UNIVERSITAS STUDIORUM LUPIENSIS

Decision Support Systems
Business Analytics
Lab

Agricoltura biologica in serra: massimizzare la biodiversità mediante microservizi AI

Prof.ssa Emanuela Guerriero

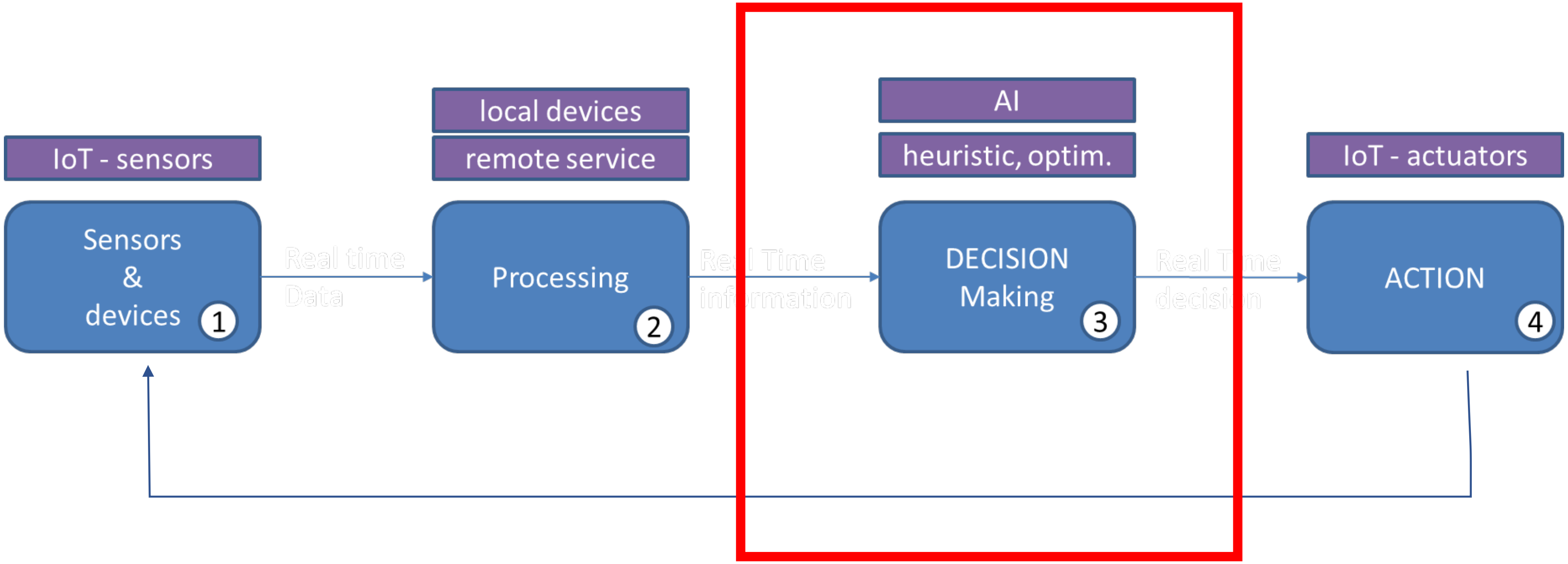
Sustainable agriculture aims to meet food and textile needs of present world's population, but without compromising the opportunity for next generations to meet their needs

GAZZETTA UFFICIALE
DELLA REPUBBLICA ITALIANA

La Repubblica (…) tutela l'ambiente, la biodiversità e gli ecosistemi, anche nell'interesse delle future generazioni”

Decision Support Systems
Business Analytics
Lab

The Precision Smart Farming process template



IoT - sensors

Sensors
&
devices ①

Real time
Data

local devices

remote service

Processing ②

Real Time
information

AI

heuristic, optim.

DECISION
Making ③

Real Time
decision

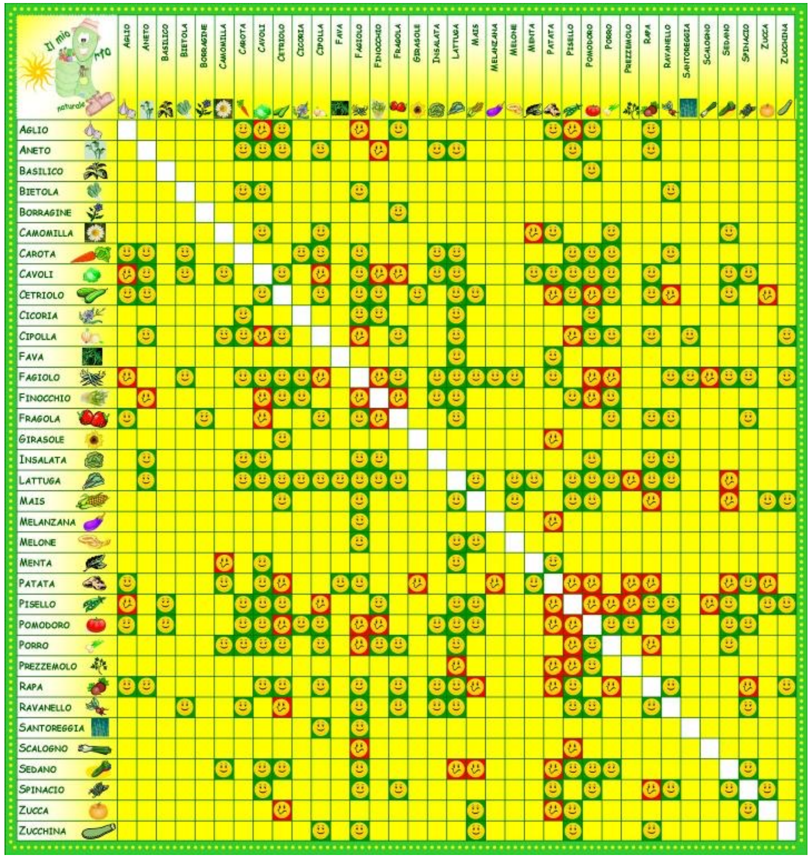
IoT - actuators

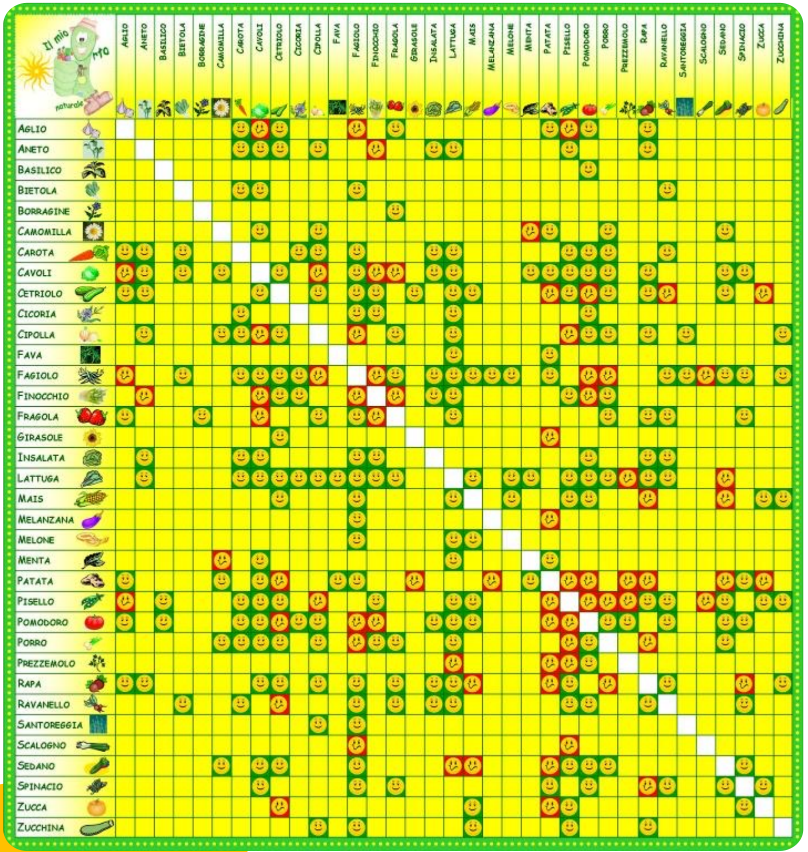
ACTION ④

Decision Support Systems
Business Analytics
Lab

Suistainable Intensification

- **Sustainable Intensification:** gestione **agroecologica** e adattativa del sistema agroalimentare **industriale**.
- **Intecropping** : La consociazione è la pratica di coltivare più specie di colture contemporaneamente nello stesso luogo in passato utilizzata per:
  - aumentare la produzione agricola
  - l'efficienza del terreno,
  - strategia per mitigare il rischio .

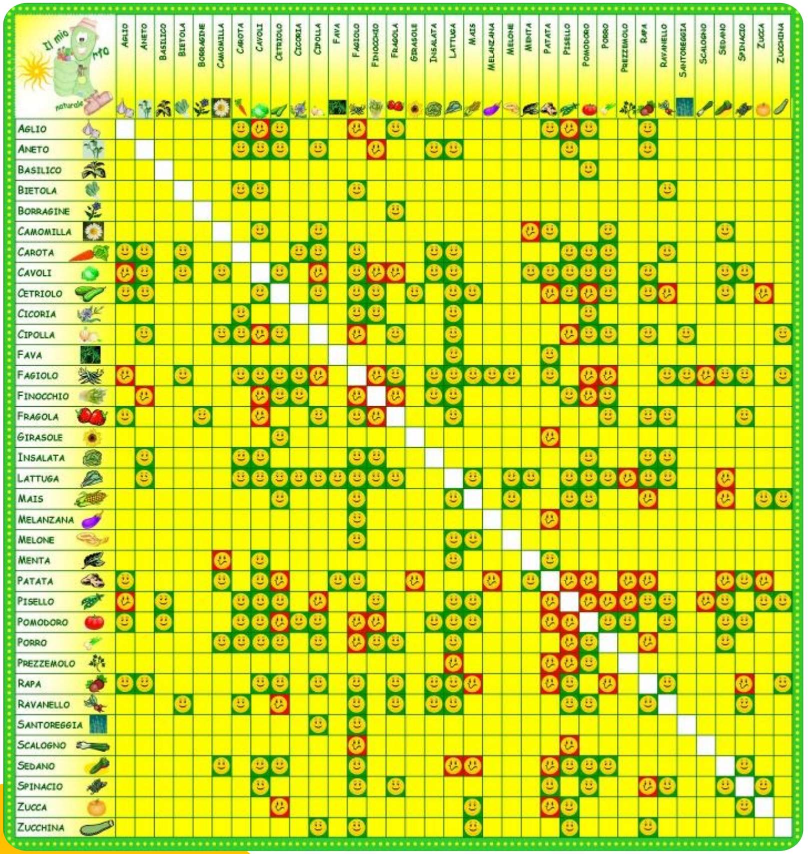




Consociazione

- Componente essenziale dei sistemi di coltivazione di piccole aziende biologiche
- Nella produzione industrializzata in cui i cicli dei nutrienti sono regolati con apporti esterni, la consociazione è sottoutilizzata.

Intercropping Research



agriculture MDPI

Review

Advancing Intercropping Research and Practices in Industrialized Agricultural Landscapes

K. Ann Bybee-Finley and Matthew R. Ryan

Section of Soil and Crop Sciences in the School of Integrative Plant Sciences, Cornell University, Ithaca, NY 14853, USA; mrr232@cornell.edu
* Correspondence: kab436@cornell.edu; Tel.: +1-304-549-0598

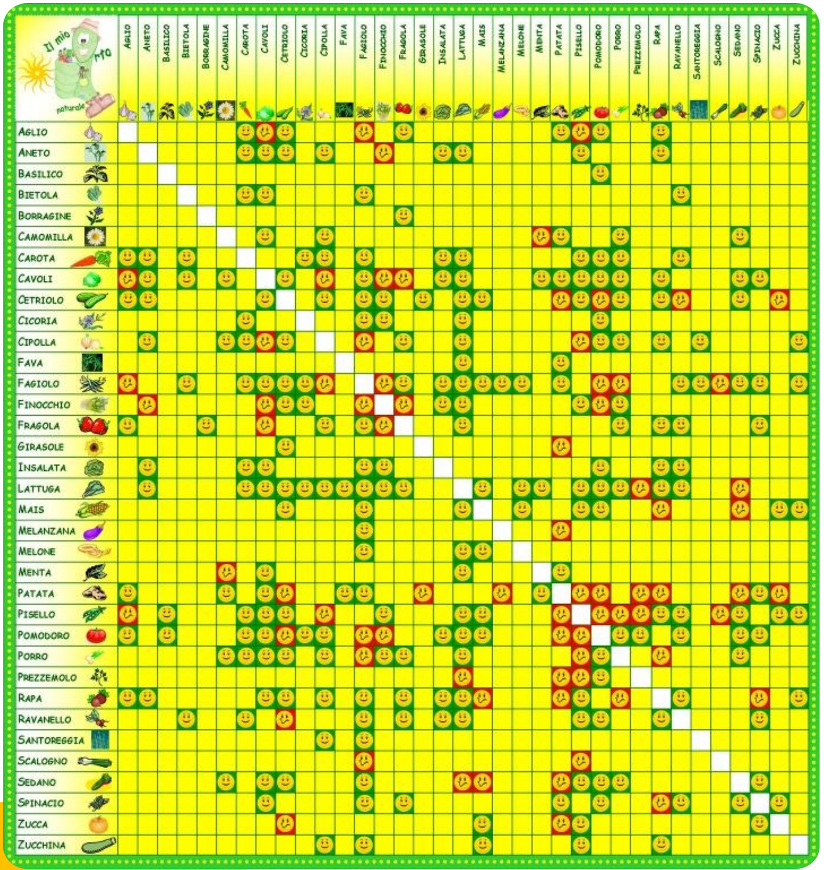
Received: 2 May 2018; Accepted: 6 June 2018; Published: 8 June 2018

Abstract: Sustainable intensification calls for agroecological and adaptive management of the agrifood system. Here, we focus on intercropping and how this agroecological practice can be used to increase the sustainability of crop production. Strip, mixed, and relay intercropping can be used to increase crop yields through resource partitioning and facilitation. In addition to achieving greater productivity, diversifying cropping systems through the use of strategic intercrops can increase yield stability, reduce pests, and improve soil health. Several intercropping systems are already implemented in industrialized agricultural landscapes, including mixed intercropping with perennial grasses and legumes as forage and relay intercropping with winter wheat and red clover. Because intercropping can provide numerous benefits, researchers should be clear about their objectives and use appropriate methods so as to not draw spurious conclusions when studying intercrops. In order to advance the practice, experiments that test the effects of intercropping should use standardized methodology, and researchers should report a set of common criteria to facilitate cross-study comparisons. Intercropping with two or more crops appears to be less common with annuals than perennials, which is likely due to differences in the mechanisms responsible for complementarity. One area where intercropping with annuals in industrialized agricultural landscapes has advanced is with cover crops, where private, public, and governmental organizations have harmonized efforts to increase the adoption of cover crop mixtures.

Keywords: intercropping; sustainable intensification; crop diversity; cover crops; multifunctionality; weed suppression; complementarity; competition; land equivalent ratio; trade-offs

Decision Support Systems
Business Analytics
Lab

Intercropping Research



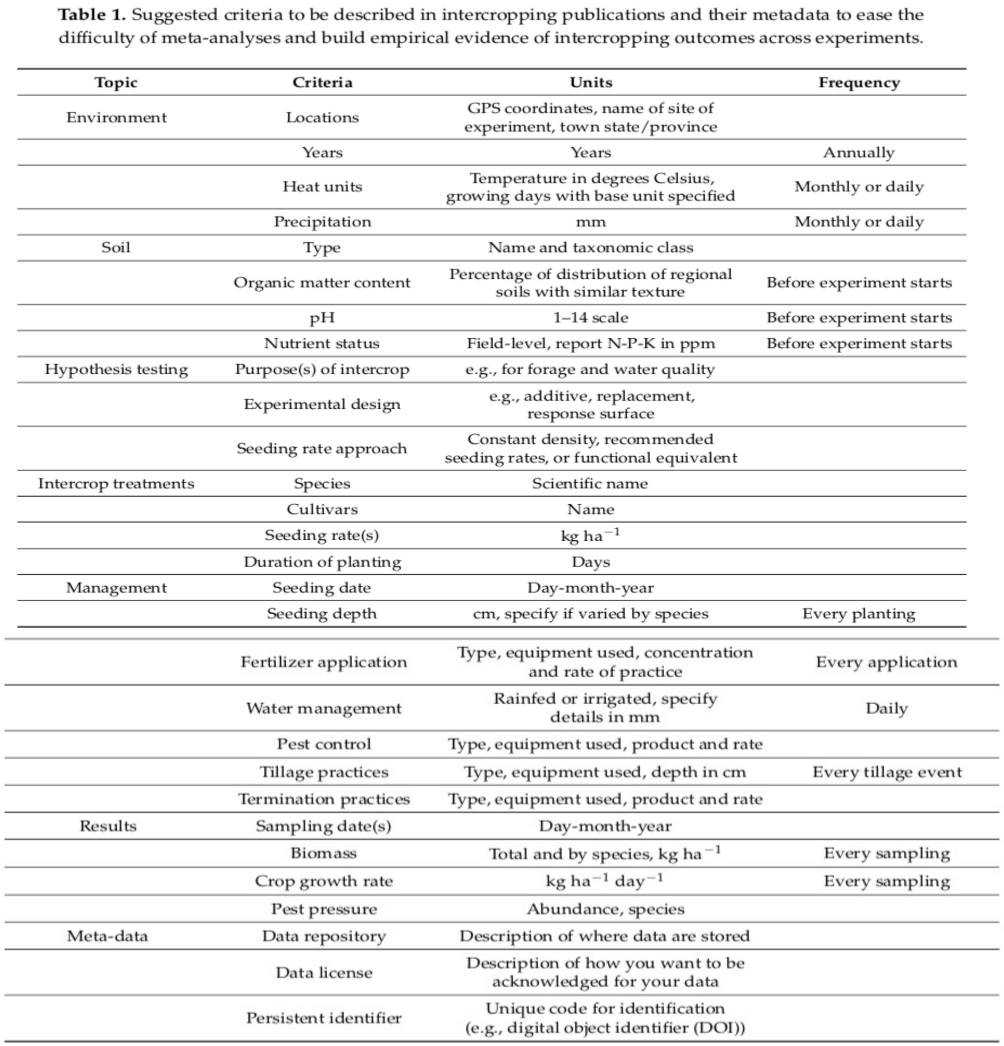


Table 1. Suggested criteria to be described in intercropping publications and their metadata to ease the difficulty of meta-analyses and build empirical evidence of intercropping outcomes across experiments.

Topic	Criteria	Units	Frequency
Environment	Locations	GPS coordinates, name of site of experiment, town state/province	
	Years	Years	Annually
	Heat units	Temperature in degrees Celsius, growing days with base unit specified	Monthly or daily
	Precipitation	mm	Monthly or daily
Soil	Type	Name and taxonomic class	
	Organic matter content	Percentage of distribution of regional soils with similar texture	Before experiment starts
	pH	1–14 scale	Before experiment starts
	Nutrient status	Field-level, report N-P-K in ppm	Before experiment starts
Hypothesis testing	Purpose(s) of intercrop	e.g., for forage and water quality	
	Experimental design	e.g., additive, replacement, response surface	
	Seeding rate approach	Constant density, recommended seeding rates, or functional equivalent	
Intercrop treatments	Species	Scientific name	
	Cultivars	Name	
	Seeding rate(s)	kg ha^{-1}	
	Duration of planting	Days	
Management	Seeding date	Day-month-year	
	Seeding depth	cm, specify if varied by species	Every planting
	Fertilizer application	Type, equipment used, concentration and rate of practice	Every application
	Water management	Rainfed or irrigated, specify details in mm	Daily
	Pest control	Type, equipment used, product and rate	
	Tillage practices	Type, equipment used, depth in cm	Every tillage event
	Termination practices	Type, equipment used, product and rate	
Results	Sampling date(s)	Day-month-year	
	Biomass	Total and by species, kg ha^{-1}	Every sampling
	Crop growth rate	kg ha^{-1} day^{-1}	Every sampling
	Pest pressure	Abundance, species	
Meta-data	Data repository	Description of where data are stored	
	Data license	Description of how you want to be acknowledged for your data	
	Persistent identifier	Unique code for identification (e.g., digital object identifier (DOI))	

- Al fine di far promuovere la pratica in ambito industriale, gli esperimenti che testano gli effetti delle consociazioni dovrebbero utilizzare una metodologia standardizzata che i ricercatori dovrebbero riportare una serie di criteri comuni per facilitare i confronti tra studi

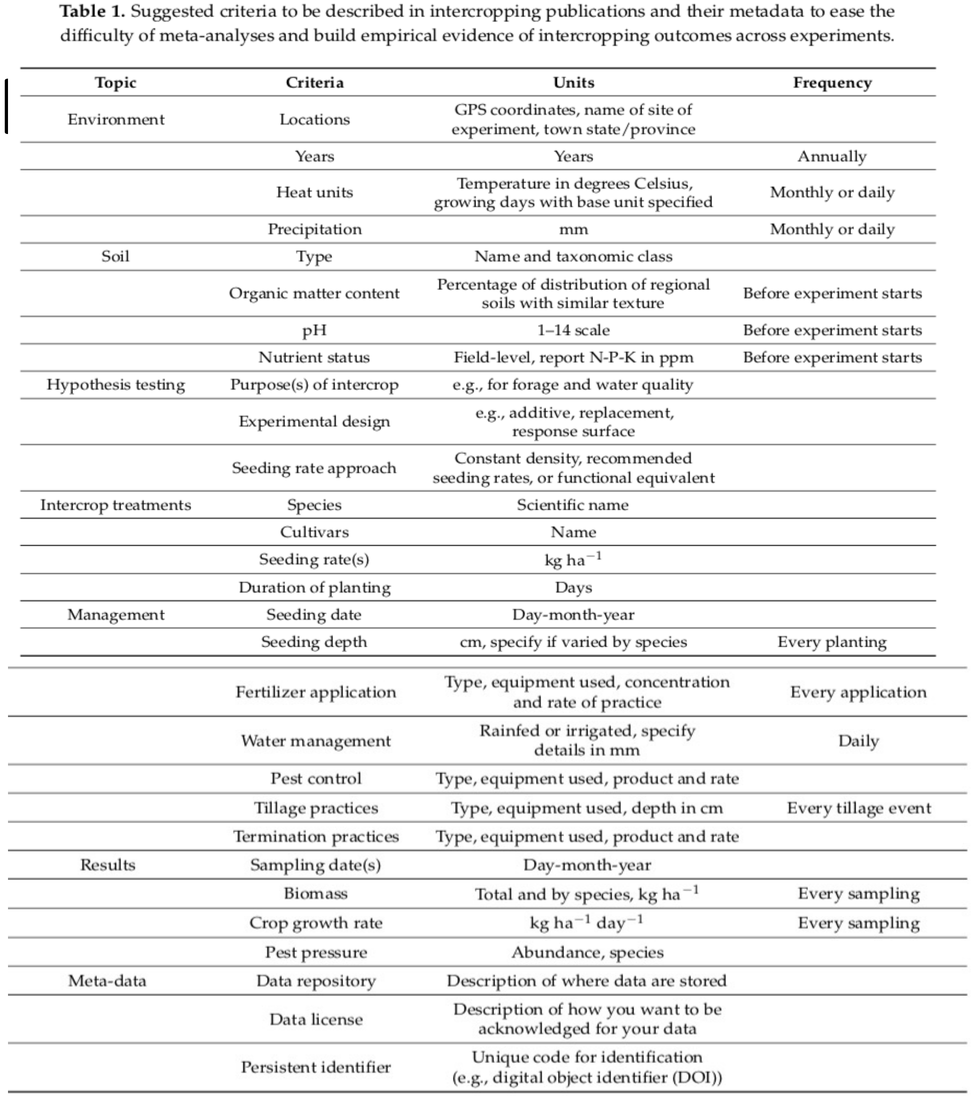
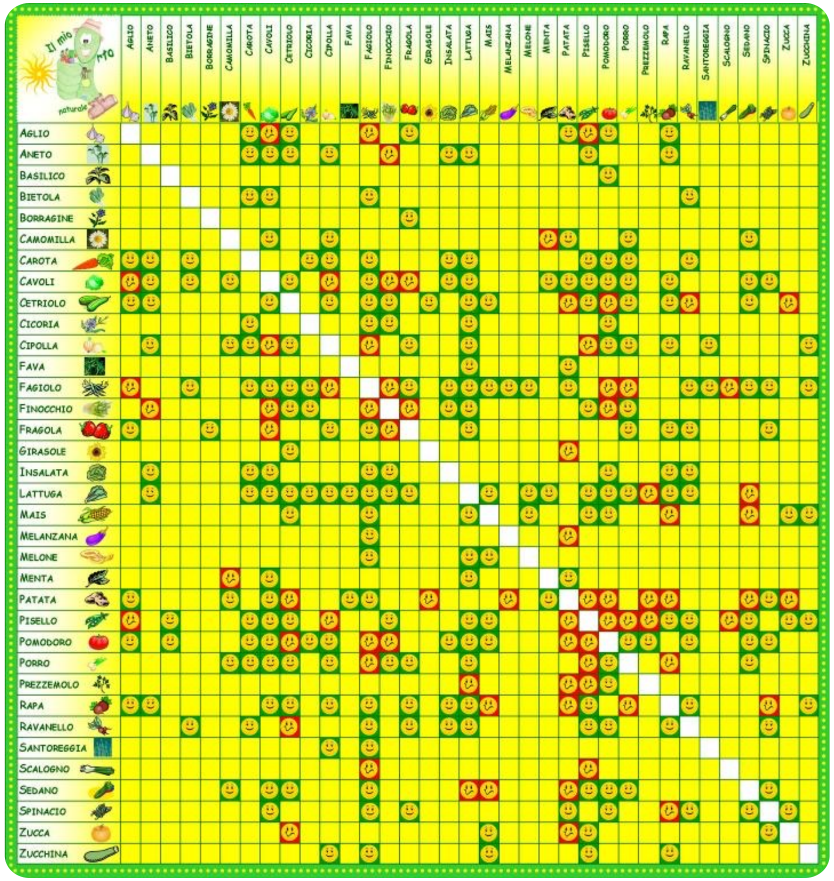


Table 1. Suggested criteria to be described in intercropping publications and their metadata to ease the difficulty of meta-analyses and build empirical evidence of intercropping outcomes across experiments.

Topic	Criteria	Units	Frequency
Environment	Locations	GPS coordinates, name of site of experiment, town state/province	
	Years	Years	Annually
	Heat units	Temperature in degrees Celsius, growing days with base unit specified	Monthly or daily
	Precipitation	mm	Monthly or daily
Soil	Type	Name and taxonomic class	
	Organic matter content	Percentage of distribution of regional soils with similar texture	Before experiment starts
	pH	1–14 scale	Before experiment starts
	Nutrient status	Field-level, report N-P-K in ppm	Before experiment starts
Hypothesis testing	Purpose(s) of intercrop	e.g., for forage and water quality	
	Experimental design	e.g., additive, replacement, response surface	
	Seeding rate approach	Constant density, recommended seeding rates, or functional equivalent	
Intercrop treatments	Species	Scientific name	
	Cultivars	Name	
	Seeding rate(s)	kg ha^{-1}	
	Duration of planting	Days	
Management	Seeding date	Day-month-year	
	Seeding depth	cm, specify if varied by species	Every planting
	Fertilizer application	Type, equipment used, concentration and rate of practice	Every application
	Water management	Rainfed or irrigated, specify details in mm	Daily
	Pest control	Type, equipment used, product and rate	
	Tillage practices	Type, equipment used, depth in cm	Every tillage event
	Termination practices	Type, equipment used, product and rate	
Results	Sampling date(s)	Day-month-year	
	Biomass	Total and by species, kg ha^{-1}	Every sampling
	Crop growth rate	kg ha^{-1} day^{-1}	Every sampling
	Pest pressure	Abundance, species	
Meta-data	Data repository	Description of where data are stored	
	Data license	Description of how you want to be acknowledged for your data	
	Persistent identifier	Unique code for identification (e.g., digital object identifier (DOI))	

Intercropping Research



Le caratteristiche di un buon repository sono: dati sono rilevabili, accessibili e conservati a lungo termine

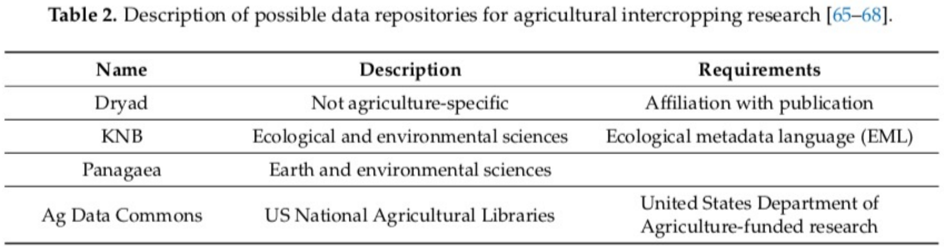


Table 2. Description of possible data repositories for agricultural intercropping research [65–68].

Name	Description	Requirements
Dryad	Not agriculture-specific	Affiliation with publication
KNB	Ecological and environmental sciences	Ecological metadata language (EML)
Panagaea	Earth and environmental sciences	
Ag Data Commons	US National Agricultural Libraries	United States Department of Agriculture-funded research

Bilanciare biodiversità e complessità gestionale

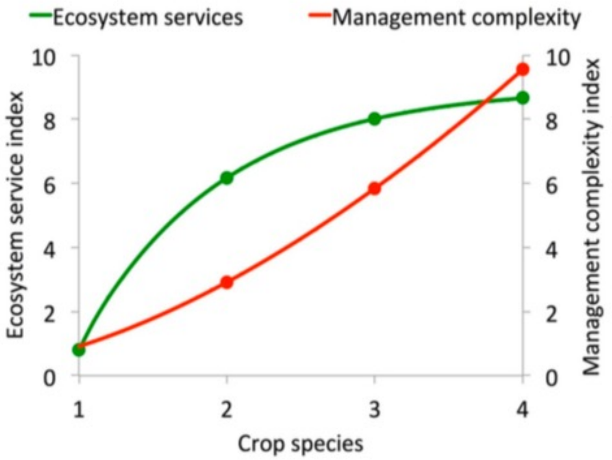
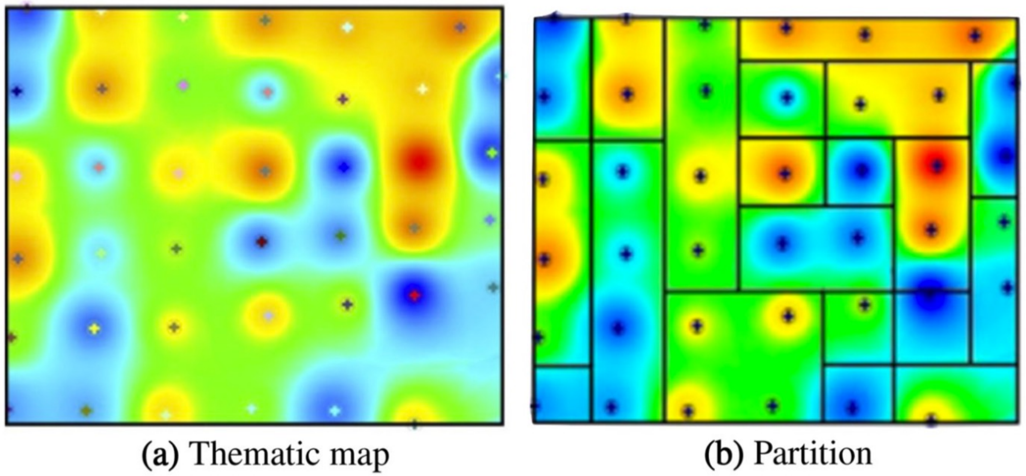


Figure 9. Hypothesized relationships between ecosystem services (green line, left *y*-axis) a management complexity (red line, right *y*-axis) as a function of crop species in an intercı Modified from Ryan et al., 2018 [89].

Decision Support Systems
Business Analytics
Lab

Optimization algorithms for sustainable agricolture

- Víctor M. Albornoz & Gabriel E. Zamora (2020) *Decomposition-based heuristic for the zoning and crop planning problem with adjacency constraints.* TOP
- L. Alfandari, A. Plateau, X. Schepler (2015) *A Branch-and-Price-and-Cut approach for Sustainable Crop Rotation Planning.* European Journal of Operational Research
- L. M. Rodrigues dos Santos · P. Michelon M. Nereu Arenales · R. H. S. Santos (2011) *Crop rotation scheduling with adjacency constraints . Annals of Operations Research*

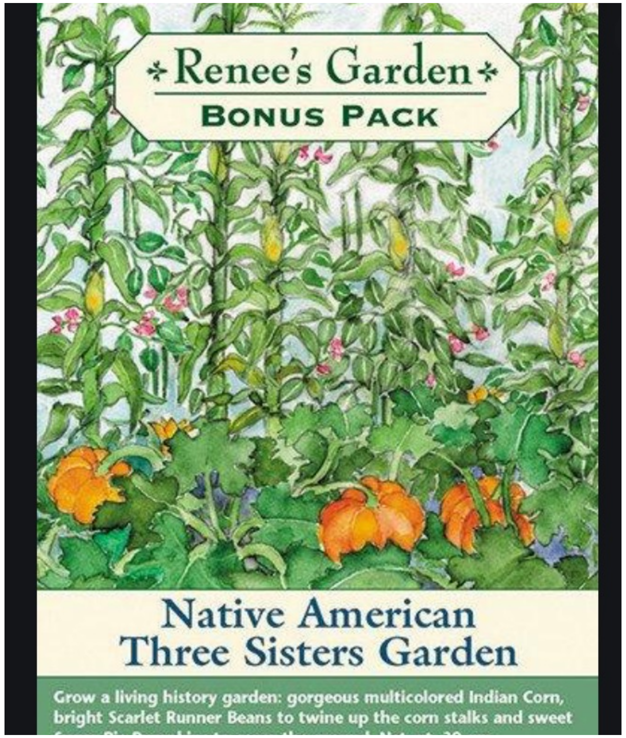


(a) Thematic map (b) Partition

Fig. 1 Thematic map of a soil property of a field composed of 42 sampling points and a partition formed by 20 management zones. Source: Cid-García et al. (2013)

Crop Rotation and scheduling

Consociazione



- **Facilitation**
  - **leguminose**
- ***Resource partitioning***
  - ***Three-syster: corn-beans-squash***

Layout di consociazione

- **Mixed Intercropping**
    - *practice of growing two or more crop species together at the same time in a field without using any particular spatial configuration*

Example :Mixed Perennial Forage Crop;

Layout di consociazione

- **Strip intercropping**
  - *The practice of growing two or more crop species in separate, but adjacent, rows at the same time.*

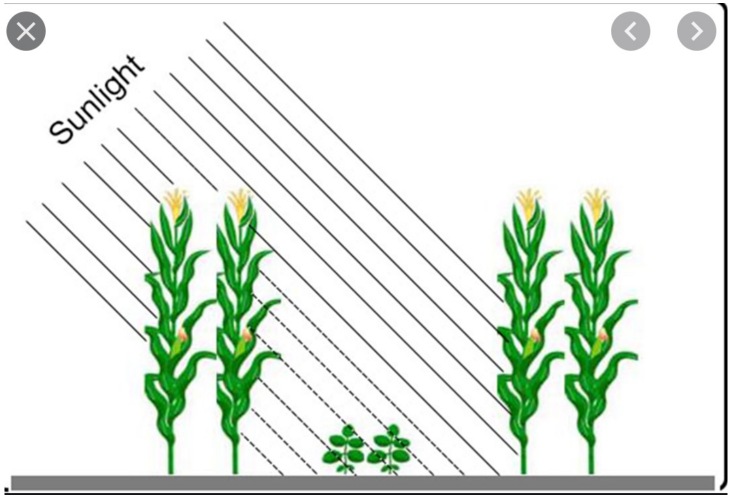
Example :wheat, corn and soybean

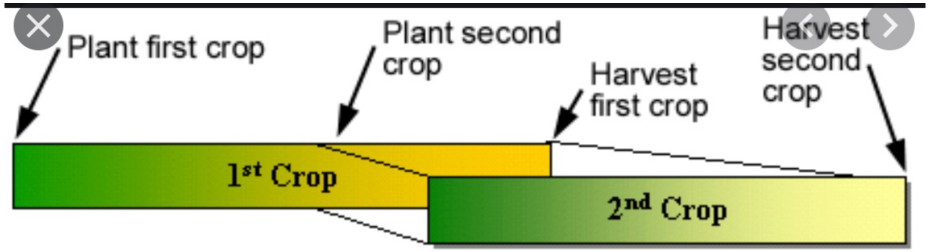
Decision Support Systems
Business Analytics
Lab

Layout di consociazione

- **Relay intercropping**
  - involves the staggered planting of two or more crops together way whereby only parts of their life cycles overlap. (strip or mixed)

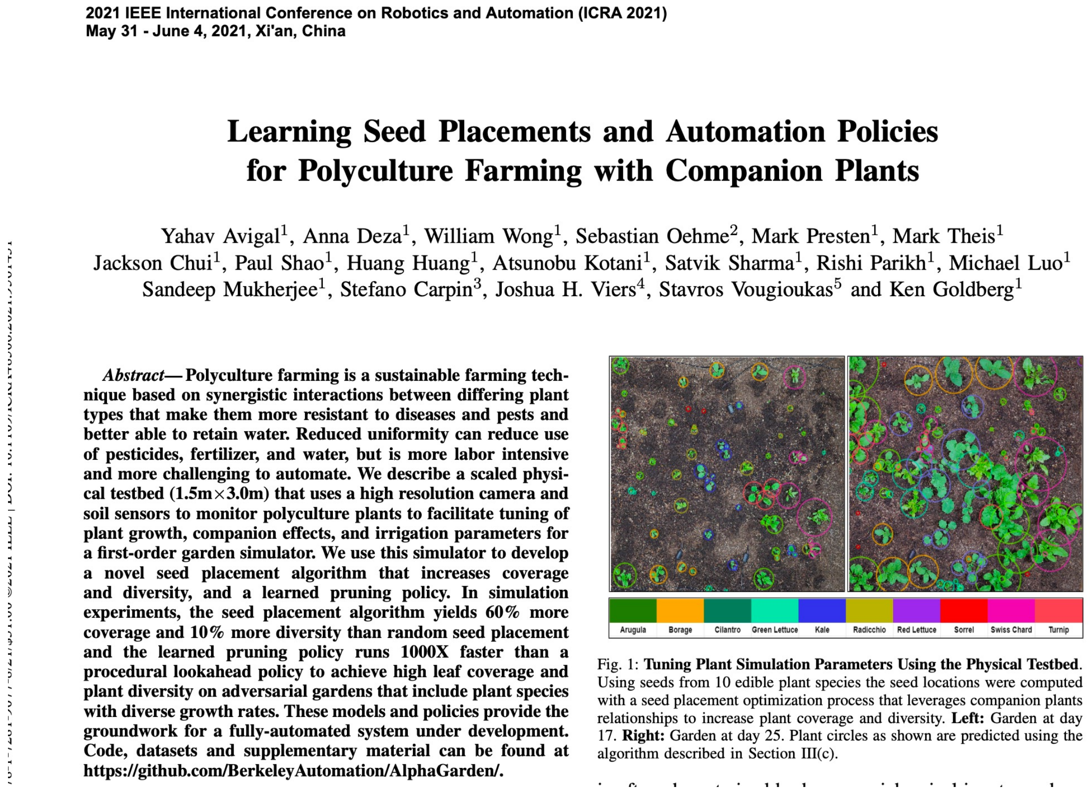
Example :maize soybean





Optimization algorithms for sustainable agricolture

- Modello di competizione
- Spazio discretizzato
- Spazio continuo



2021 IEEE International Conference on Robotics and Automation (ICRA 2021)
May 31 - June 4, 2021, Xi'an, China

Learning Seed Placements and Automation Policies for Polyculture Farming with Companion Plants

Yahav Avigal[1], Anna Deza[1], William Wong[1], Sebastian Oehme[2], Mark Presten[1], Mark Theis[1]
Jackson Chui[1], Paul Shao[1], Huang Huang[1], Atsunobu Kotani[1], Satvik Sharma[1], Rishi Parikh[1], Michael Luo[1]
Sandeep Mukherjee[1], Stefano Carpin[3], Joshua H. Viers[4], Stavros Vougioukas[5] and Ken Goldberg[1]

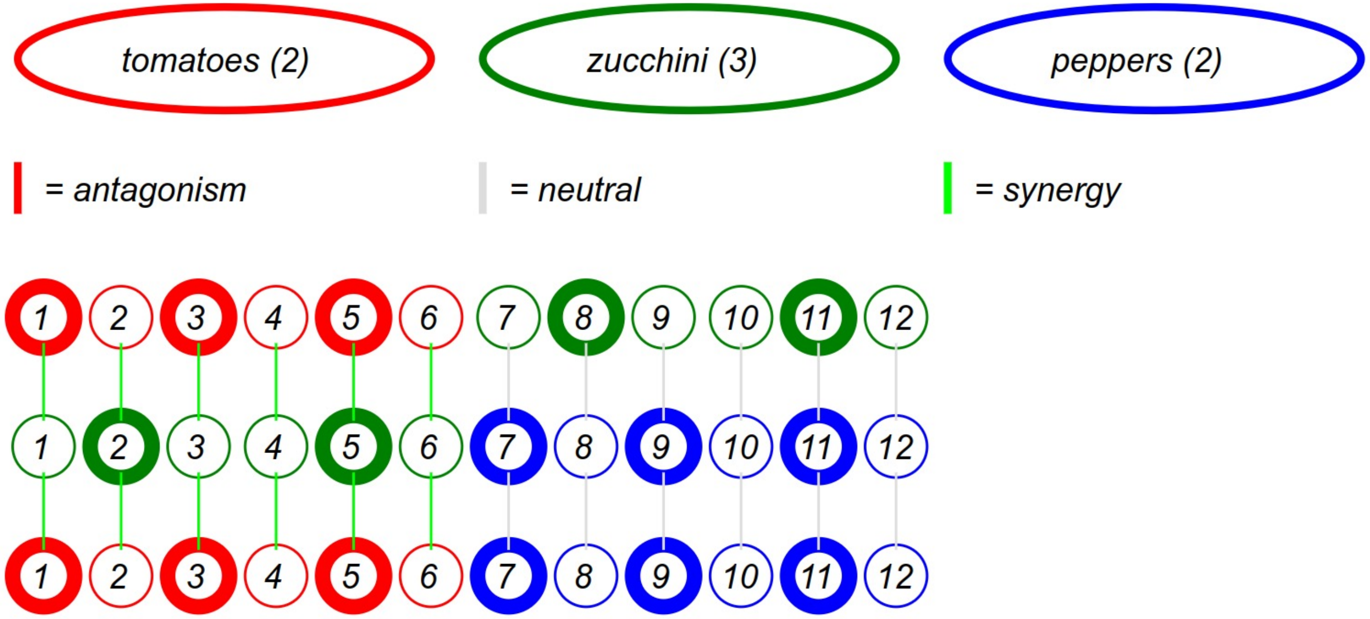
Abstract— **Polyculture farming is a sustainable farming technique based on synergistic interactions between differing plant types that make them more resistant to diseases and pests and better able to retain water. Reduced uniformity can reduce use of pesticides, fertilizer, and water, but is more labor intensive and more challenging to automate. We describe a scaled physical testbed (1.5m×3.0m) that uses a high resolution camera and soil sensors to monitor polyculture plants to facilitate tuning of plant growth, companion effects, and irrigation parameters for a first-order garden simulator. We use this simulator to develop a novel seed placement algorithm that increases coverage and diversity, and a learned pruning policy. In simulation experiments, the seed placement algorithm yields 60% more coverage and 10% more diversity than random seed placement and the learned pruning policy runs 1000X faster than a procedural lookahead policy to achieve high leaf coverage and plant diversity on adversarial gardens that include plant species with diverse growth rates. These models and policies provide the groundwork for a fully-automated system under development. Code, datasets and supplementary material can be found at https://github.com/BerkeleyAutomation/AlphaGarden/.**

Fig. 1: **Tuning Plant Simulation Parameters Using the Physical Testbed**. Using seeds from 10 edible plant species the seed locations were computed with a seed placement optimization process that leverages companion plants relationships to increase plant coverage and diversity. **Left:** Garden at day 17. **Right:** Garden at day 25. Plant circles as shown are predicted using the algorithm described in Section III(c).

Ottimizzazione delle consociazioni

Layout di consociazione Simple

- Orientato ai sistemi orticoli
- Mixed Strip Intercropping



Algoritmo SIMPLE per l’ottimizzazione del mixed strip intercropping

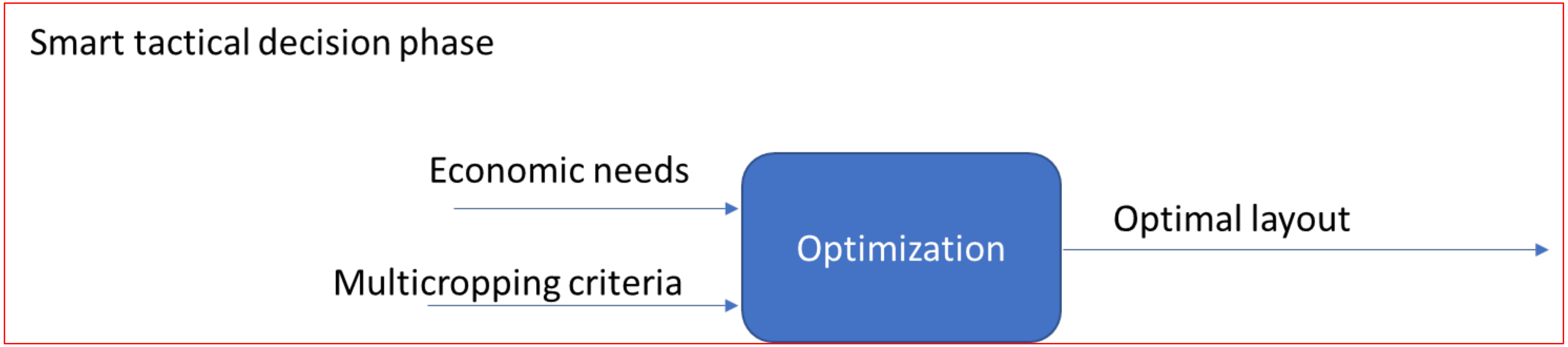
- **Problema :** Massimizzare la biodiversità attraverso le consociazioni rispettando i vincoli di layout e domanda

- **Problema di natura combinatoriale:** con 15 piantine e 3 specie numero di configurazioni possibili dell’ordine di 10^6
- Complessità n! -→ n=1000 -> n. combinazioni possibili **10^{2567}**

- **Studio del problema**
  - Codifica
  - Risoluzione

AI based big scale synergic agriculture microservice

Su scala medio grande pesa la complessità decisionale del sistema.



Smart tactical decision phase

Economic needs

Multicropping criteria

Optimization

Optimal layout

Il servizio di pianificazione convalida e costruisce l'istanza da passare al solutore CP Optimizer (IBM ILOG) direttamente in memoria senza scambi di file

$$\max \sum_{\substack{h,k\in H:\\ a_{h,k}\neq 0}} \alpha_{h,k} \cdot \sum_{\substack{s\in K, i\in P_h, j\in P_k:\\ s\neq \ell}} \theta(z_{h,s,i}, z_{k,s+1,j}) \longrightarrow$$

Funzioni Obiettivo

$s.t.$

$$\sum_{s\in K, i\in P_h} \lambda(z_{h,s,i}) = o_h \cdot d_h \qquad h \in H \longrightarrow$$

Soddisfare la domanda

$$\lambda(z_{h,s,i}) \ mod \ o_h = 0 \qquad h \in H, s \in K, i \in P_h \longrightarrow$$

$$noOverlap(p_s, M, After) \qquad s \in K \longrightarrow$$

Global Constraint: no OVERLAP cluster in uno strip

$$dom(p_s) = \{z_{h,s,i}\}_{h\in H, i\in P_h} \qquad s \in K$$

$$dom(z_{h,s,i}) = \{\perp\} \cup \{[a,b) \cap N^+, c'_h \leq b - a \leq C'_h\} \qquad h \in H, s \in K, i \in P_h$$

Vincoli sul dominio delle variabili

$$endBeforeStart(z_{h,s,i}, z_{h,s,j}, \widetilde{c}_h) \qquad h \in H, s \in K, i, j \in P_h : i < j$$

$$before(p_s, z_{h,s,i}, z_{h,s,j}) \qquad h \in H, s \in K, i, j \in P_h : i < j$$

$$endOfPrev(p_s, z_{h,s,i}, 1) = \sigma(z_{h,s,i}) \qquad h \in H, s \in K, i \in P_h$$

$$startOfNext(p_s, z_{h,s,i}, n+1) = \epsilon(z_{h,s,i}) \qquad h \in H, s \in K, i \in P_h$$

Global Constraint: per accelerare la ricerca riducendo lo spazio di esplorazione ovvero elimino soluzioni simmetriche

Il servizio di pianificazione convalida e costruisce l'istanza da passare al solutore OR Tools (IGoogle) direttamente in memoria senza scambi di file

$$Maximize \quad \sum_{h=1}^{H}\sum_{k=1}^{H} a_{h,k} \times \sum_{r=1}^{R-1}\sum_{i=1}^{\eta_{rh}}\sum_{j=1}^{\eta_{r+1,k}} \theta(h,k,r,i,j) \tag{12}$$

$s.t.$

$$z_{rhj} = 0 \implies y_{rhj} = 0 \qquad h = 1,\dots,H, r = 1,\dots,R, j = 1,\dots,\eta_{rh} \tag{13}$$

$$z_{rhj} + y_{rhj} \leq N + 1 \qquad h = 1,\dots,H, r = 1,\dots,R, j = 1,\dots,\eta_{rh} \tag{14}$$

$$\sum_{r=1}^{R}\sum_{i=1}^{\eta_{rh}} \frac{y_{rhi}}{g_{rh}} = d_h \qquad h = 1,\dots,H \tag{15}$$

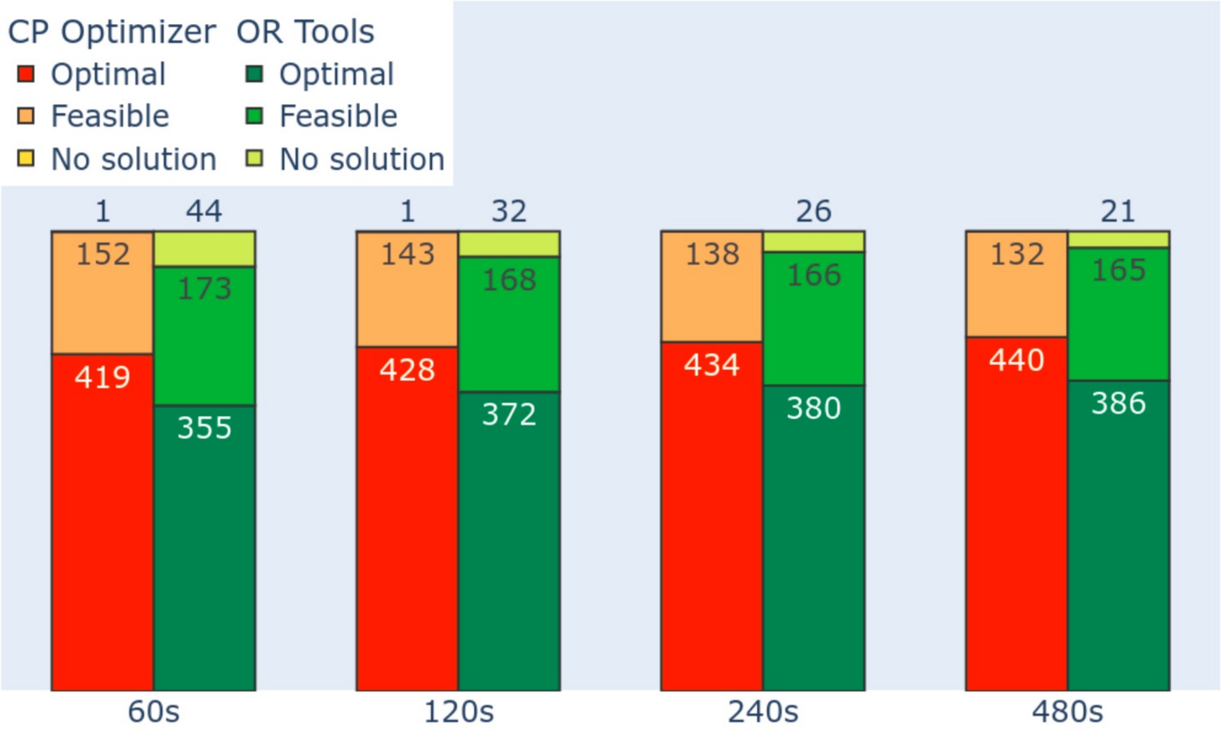
$$y_{rhi} \mod g_{rh} = 0 \qquad h = 1,\dots,H, j = 1,\dots,\eta_{rh}, r = 1\dots,R \tag{16}$$

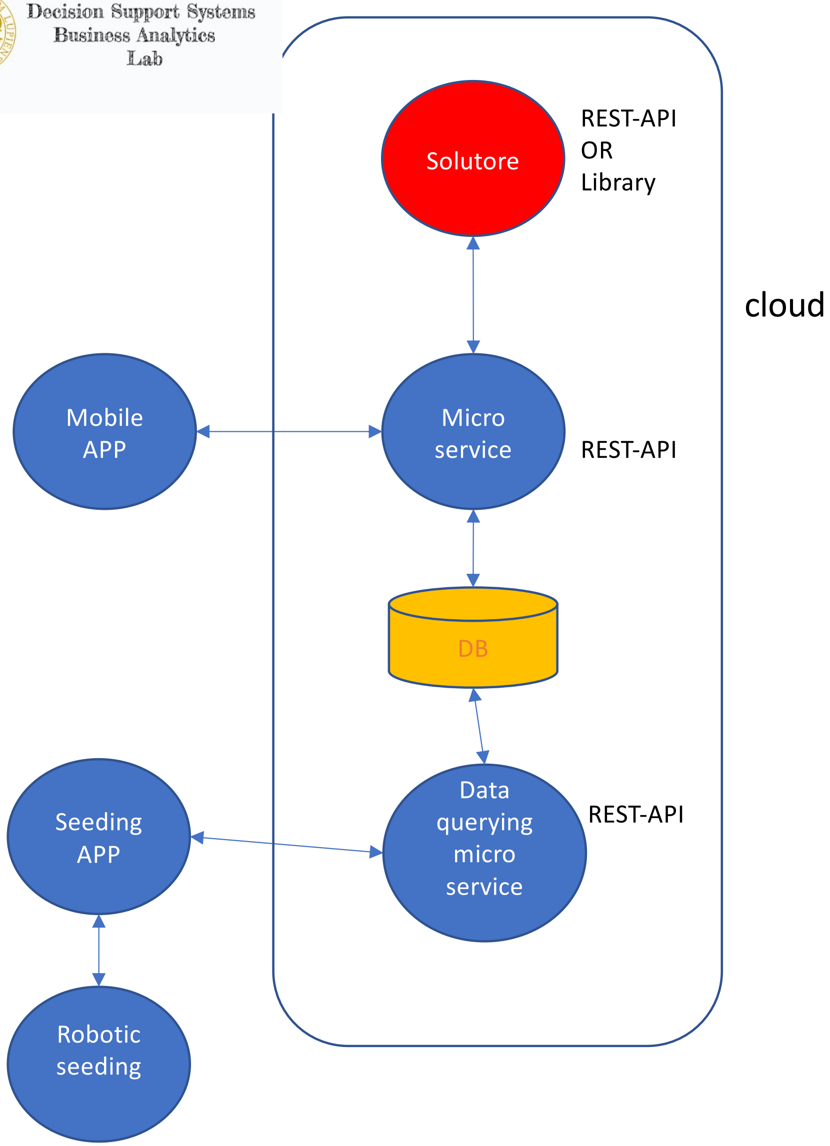
$$z_{rhj} \neq 0 \wedge z_{rki} \neq 0 \Rightarrow z_{rhj} + y_{rhj} \leq z_{rki} \vee z_{rki} + y_{rki} \leq z_{rhj}$$
$$h,k = 1,\dots,H, r = 1,\dots,R, j = 1,\dots,\eta_{rh}, i = 1,\dots,\eta_{rk} \tag{17}$$

$$z_{rhi} \neq 0 \wedge z_{rhi+1} \neq 0 \implies z_{rhi} + y_{rhi} + \tilde{c}_{rh} \leq z_{r,h,i+1}$$
$$h = 1,\dots,H, r = 1,\dots,R, i = 1,\dots,\eta_{rh} - 1 \tag{18}$$

$$z_{rhi} \neq 0 \wedge z_{r+1,k,j} \neq 0 \implies z_{rhi} + y_{rhi} \leq z_{r+1,k,j} \vee \ z_{rhi} \geq z_{r+1,k,j} + y_{r+1,k,j}$$
$$i = 1,\dots,\eta_{rh}, j = 1,\dots,\eta_{r+1,k}, r = 1,\dots,R-1, (h,k) \in \mathcal{S} \tag{19}$$

$$z_{rhi} \neq 0 \Rightarrow z_{rh,i-1} \neq 0 \qquad r = 1,\dots,R, h = 1\dots,H, i = 2,\dots\eta_{hr} \tag{20}$$


CP Optimizer
Optimal
Feasible
No solution
OR Tools
Optimal
Feasible
No solution
1
44
152
173
419
355
1
32
143
168
428
372
26
138
166
434
380
21
132
165
440
386
60s
120s
240s
480s



Solutore

REST-API
OR
Library

cloud

Mobile APP

Micro service

REST-API

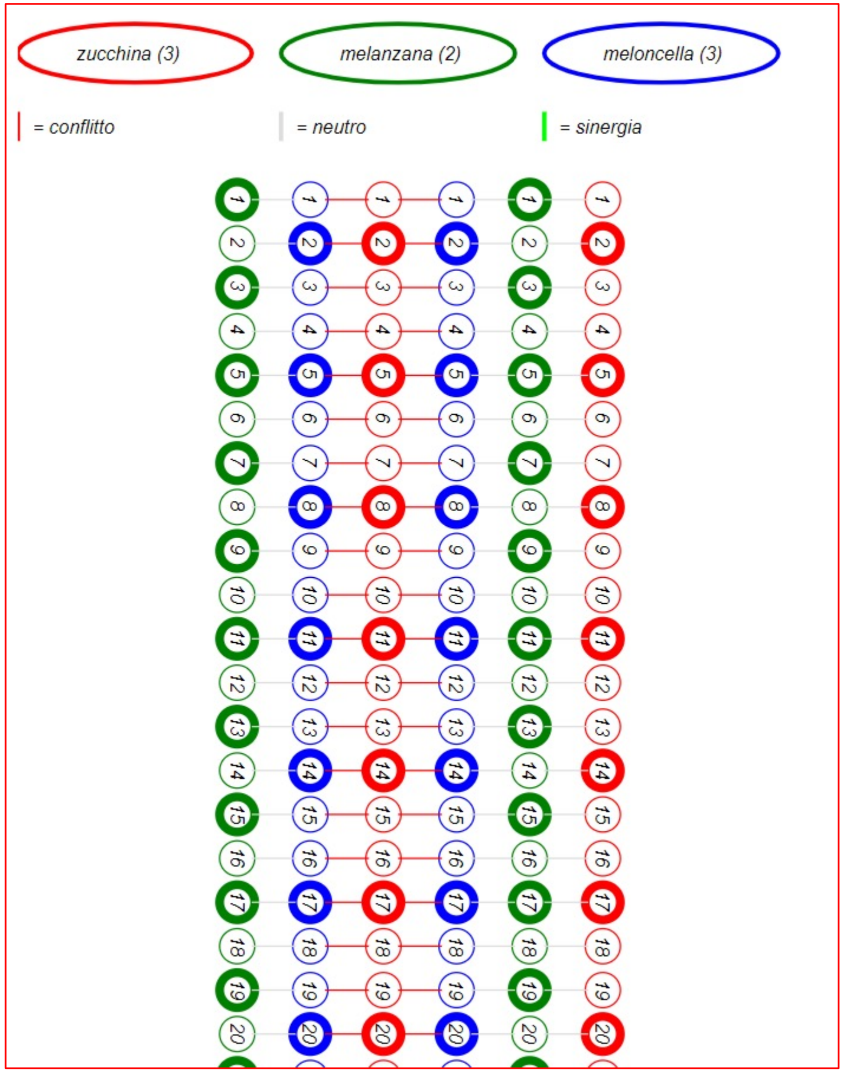
DB

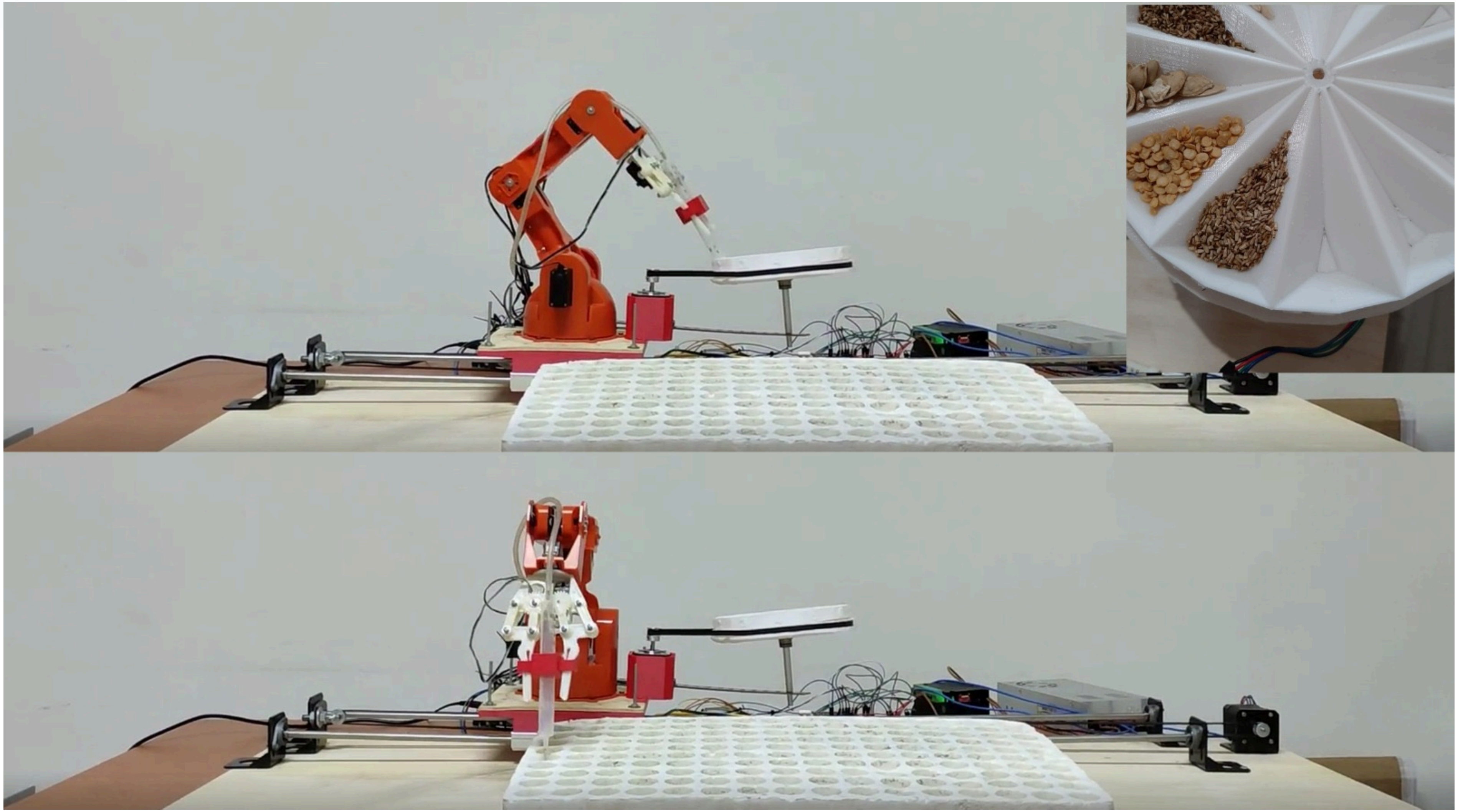
Seeding APP

Data querying micro service

REST-API

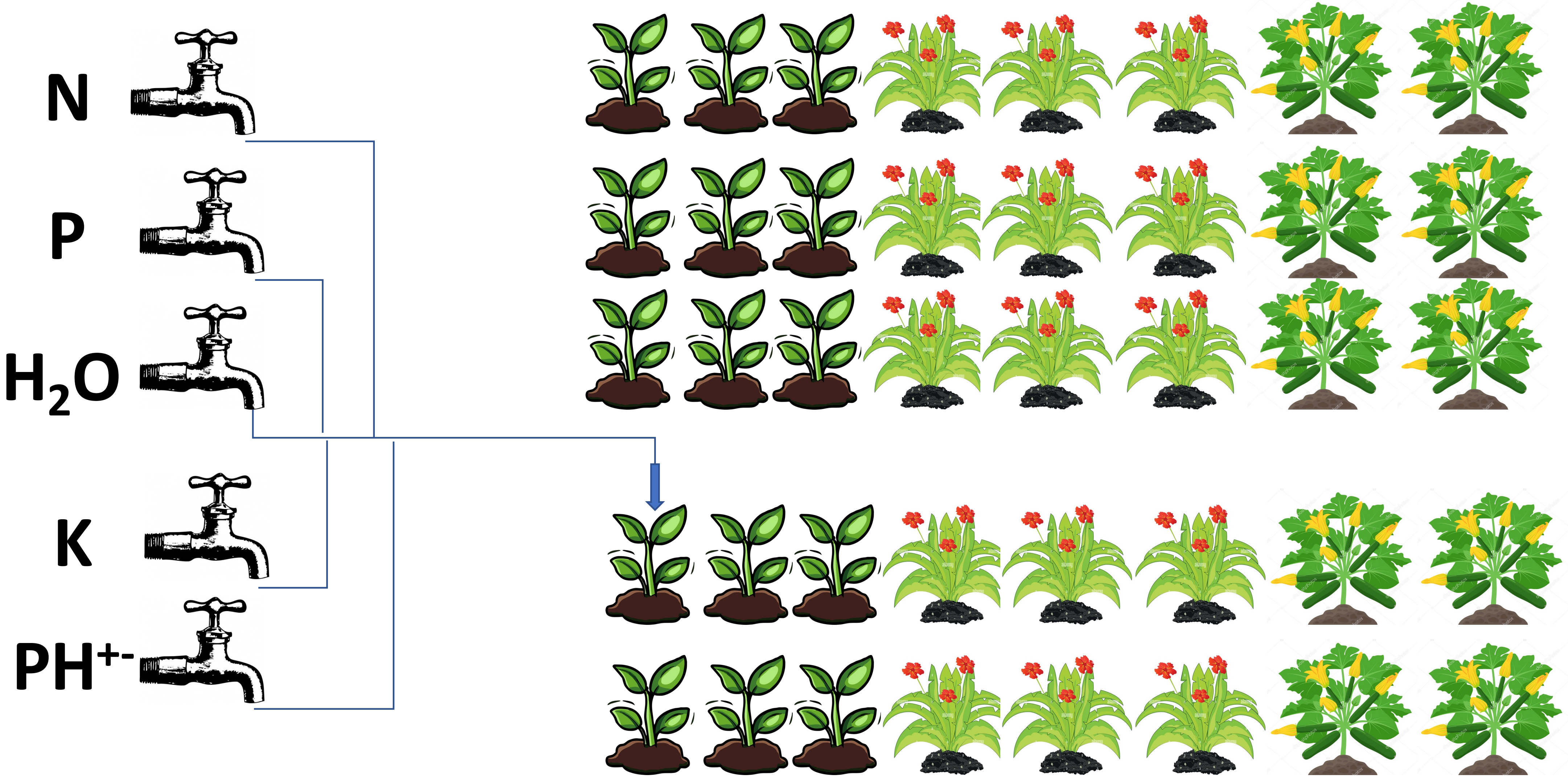
Robotic seeding





Sviluppo di algoritmi di AI

- Decisioni Tattiche
  - Configurazione del campo all’inizio del ciclo colturale
- Decisioni Operative
  - Irrigazione, fertirrigazione


N
P
H_2O
K
PH^{+-}

Sviluppo di algoritmi di AI

$$\sum_{j=1}^{N} \sum_{i=1}^{M} z_{ij}$$

s.v.

$$x_j \leq \sum_{i \in A_j} y_i \qquad j = 1, \ldots, N \quad j \notin E$$

$$y_i + x_j \leq 1 \qquad i = 1, \ldots, M \quad j \in B_i$$

$$z_{ij} \leq x_j \qquad j = 1, \ldots, N \quad i \in A_j$$

$$z_{ij} \leq y_i \qquad j = 1, \ldots, N \quad i \in A_j$$

$$0 \leq z_{ij} \leq 1 \qquad i = 1, \ldots, M \quad j = 1, \ldots, N$$

$$x_j \in \{0, 1\} \qquad j = 1, \ldots, N$$

$$y_i \in \{0, 1\} \qquad i = 1, \ldots, M$$

Crop planting layout optimization in sustainable agriculture: a constraint programming approach

Tommaso Adamo[1], Lucio Colizzi[2], Giovanni Dimauro[2], Emanuela Guerriero[1], and Deborah Pareo[1]

[1] *Dipartimento di Ingegneria dell'Innovazione, Università del Salento- Italy*
[2] *Dipartimento di Informatica - Università di Bari- Aldo Moro - Italy*

June 15, 2023

Abstract

This work is part of a research project aiming to automate the design and control of sustainable agriculture systems according to the Industry 4.0 paradigm. Intercropping systems, where mutually beneficial plant types are grown in close proximity, have emerged as a valuable approach in sustainable agriculture. By leveraging biodiversity, intercropping can reduce pesticide and water usage while optimizing soil nutrient utilization. Despite its potential, the optimization of intercropping systems has received limited attention in previous studies, especially in the context of broadacre cropping systems. In this study, we demonstrate the application of AI planning techniques to automate intercropping systems and assist farm workers in managing the complex optimization challenges associated with crop diversification. We focus on the crop planting layout problem, which involves meeting crop demand while maximizing positive interactions between adjacent plants. To address this problem, we propose the use of constraint programming and present two models based on integer variables and interval variables, respectively. Through a computational study using realistic instances, we examine the impact of different modeling approaches on the difficulty of solving the crop planting layout problem with constraint programming standard solvers.