



SWIM

**(SMART WEED IMPACT
MANAGEMENT): UN SISTEMA DI
SUPPORTO ALLE DECISIONI PER
LA GESTIONE SITO SPECIFICA
DELLE INFESTANTI NEL MAIS**

**Leonardo Ercolini, Nicola Grossi, Andrea Berton, Massimo Martinelli, Davide Moroni,
Nicola Silvestri**



The challenge of modern agriculture



1. A growing demand for sustainable food systems

Global population and food demand are increasing, requiring higher agricultural productivity.



+50%
global food demand by 2050
(FAO, 2025)



More efficient and resilient agricultural systems are needed



Minimizing environmental impact is essential to ensure a long-term food supply



2. The European response

The Farm to Fork Strategy sets ambitious targets to make food systems more sustainable.



Farm to Fork Strategy

A fair, healthy and environmentally friendly food system (European Commission, 2020)



-50%
use and risk of chemical pesticides by 2030



-50%
nutrient losses by 2030



25%
of agricultural land under organic farming by 2030



Sustainable Use Regulation (SUR)

Proposal for a mandatory reduction of pesticides withdrawn in March 2024.



Directive 2009/128/EC remains in force,

promoting the sustainable use of pesticides through Integrated Pest Management (IPM) and alternative control methods.



3. Why reduce pesticide use?

Pesticides are essential for productivity, but their intensive use can lead to negative environmental, economic and social impacts.



Environment

- Loss of biodiversity
- Soil and water contamination
- Herbicide resistance





Economy

- Increasing production costs
- Lower long-term effectiveness
- Economic risks due to resistance





Health and society

- Reduced exposure to chemicals
- Safer food systems
- Greater social acceptance of sustainable practices

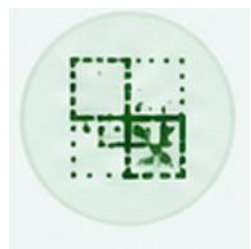




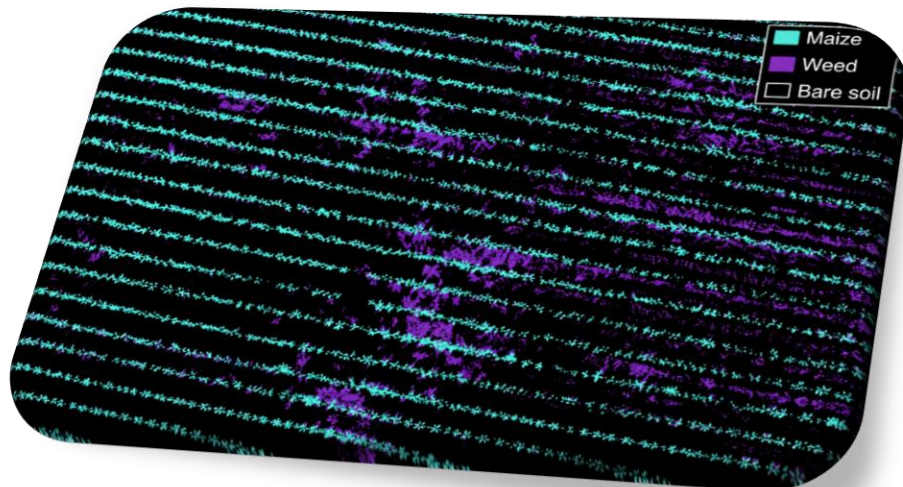
Modern agriculture must reconcile productivity, food security and environmental sustainability,
and reducing pesticide use is a key step towards this goal.



Why Site-Specific Weed Management?



- Weed infestations are **spatially heterogeneous**



- Why apply herbicide **uniformly** across the entire field?



- We need to improve the **APPLICATION EFFICIENCY**





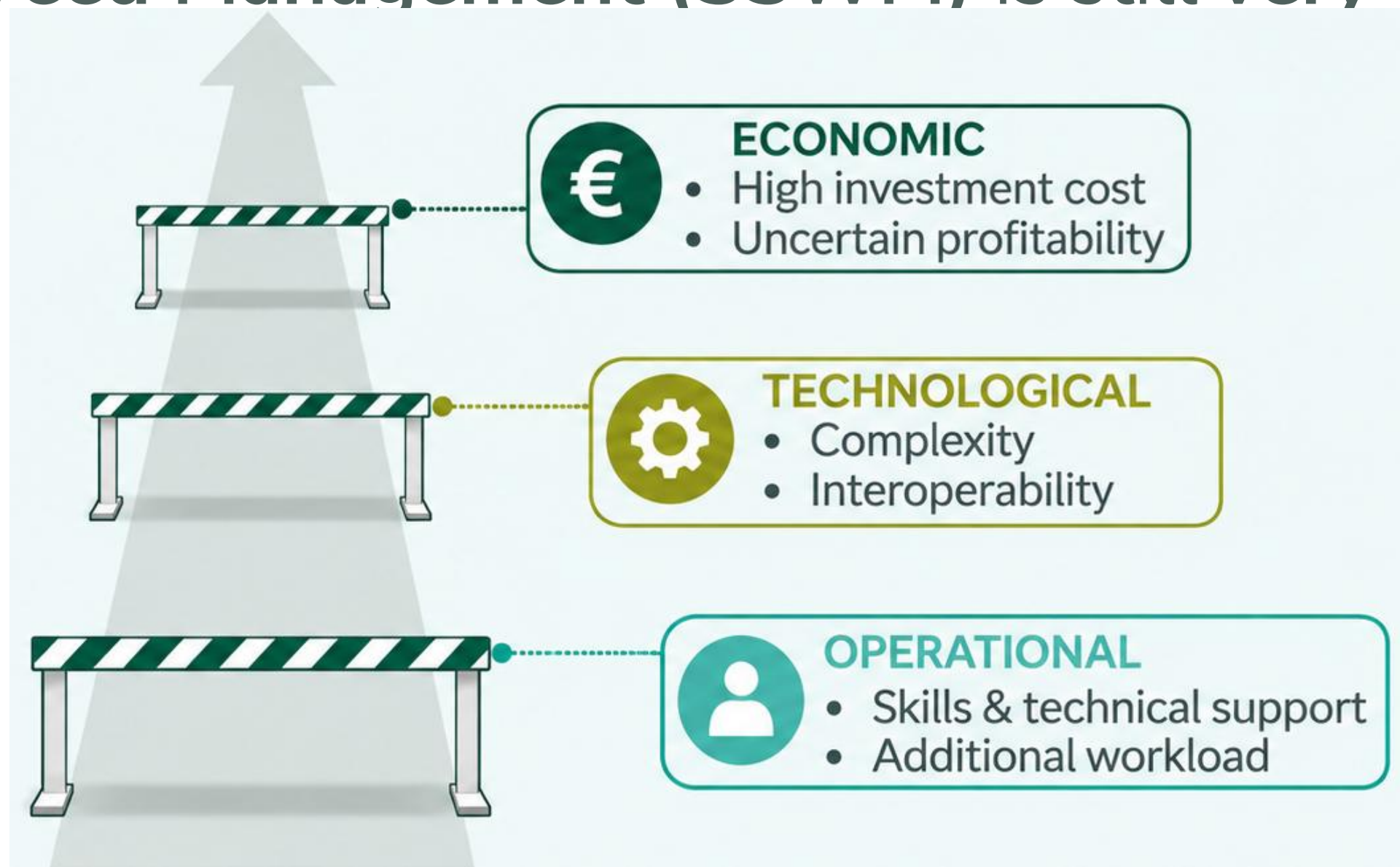
Despite the technological progress...

The adoption of Site-Specific Weed Management (SSWM) is still very limited

6 %

EU farms use Site Specific herbicide application

Pitsyk et al., 2026, Precision Agriculture



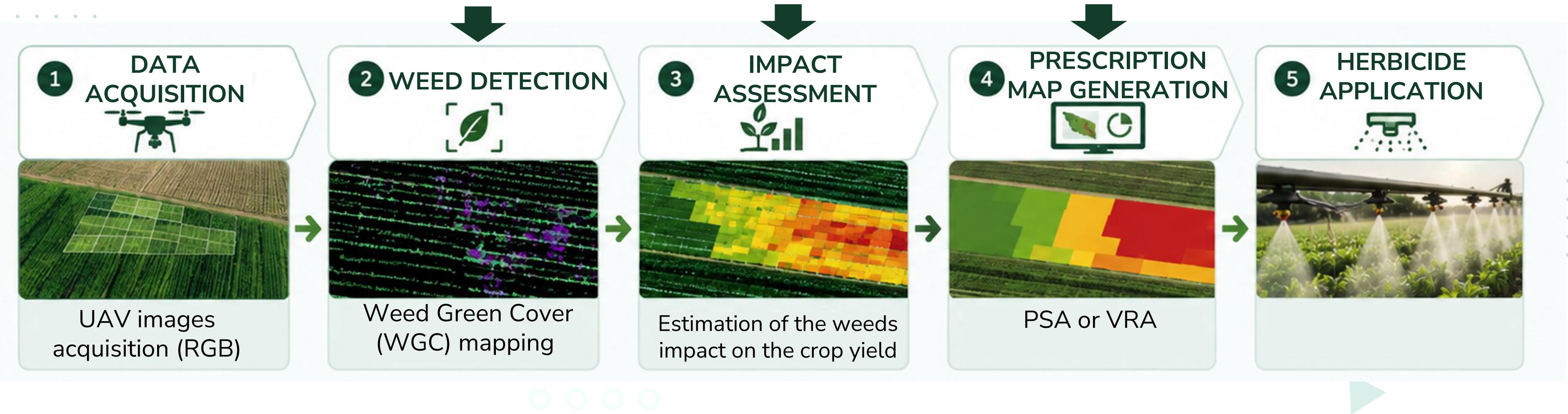


Our idea: SWIM

Smart Weed Impact Management: a DSS

- Simple
- Exportable
- Low-cost

 Farmer is in the center of the process defining parameters and strategy



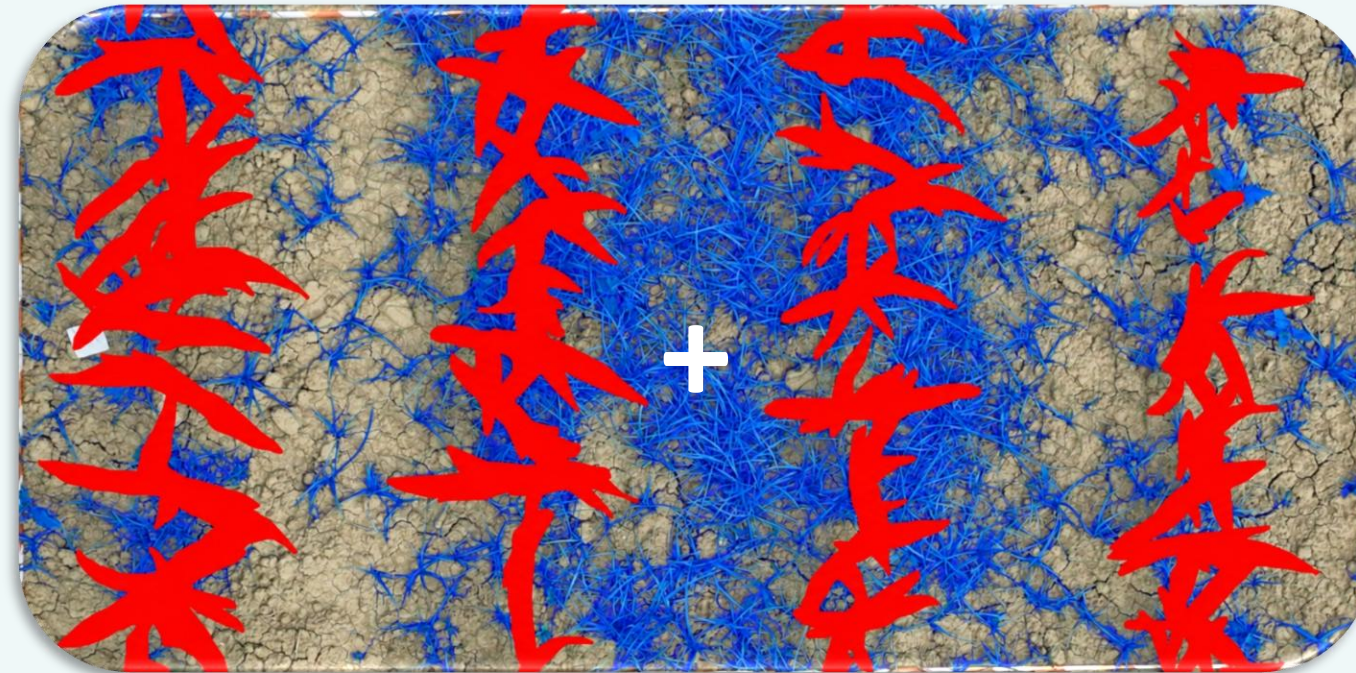
Weed Detection (WD):

Total Green Cover (TGC)



=

Maize Green Cover (MGC)



+

Weed Green Cover (WGC)

CV = 0.137
Low variability

CV = 0.889
high variability

$$WGC = TGC - MGC$$

 The crop component (MGC) is relatively stable, while the weed component (WGC) is highly variable across the field

Weed Detection (WD):

Estimating MGC through site specific calibration:

$$\text{MGC} = \text{n}^\circ \text{maize plants (NMP)} \times \text{Maize Plant Green cover (MPGC)}$$

SWIM calibration phase

Pre-cut (TGC)

Post-cut (WGC)



Calibration parameters



Maize Green Cover (MGC)



Number of Maize Plants (NMP)



$$\text{mMPGC} = \text{mMGC} / \text{mNMP}$$

Weed Detection (WD)

SIMPLE METHOD



Designed for beginner farmers



Only calibrated parameters

Fixed value

$$\boxed{\text{MGC}} = \text{mMPGC} \times \text{mNMP}$$



$$\text{WGC} = \text{TGC} - \text{mMGC}$$

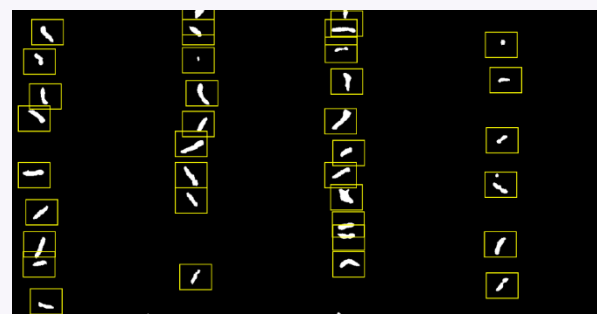
IMPROVED METHOD



Designed for skilled farmers



Plants number detector:



rNMP
real NMP

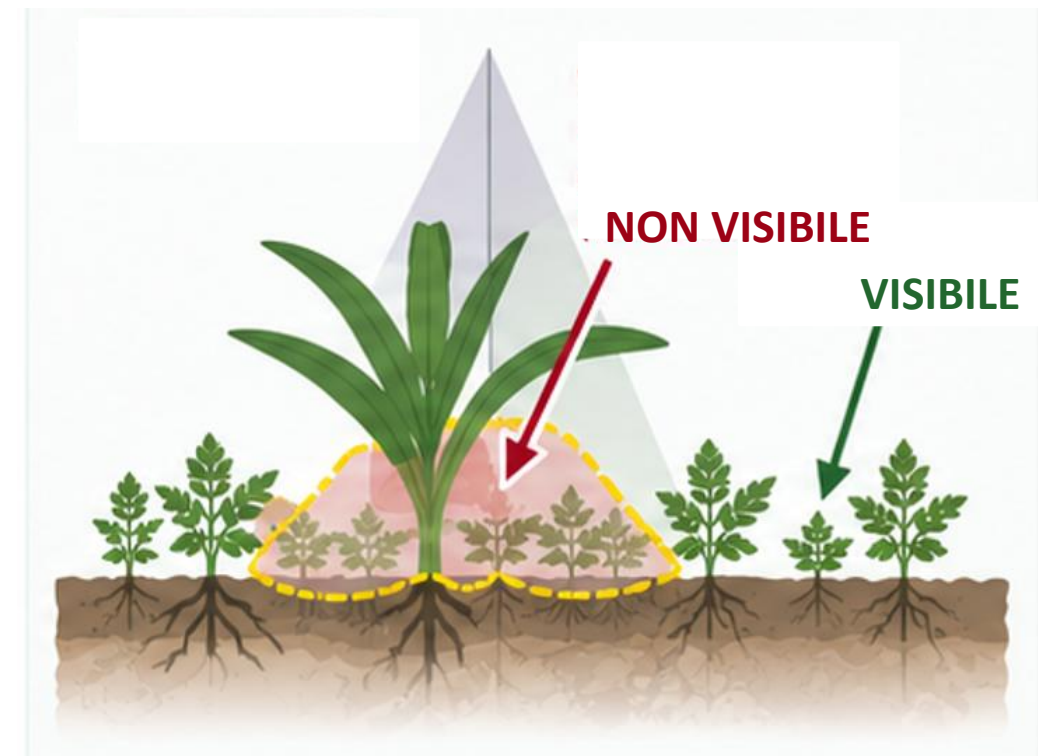
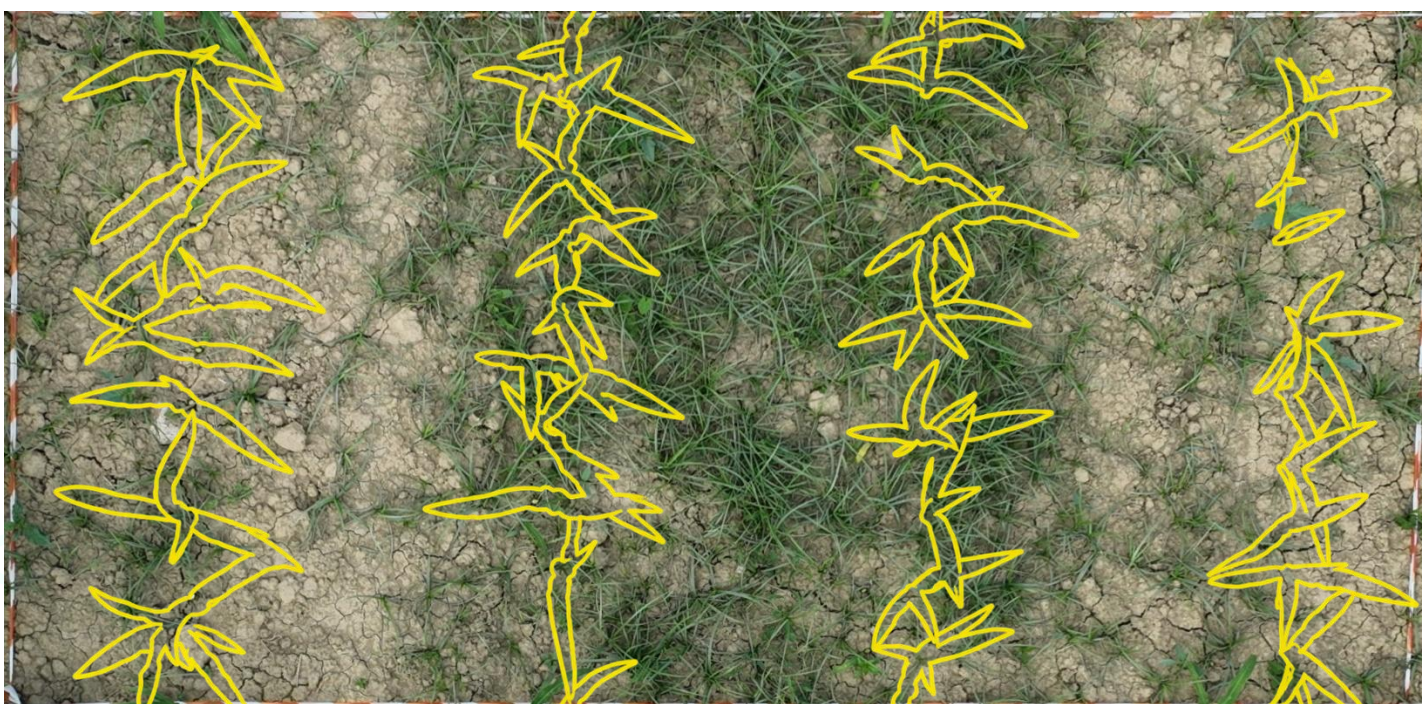
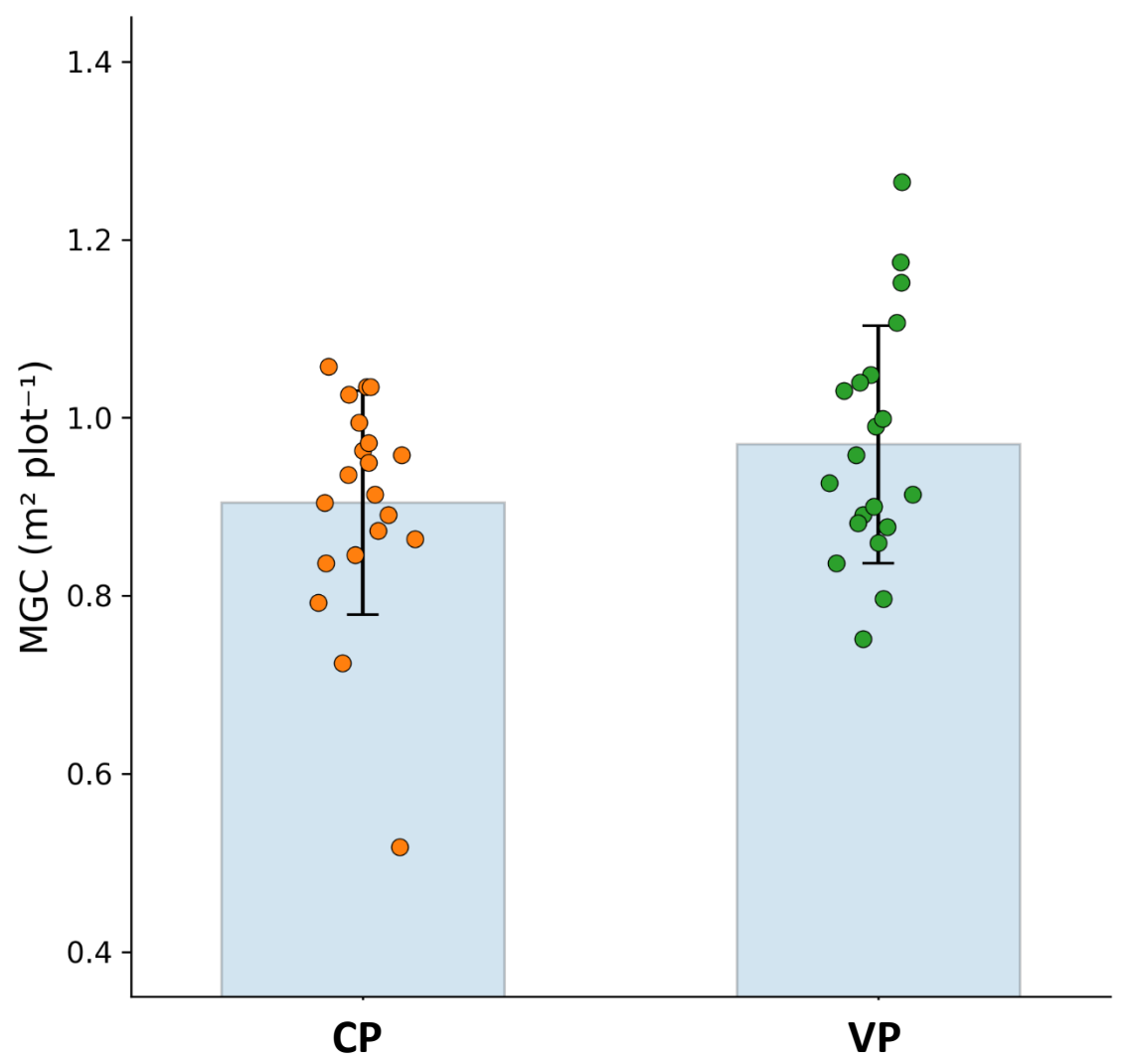
Dynamic value

$$\boxed{\text{dMGC}} = \text{mMPGC} \times \text{rNMP}$$



$$\text{WGC} = \text{TGC} - \text{dMGC}$$

The overlap problem:



$R\text{-WGC} = \text{WGC} + \text{hidden WGC}$

$R\text{-WGC} = \text{WGC} + \text{estimated hidden WGC}$

Impact assessment

From weed pressure to expected yield loss :

$$YL = \left(\frac{WMR \times q}{1 + (q - 1)WMR} \right) \times Y_{out}$$

YL = Yield Loss
WMR = WGC/TGC
q = competition coefficient
Yout = max yield

Goldsmith, A. et. al (2025)



WMR_{EIT} | YL = cost of the treatment

SIMPLE METHOD

q = fixed value (1,0)
Yout = historical data or farmer experience



IMPROVED METHOD

Site specific calibration

Wedded Plots	→	Yout
Unwedded Plots	→	WGC Final Yield

q = calculated value (0,93)

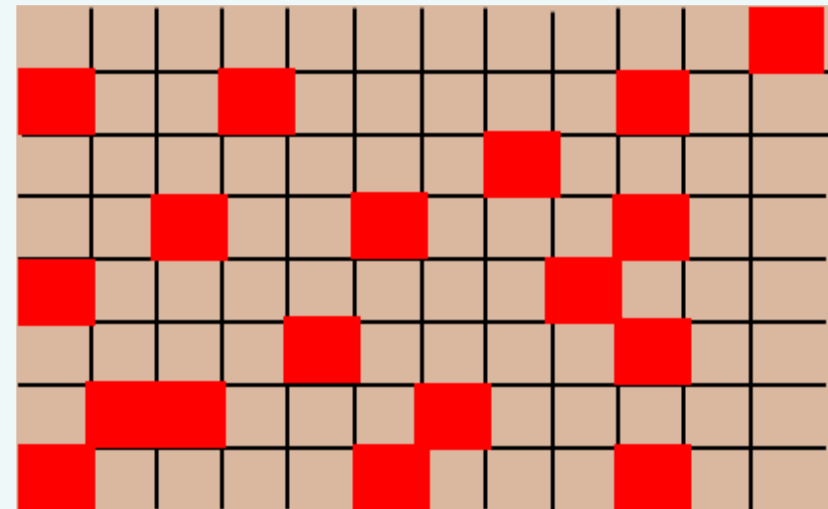


Prescription map generation

From economic intervention threshold to site specific herbicide application:

Patch Spray Application (PSA): 

If $WMR_{MZ} \geq WMR_{EIT}$,
then chemical weeding (x l/ha); 
else no chemical weeding (0 l/ha). 



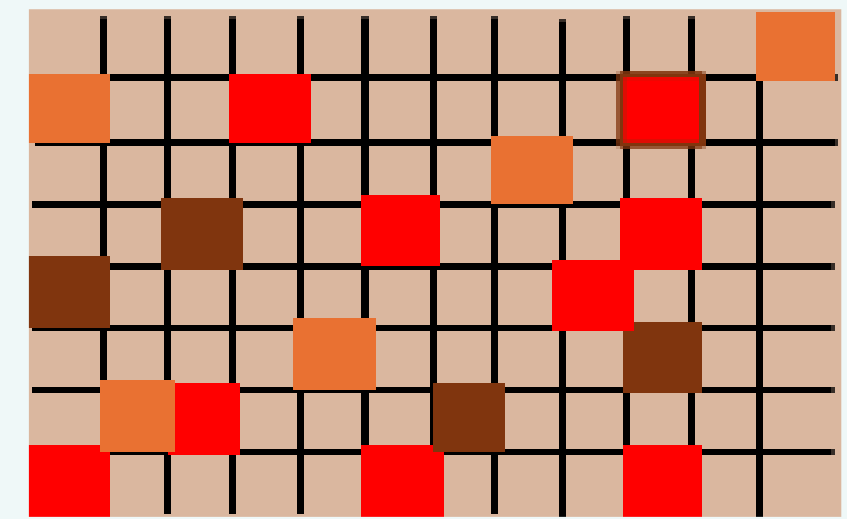
Variable Rate Application (VRA): 

if $W/TG_{MZ} \geq W/TG_{EIT}$:

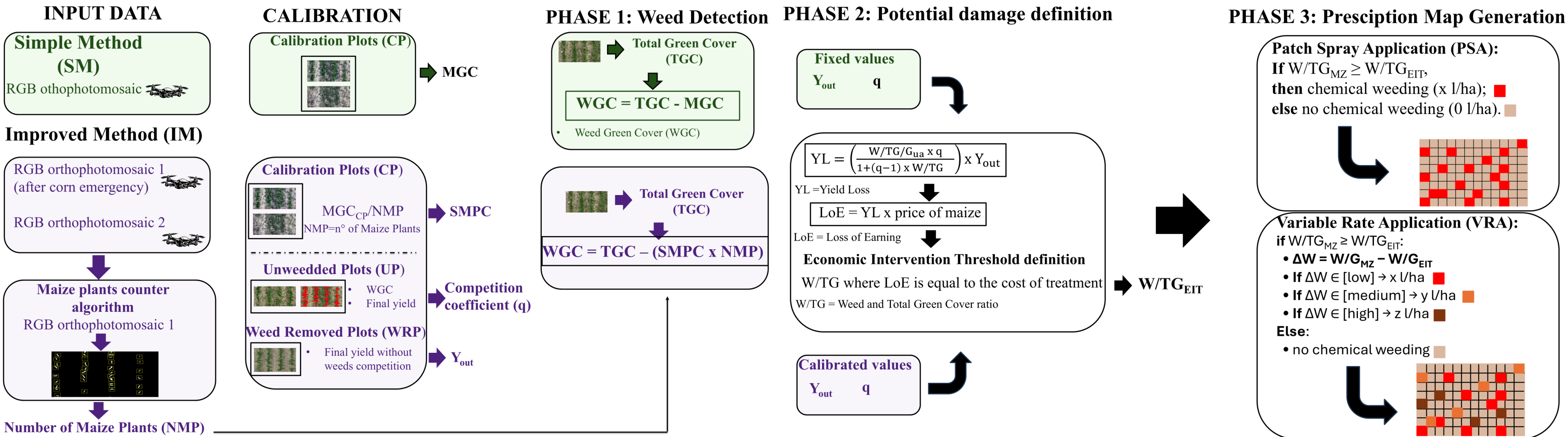
- $\Delta W = W/G_{MZ} - W/G_{EIT}$
- If $\Delta W \in [\text{low}] \rightarrow x \text{ l/ha}$ 
- If $\Delta W \in [\text{medium}] \rightarrow y \text{ l/ha}$ 
- If $\Delta W \in [\text{high}] \rightarrow z \text{ l/ha}$ 

Else:

- no chemical weeding 



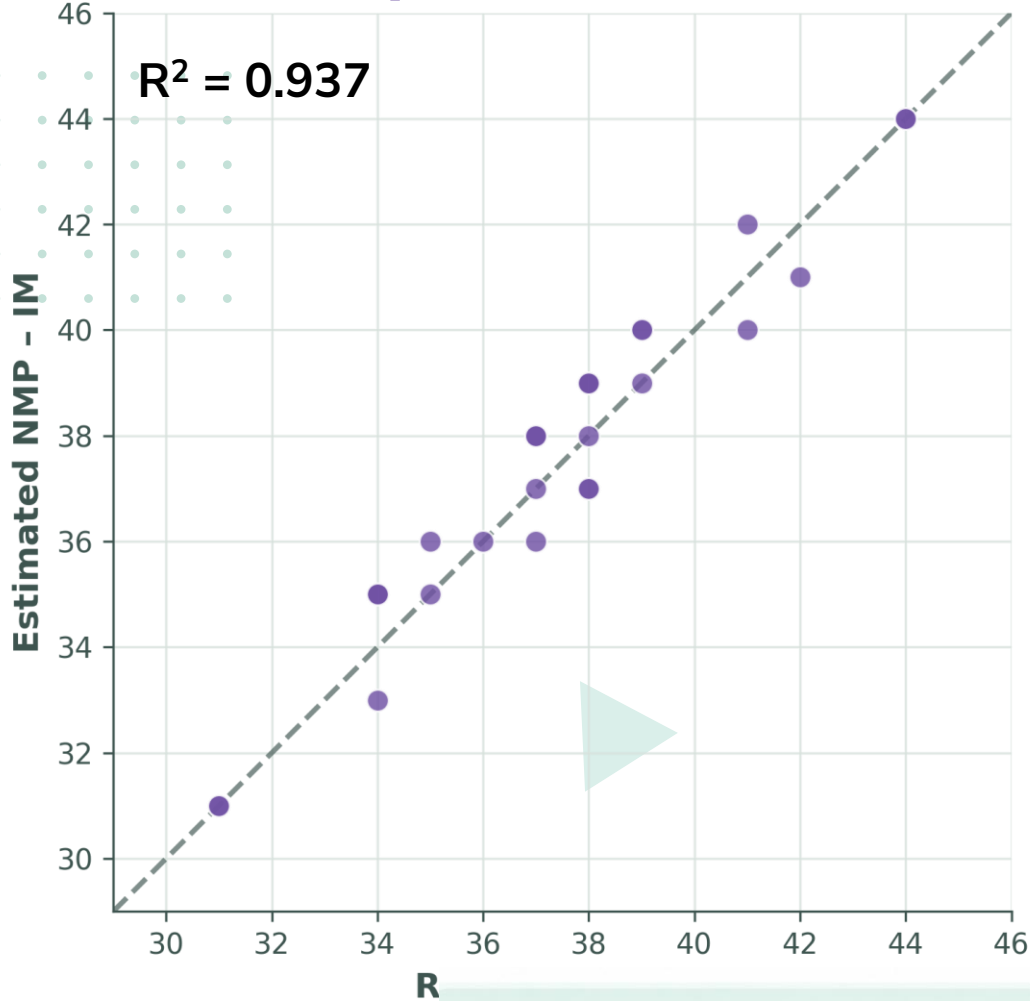
SWIM workflow:



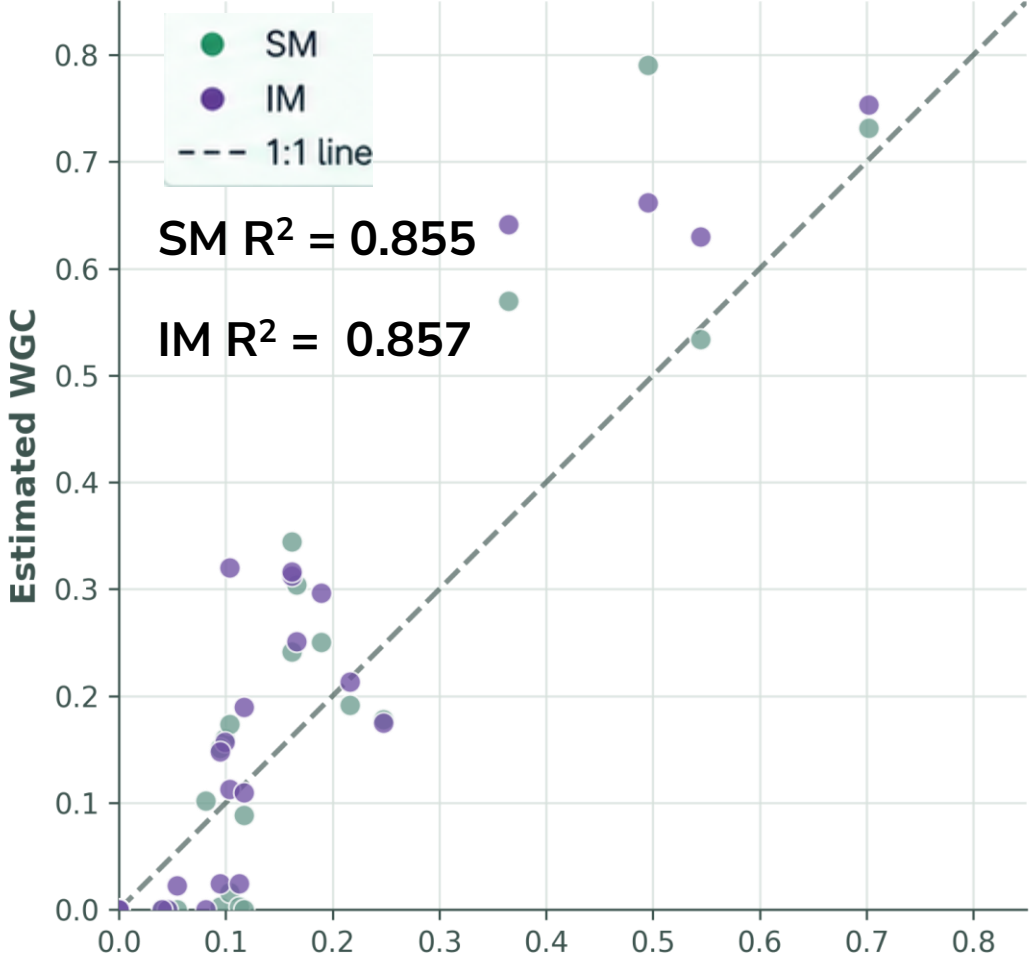


Some results :

Maize Plants Number Improved Method



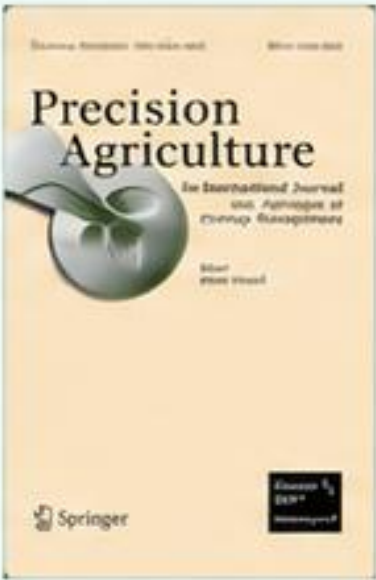
Weed Green Cover Simple Method vs Improved Method



	RMSE ↓	MAE ↓	$\beta_1 \rightarrow 1$	CCC $\rightarrow 1$	MEF $\rightarrow 1$	$R^2 \rightarrow 1$
NMP – IM	0.186	0.156	0.974	0.963	0.927	0.937
MGC – IM	0.113	0.095	0.933	0.461	0.261	0.295
WGC – SM	0.096	0.082	0.893	0.915	0.821	0.857
WGC – IM	0.089	0.076	0.916	0.924	0.845	0.855

SWIM (Smart Weed Impact Management): A decision support system (DSS) for the site-specific weed control in maize cultivation

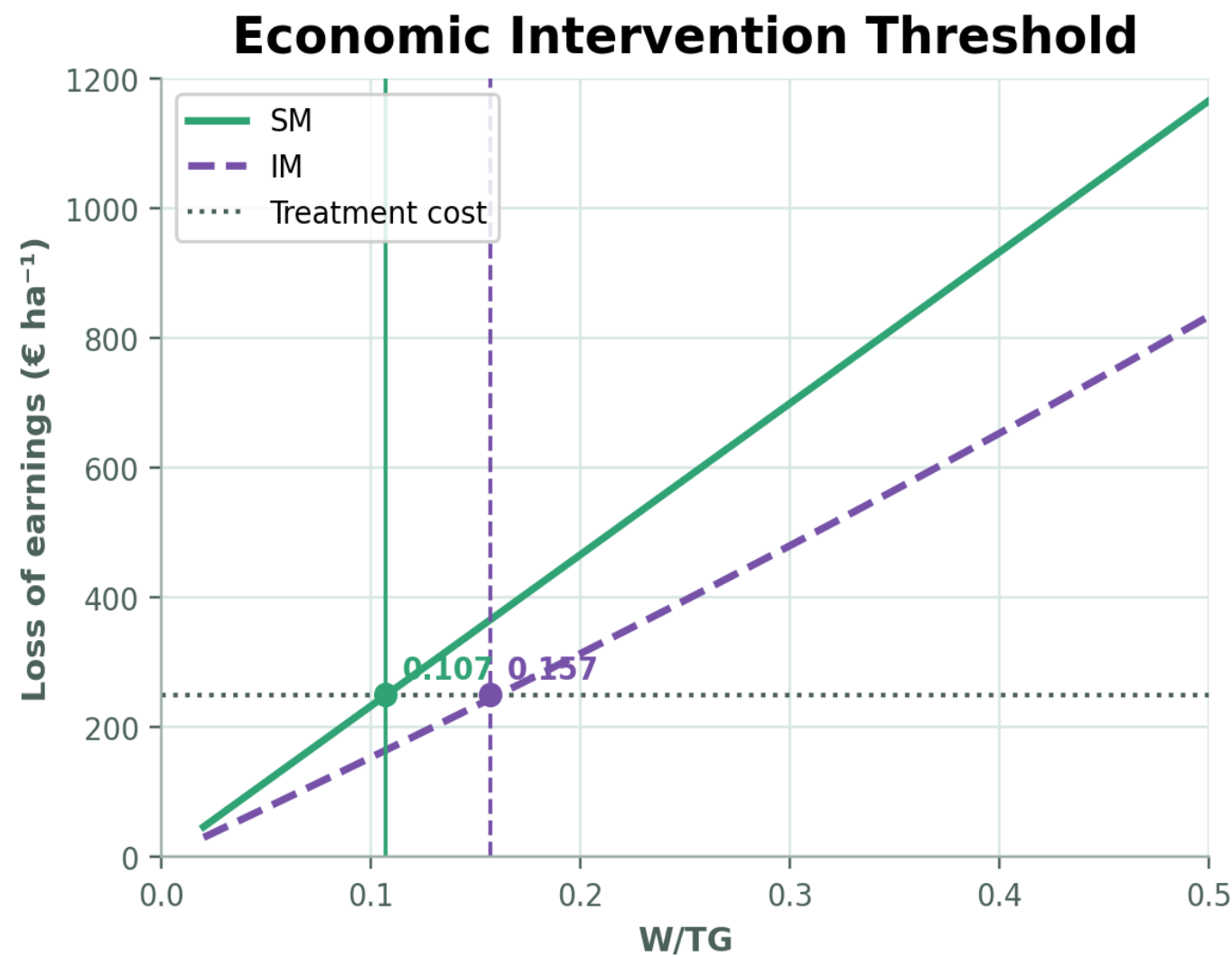
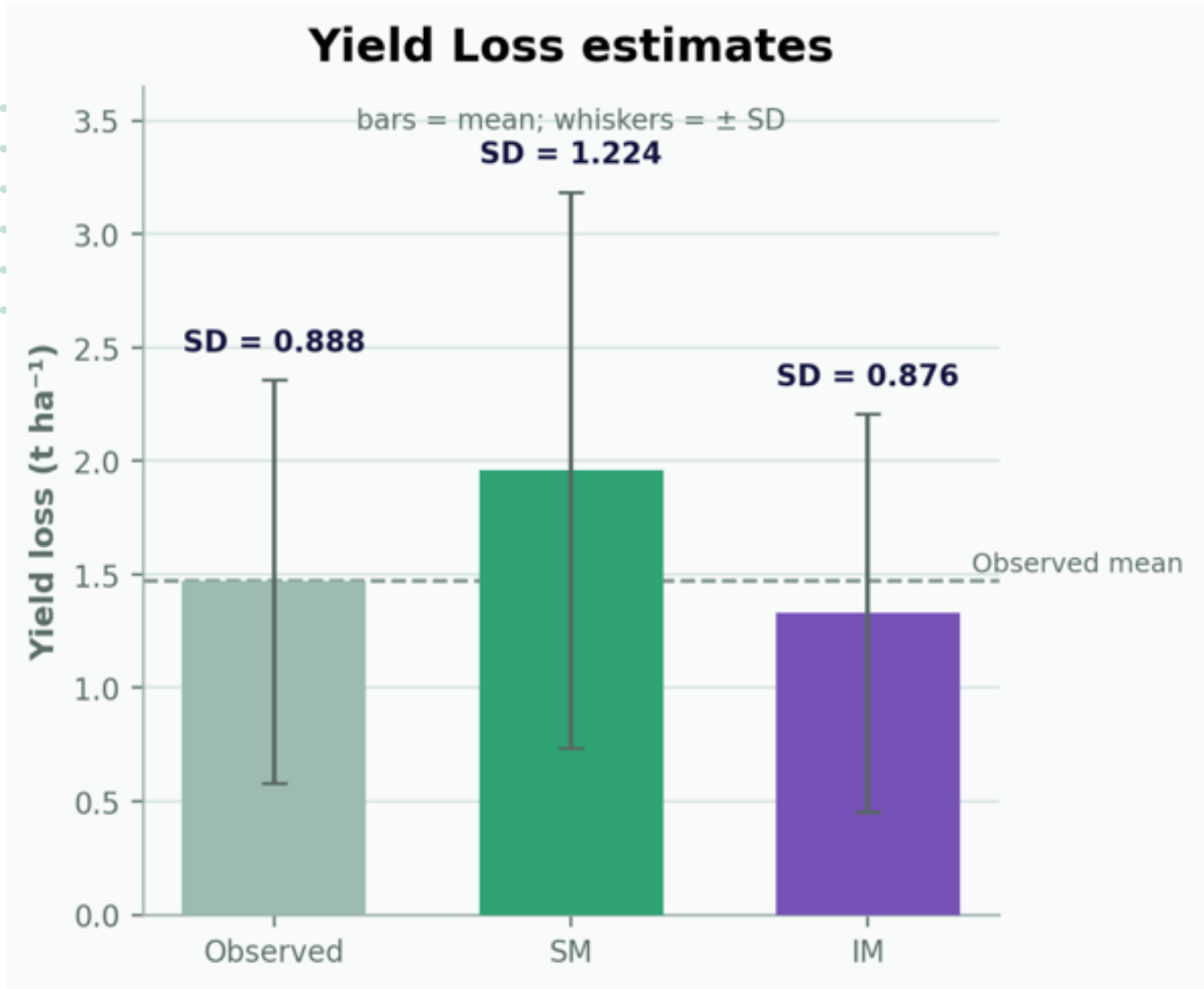
Leonardo Ercolini, Nicola Grossi,
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Scan to read
the full paper



Some results :



Key outcomes

SM YL bias **+25%**

IM YL bias **-10%**

W/TG_EIT **0.107 vs 0.157**

	Observed	SM	IM
q (-)	-	1.00	0.81
Yout (t ha ⁻¹)	8.63 ± 1.429	10.80	8.63
YL (t ha ⁻¹)	1.47 ± 0.888	1.96 ± 1.224	1.33 ± 0.876
W/TG EIT (-)	-	0.107	0.157

Some preliminary agronomic results..

Prescription map for PSA (IM)



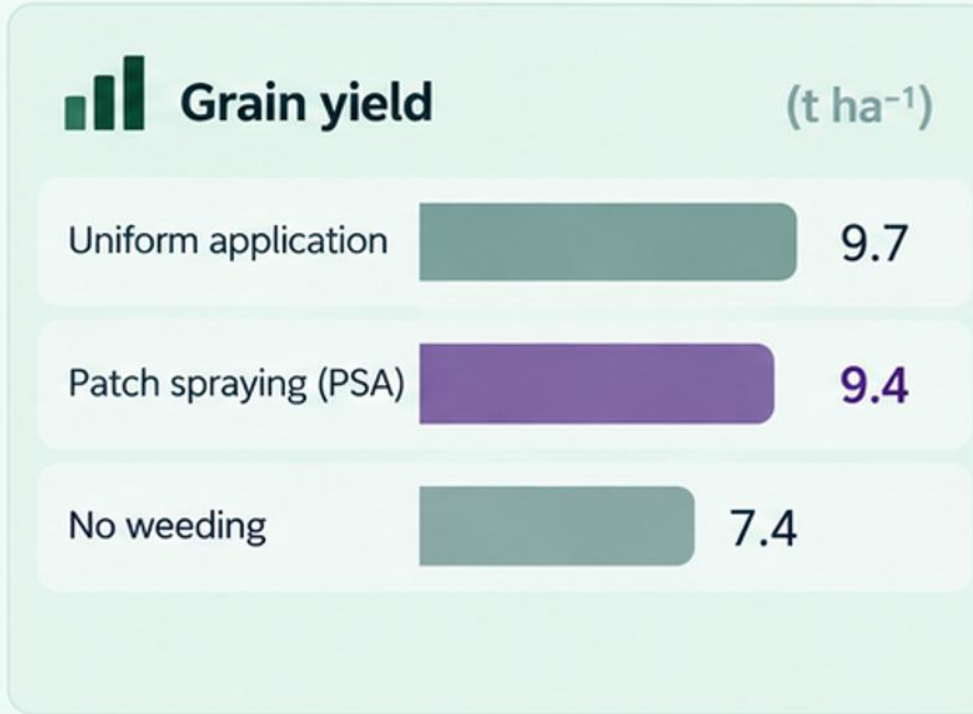
“Only where needed”

Yield map



Yield obtained in each MZs

 **- 38 %**
HERBICIDE USE
Compared to uniform application



Limits



Time-consuming calibration

Experimental plots, image acquisition, and data processing are still needed for site-specific calibration.



IM requires two UAV flights

One flight at maize emergence is needed to estimate plant density, and a second flight at post-emergence timing is needed to estimate canopy cover.



Post-processing workflow

The current SWIM pipeline works offline and does not yet support real-time or on-the-go decision making.



Limited validation of damage estimation

The potential-damage module was not independently validated, because the same UP dataset was also used to calibrate the Goldsmith model.

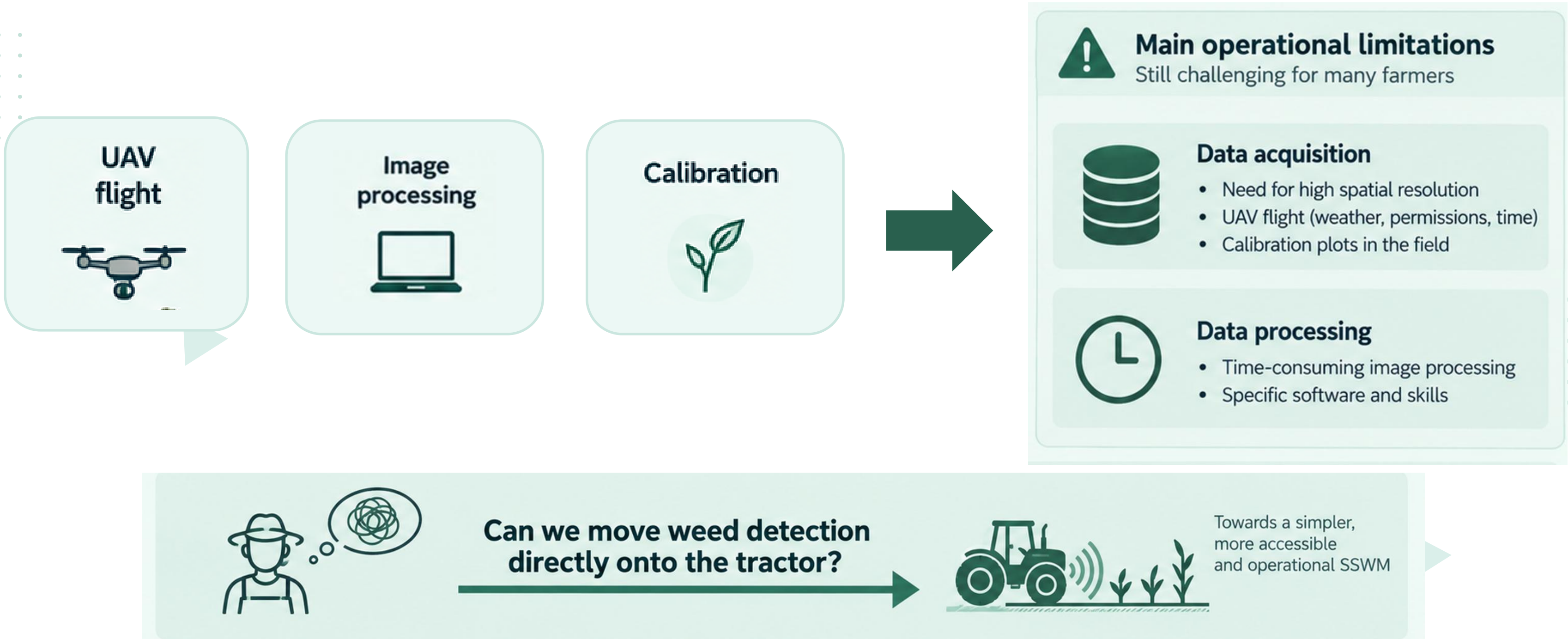


q parameter needs refinement

The competition coefficient should be improved by accounting for additional factors such as weed species, distance from maize rows, and other indicators of competitive ability.

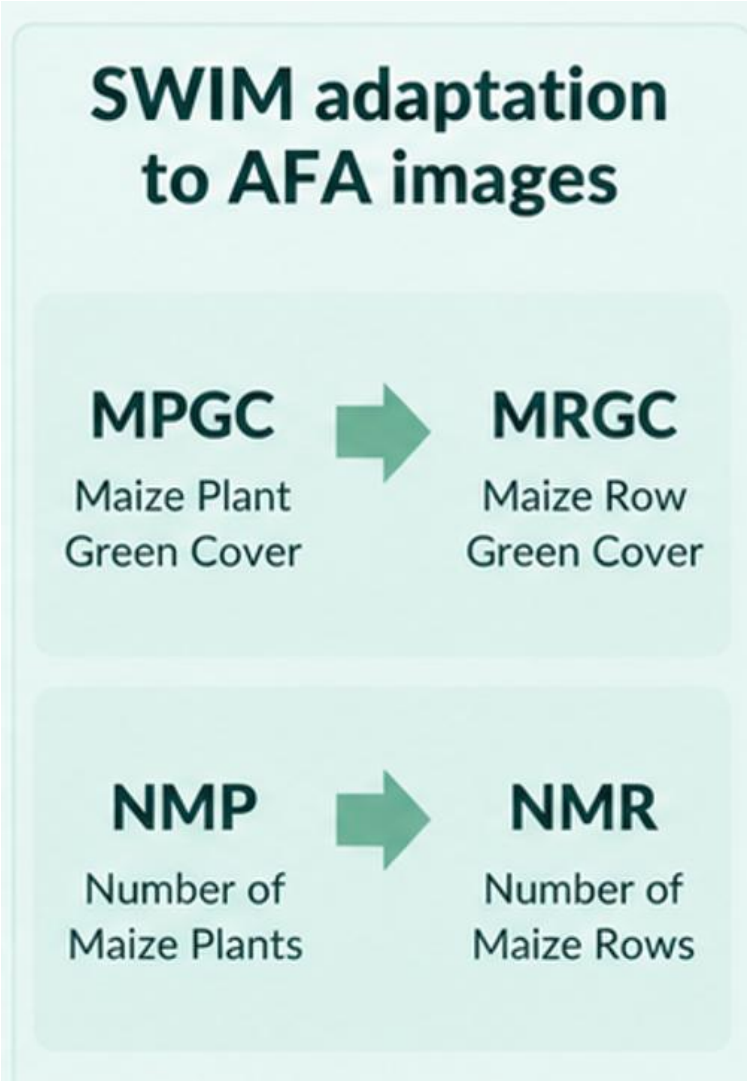
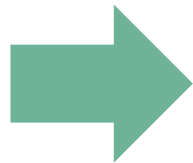
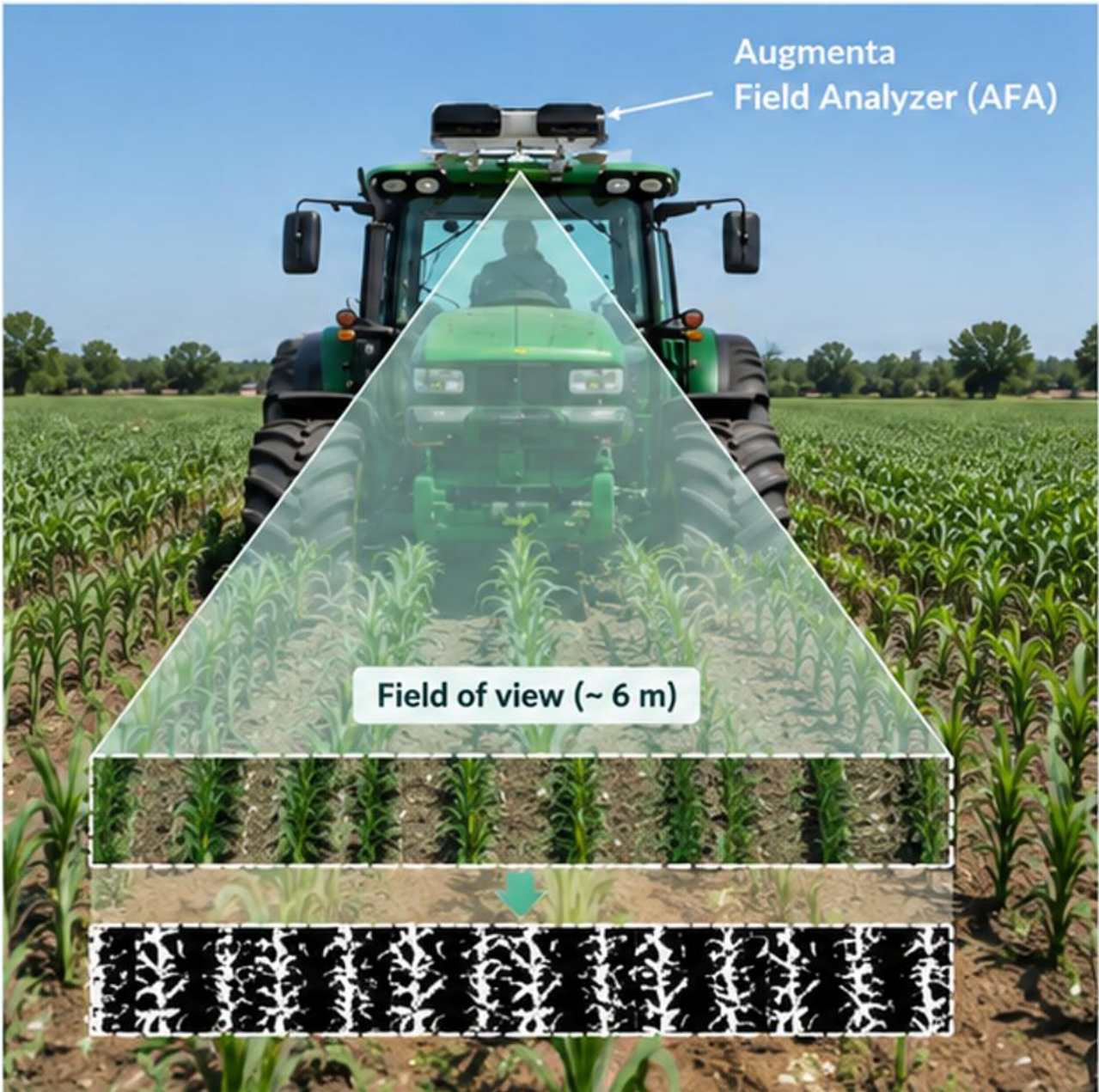
Future developments: simplify calibration, improve q, and move toward field-scale and near-real-time applications.

How to improve the applicability?



SWIM - AFA

Adapting a UAV-Based Weed Detection Method (SWIM) for a Tractor-Mounted Optical Sensor



SIMPLE METHOD
Calibration session



$mMGC = mMRGC \times mNMR$

IMPROVED METHOD
Dynamic Maize-row detector



$dMGC = mMRGC \times rNMR$

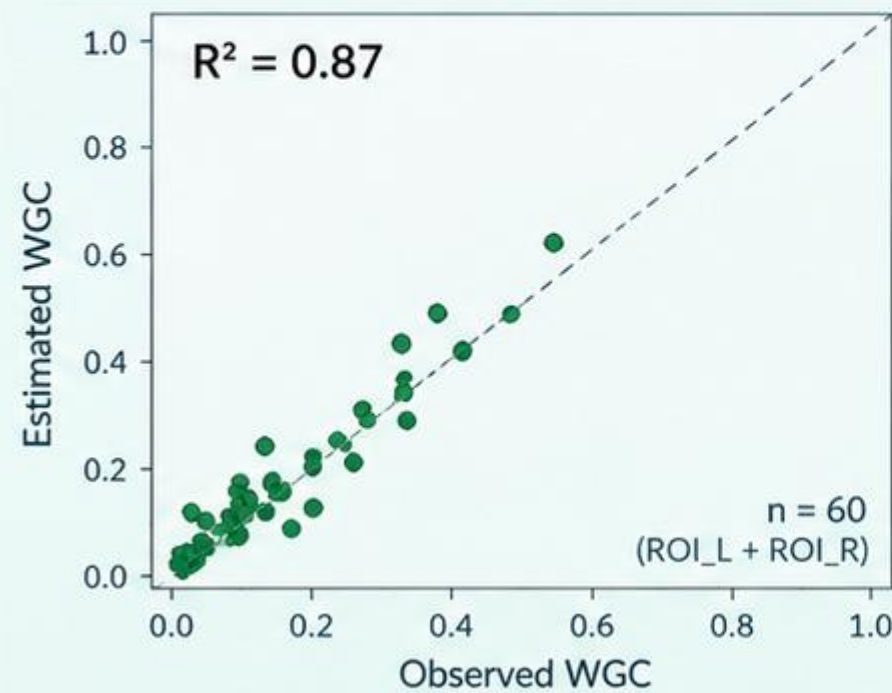
SWIM - AFA



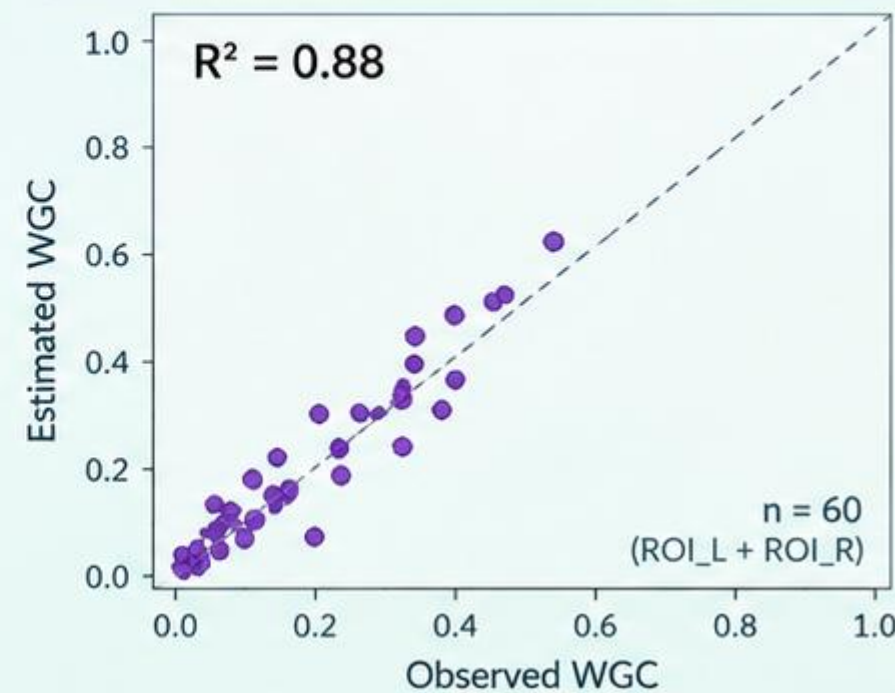
Weed Green Cover (WGC)

Observed vs. Estimated

SIMPLE METHOD (SM)



IMPROVED METHOD (IM)



KEY TAKEAWAYS

- ✓ SWIM seems to be exportable from UAV to tractor mounted sensor
- ✓ Similar magnitude of performance to original SWIM
- ✓ Promising first step towards real-time weed detection



WHAT STILL NEEDS IMPROVEMENT

- Perspective distortion limits the usable field of view (6 m)
- Validation across fields, growth stages and enviromental conditions
- Integration into an on-the-go DSS



agronomy



Article

Adapting a UAV-Based Weed Detection Method (SWIM) for a Tractor-Mounted Optical Sensor

Leonardo Ercolini ^{1,*}, Nikolaos Georgiadis ², Anastasia Boile ², Anthi Korre ², Giannis Kousis ², Evangelos Adamopoulos ² and Nicola Silvestri ¹

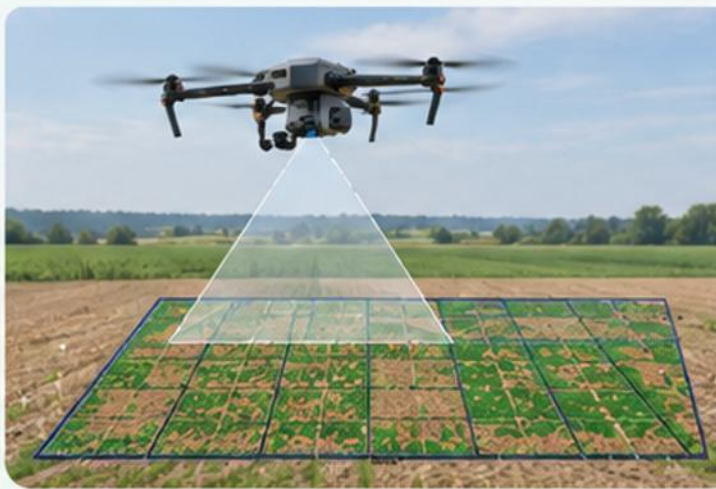


FULL METHODOLOGY & RESULTS



SWIM – Drone

UAV-based workflow (research-oriented)



✓ Strengths

- + High spatial resolution
- + Field monitoring even when field access is limited
- + High accuracy in weed and crop metrics
- + No perspective distortion

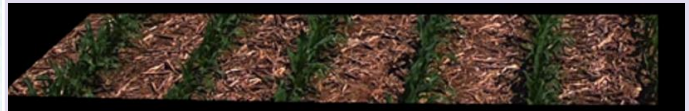
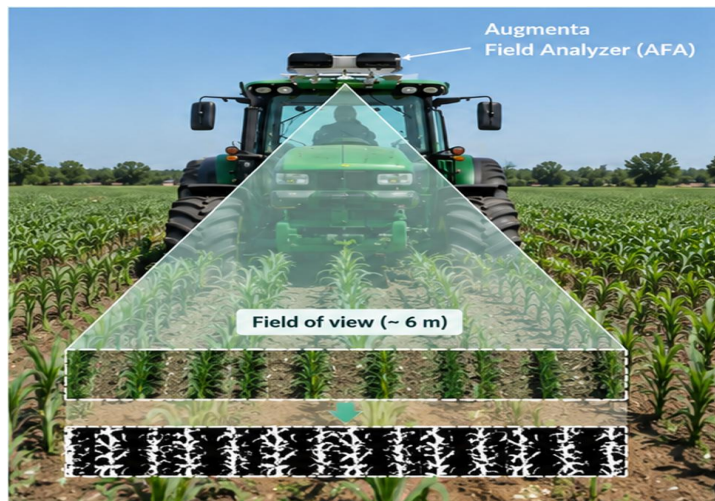
– Limitations

- Dedicated flight planning
- Post processing
- Complex and time consuming
- UAV legislation



SWIM – AFA

On-board multispectral sensor (operational-oriented)



✓ Strengths

- + More User friendly
- + Interoperability
- + High accuracy in weed and crop metrics
- + Real time (work in progress)

– Limitations

- Limited field of view (6 m)
- Perspective distortion
- Depending on weather conditions
- Further development needed

Il Giovedì della SIRFI
Le piante infestanti Conoscerle per gestirle
08 Ottobre 2026



Thank you for your attention !



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