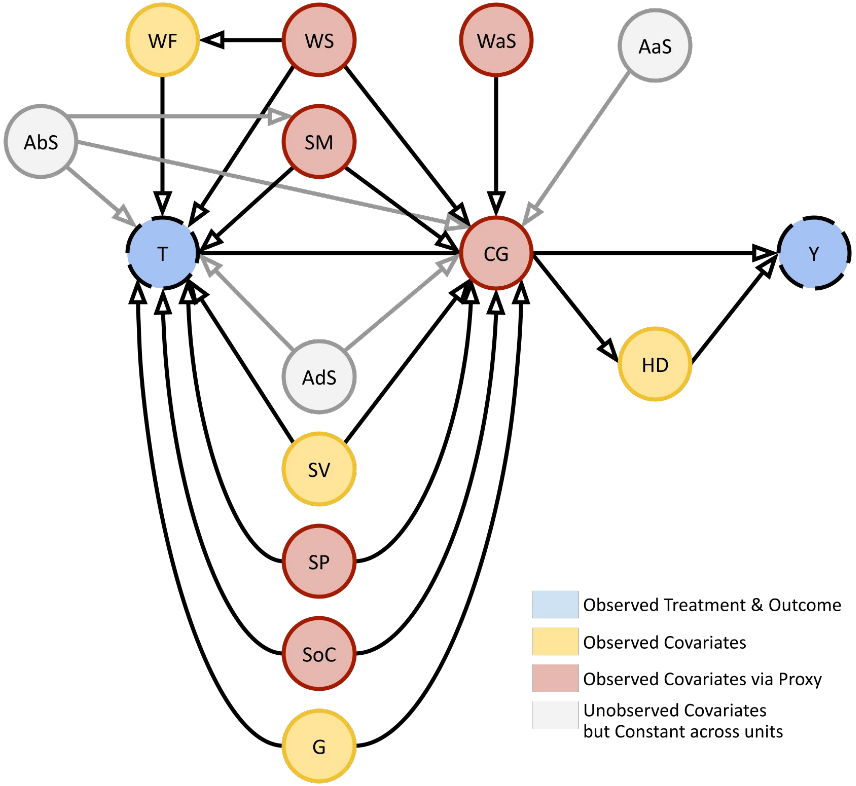
$$\text{ATE} = \mathbb{E}[Y|do(T=1)] - \mathbb{E}[Y|do(T=0)]$$

Our end goal is to account for exactly the variables that will allow us to identify the Average Treatment Effect (ATE) of the treatment on outcome

Unobserved confounding, selection bias, counterfactual yield not observed

Exploit our understanding of the cooperative's modus operandi and harness agricultural knowledge

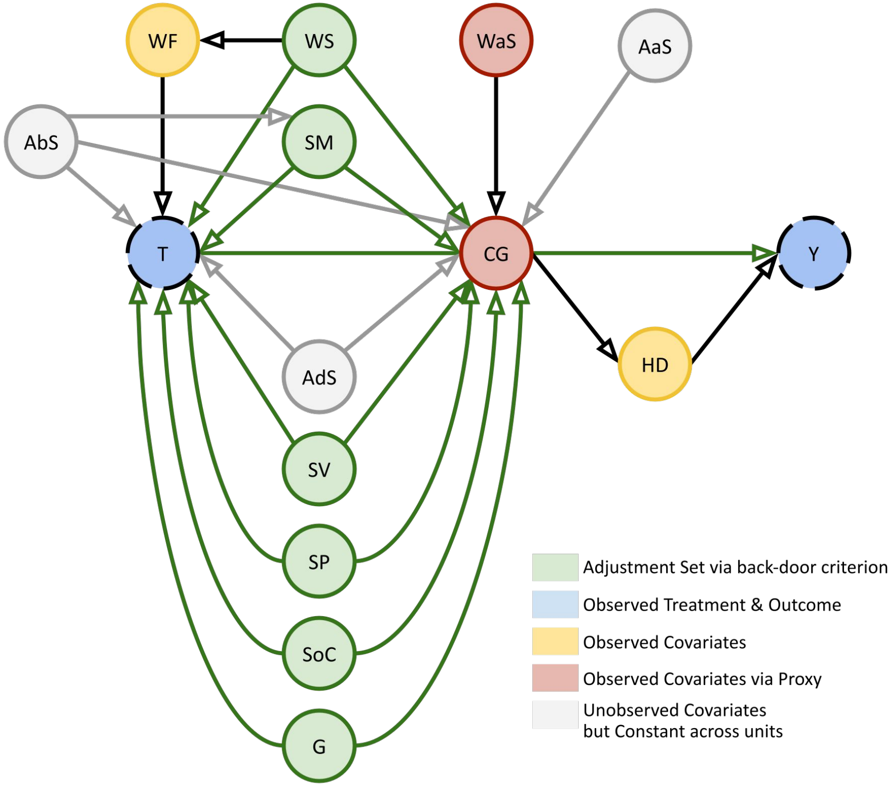
Graph Building



Id	Variable Description	Source
T	Treatment	Recommendation System
WF	Weather forecast	GFS, WRF
WS	Weather on sowing day	Nearest weather station
WaS	Weather after sowing	Nearest weather station
CG	Crop Growth	NDVI via Sentinel-2
SM	Soil Moisture on sowing	NDWI via Sentinel-2
SP	Topsoil physical properties	Map by ESDAC
SoC	Topsoil organic carbon	Map by ESDAC
SV	Seed Variety	Farmers' Cooperative
G	Geometry of field	Farmers' Cooperative
AdS	Practices during sowing	Farmers' Cooperative
AbS	Practices before sowing	Farmers' Cooperative
AaS	Practices after sowing	Farmers' Cooperative
HD	Harvest Date	Farmers' Cooperative
Y	Outcome (Yield)	Farmers' Cooperative

In collaboration with domain experts and by making clear assumptions, we establish a causal graph of the farm system

Effect Identification



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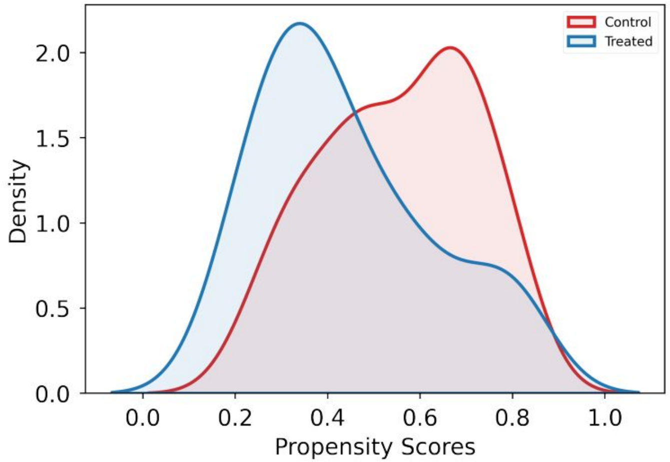
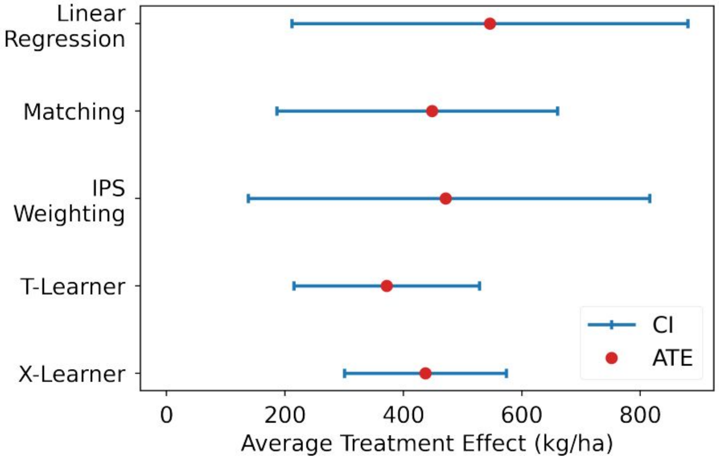
Applying the back-door criterion, the following set of variables was found to be sufficient for effect identification:

$$Z = \{\mathrm{WS}_{\mathrm{MIN,\ MAX}},\ \mathrm{SOC},\ \mathrm{SM},\ \mathrm{G},\ \mathrm{SP}_{\mathrm{SILT,\ CLAY,\ SAND}},\ \mathrm{ABS},\ \mathrm{ADS},\ \mathrm{SV}_{1\text{-}13}\}$$

Effect Estimation



Propensity score P(T=1|Z) distribution and overlap for treatment and control groups



Point ATE estimates and 95% confidence intervals

Results & Refutations

Causal Effect Estimation				Refutations						
				Placebo		RCC		UCC	RRS	
Method	**ATE**	**CI**	**p-value**	**Effect***	**p-value**	**Effect***	**p-value**	**Effect***	**Effect***	**p-value**
Linear Regression	546	(211, 880)	0.0015	-25.74	0.39	546	0.49	85	543	0.45
Matching	448	(186, 760)	0.0060	50.82	0.39	432	0.40	116	438	0.48
IPS weighting	471	(138, 816)	0.0010	38.82	0.40	470	0.40	113	462	0.45
T-Learner (RF)	372	(215, 528)	0.0240	9.26	0.49	373	0.46	-	353	0.42
X-Learner (RF)	437	(300, 574)	0.0050	5.10	0.50	430	0.37	-	409	0.36

All methods indicate a significant, positive ATE of the treatment on yield

Methods successfully passed 4 refutation tests, indicating robust estimates

Sowing on a recommended day drove a yield increase ranging from 372 to 546 cotton kg/ha (12%-17% relative to mean yield)

Conclusions & Next Steps

Evaluating Digital Tools for Sustainable Agriculture using Causal Inference

Assumptions limit external validity

To cross-check with experiments

Driving much-needed tech adoption

Transparent impact, fair service fees

Examine other forms of effect identification, fit Structural Causal Models for counterfactual analysis, learn Conditional ATEs with Machine Learning

New pilot applications will allow us to practically test the external validity of our results across different seasons, crops and locations.

Thank you!

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