Global food and climate challenges

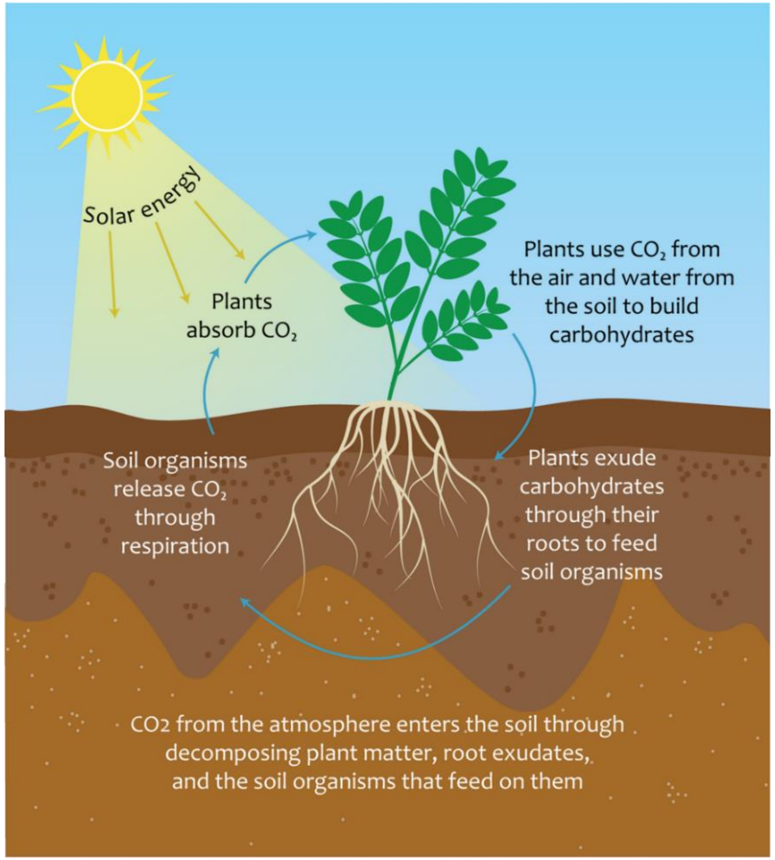
"To adequately feed more than nine billion people by 2050, the world must close a 70 percent gap between the amount of food produced today (2013) and that needed by mid-century" [1]

Global warming isn't a prediction. It is happening. [2]

James E. Hansen

[1] T. Searchinger. *Creating a sustainable food future. A menu of solutions to sustainably feed more than 9 billion people by 2050. World resources report 2013-14: interim findings*. WRI; UNEP; UNDP; CIRAD; INRA, 2014.
[2] https://www.nytimes.com/2012/05/10/opinion/game-over-for-the-climate.html.

Soil carbon sequestration impacts on climate change and food security



The global soil carbon (C) pool of 2500 gigatons (Gt) is **3.3 times** the size of the atmospheric pool (760 Gt).

Conversion of natural to agricultural ecosystems causes **depletion of the soil organic carbon (SOC) pool** by as much as 60%~75%.

An increase of 1 ton of soil carbon pool of degraded cropland soils may **increase crop yield** by 20 to 40 kilograms per hectare (kg/ha) for wheat, 10 to 20 kg/ha for maize, and 0.5 to 1 kg/ha for cowpeas.

Carbon sequestration has the potential to **offset fossil fuel emissions** by 0.4 to 1.2 Gt of carbon per year, or 5 to 15% of the global fossil-fuel emissions.

R. Lal. Soil carbon sequestration impacts on global climate change and food security. *Science* 304.5677: 1623-1627, 2014

Factors influencing soil carbon sequestration

- Contributing management practices
  - Conservation tillage
  - Cover crops
  - Manuring
  - Mixed farming
  - Irrigation
  - …

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Soil carbon sequestration potential in a Vertisol in central India- results from a 43-year long-term experiment and APSIM modeling

M. Mohanty[a], Nishant K. Sinha[a,*], J. Somasundaram[a], Sonali S. McDermid[b], Ashok K. Patra[a], Muneshwar Singh[a], A.K. Dwivedi[c], K. Sammi Reddy[d], Ch. Srinivas Rao[e], M. Prabhakar[d], K.M. Hati[a], P. Jha[a], R.K. Singh[a], R.S. Chaudhary[a], Soora Naresh Kumar[f], Prabhat Tripathi[a], Ram C. Dalal[g], Donald S. Gaydon[g,h], S.K. Chaudhari[i]

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Soil Carbon Sequestration Potential as Affected by Management Practices in Northern China: A Simulation Study*[1]

WANG Guo-Cheng[1], WANG En-Li[2,*2], HUANG Yao[3] and XU Jing-Jing[1]

How to automatically optimize the soil carbon sequestration while simultaneously improving the crop productivity?

Optimize soil carbon sequestration using simulation and reinforcement learning

Simulate the crop and soil conditions (e.g., organic matter) under management practices using **CoupModel** [1] and **APSIM** (Agricultural Production Systems sIMulator) [2]

Optimization problem

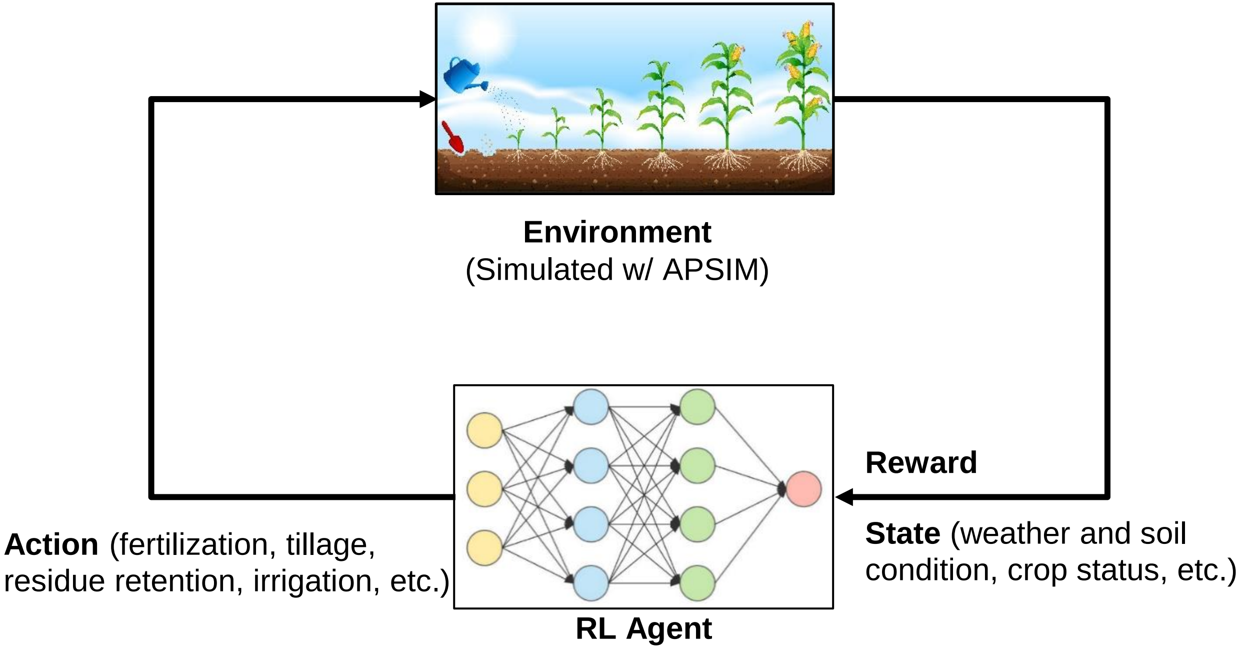
$$\max_{\text{management practices}} \mathbf{SOC}$$

$$\text{Subject to:}$$

$$\text{Plant and soil dynamics}$$

$$\textbf{Crop yield} > y_{\text{limit}}$$

$$\text{Management cost} < c_{\text{limit}}$$

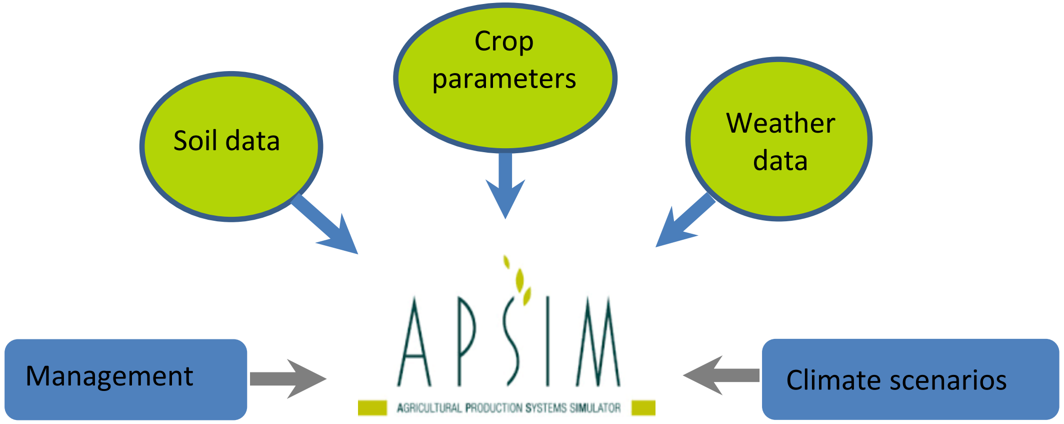


Optimize the management practices using **reinforcement learning (RL)** algorithms, e.g., deep RL (DQN, DDPG, PPO)

[1] P-E. Jansson and L. Karlberg. CoupModel – Coupled heat and mass transfer model for soil-plant-atmosphere systems. *Royal Institute of Technology*, Dept. of Land and Water Resources Engineering, Stockholm, TRITA-LWR report. 3087: 427 p, 2004.
[2] D. P. Holzworth *et al.* APSIM – Evolution towards a new generation of agricultural systems simulation. *Environmental Modelling & Software,* 62:327–350, 2014

Develop a high-fidelity interactive crop simulator based on APSIM

- APSIM is an internationally recognized software for cropping systems modeling and simulation.
- APSIM perform daily step simulations of a wide range of agricultural systems, including crops and livestock under different climate and soil conditions
- We propose to build an APSIM-based simulator to simulate the environment dynamics and crop growth.



Formulate a Markov decision process (MDP) problem for management

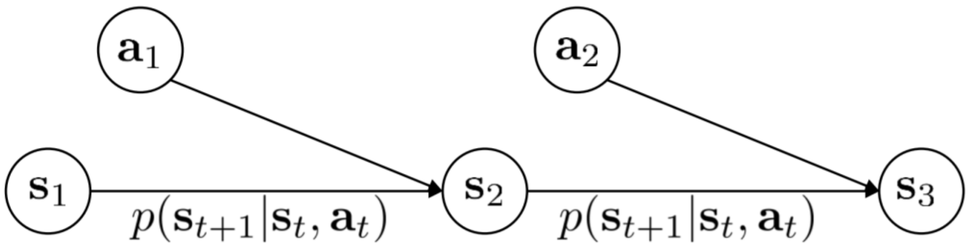
Keys of elements of MDP:

S -- State Space

A -- Action Space

r -- Reward

Get a new state based on the previous state and action.



Key elements of MDP

State Space	Action Space
• Soil condition (moisture, organic C pool, N pool, etc.) • Crop status • Weather condition (precipitation, temperature)	• Planting (time and density) • Fertilization(nitrogen rate) • Irrigation • Residue retention & Cover crop • Tillage

$$r = \Delta SOC + \omega_1 * profit + \omega_2 * N_{leaching}$$

ΔSOC -- Organic carbon added to the soil

$N_{leaching}$ -- The cumulative N leached from the soil profile

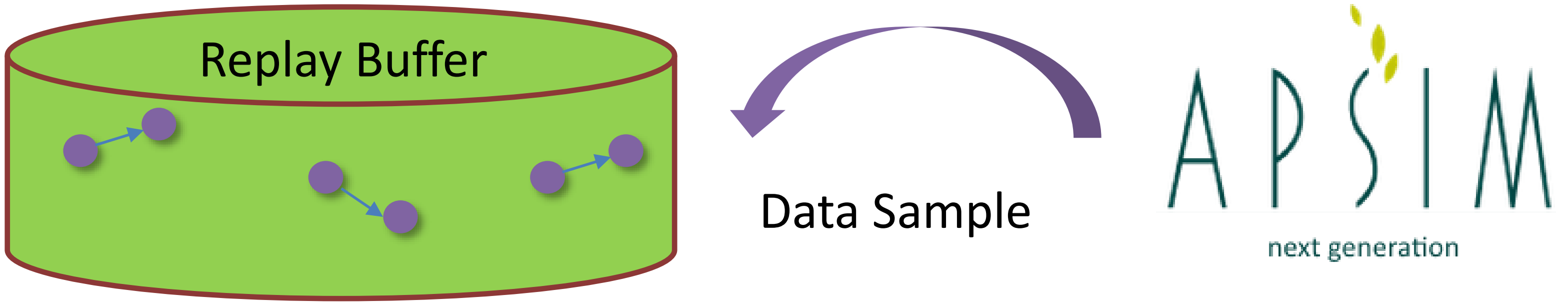
ω_1 , ω_2 -- Tuning parameters for balancing the different objectives

Train a management policy using deep reinforcement learning

1. Data collection from APSIM;

2. Each data sample is a tuple of (s,a,r,s’) and saved in a replay buffer D;

   - s, a, r and s’ denote current state, current action, immediate reward;



3. Apply deep Q-learning for decision optimization:

   - Learn an optimal action-value function with a policy;
   - Optimize by minimizing the loss function with data points from buffer;
   - Make decision by choose the actions that maximize the action-value function;

4. Calibrate models with real-world data.

Thank you for listening!