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Optimizing Crop Management with Deep Reinforcement Learning and Crop Simulations

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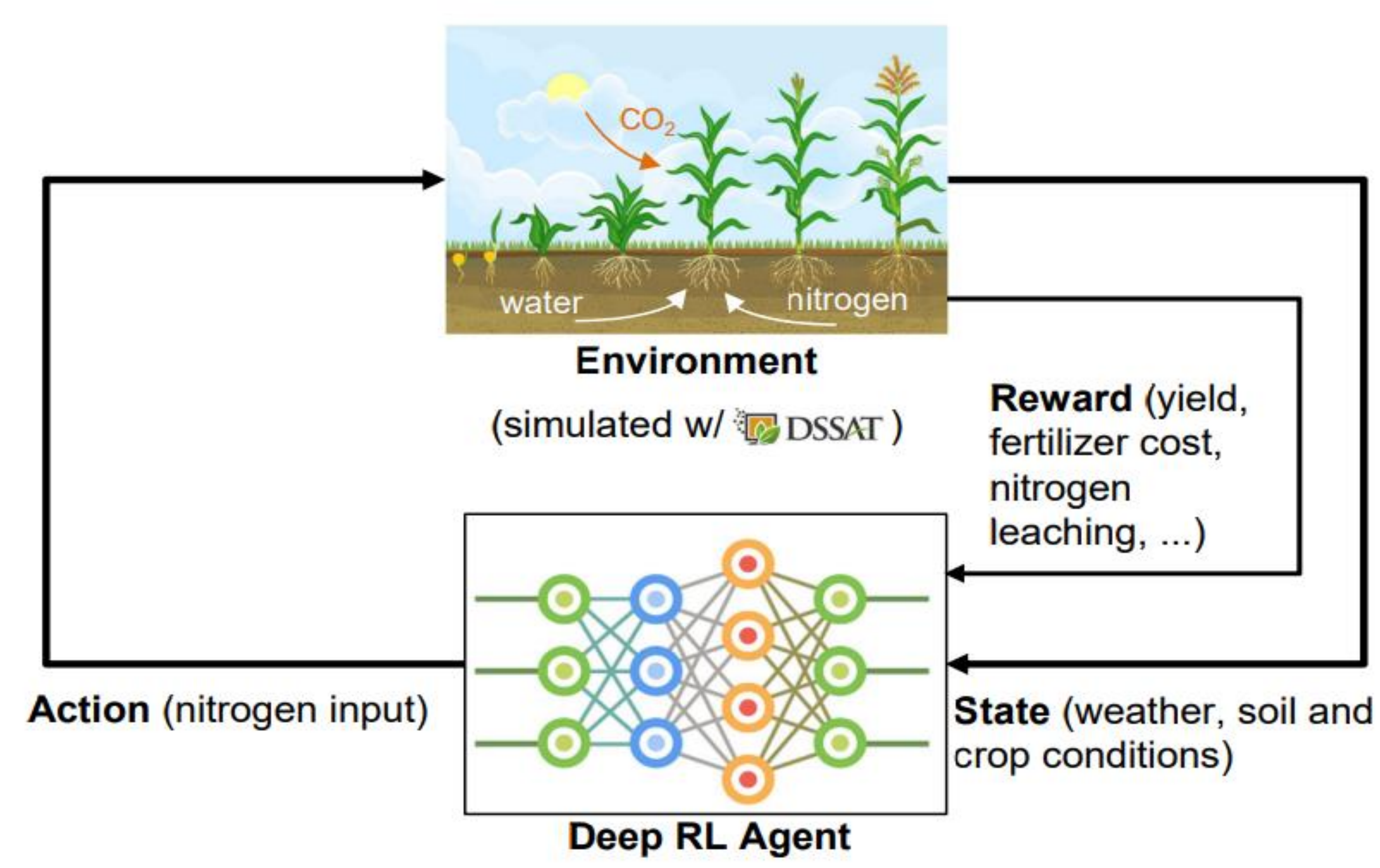
Introduction

Towards an intelligent agricultural management system, we propose to:

- Formulate Crop management as a finite Markov decision process (MDP) problem
- Simulate the crop response using Gym-DSSAT
- Optimize management policies using deep reinforcement learning (RL)
  - Policy training with deep Q-network (DQN)
  - Multiple Design of Reward functions

Overall framework



- Leverage Decision Support System for Agrotechnology Transfer (DSSAT) for crop modeling and simulation
- Use Gym-DSSAT interface to read the simulated crop and soil conditions and apply management practices on a daily basis

Method

- Action Space:
  - $40\kappa \frac{kg}{ha}$ Nitrogen fertilizer & $6\kappa \frac{L}{m^2}$ Irrigation water
  - $\kappa = 0,1,2,3,4$
- State Space: states of crops and environment of current day:
  - Temperature
  - Rain
  - Growing degrees
  - Plant vegetative stage
  - Plant population density
  - ….
- Reward:

$$r(s_t, a_t) = \begin{cases} w_1 Y - w_2 a_t - w_3 N_{l,t} - w_4 P_t & \text{if harvest at } t, \\ -w_2 a_t - w_3 N_{l,t} - w_4 P_t & \text{otherwise,} \end{cases}$$

Policy Training with DQN

$$L_i(\theta_i) \triangleq \mathop{\mathbb{E}}_{(s,a,r,s')} \left[r + \gamma \max_{a' \in \mathcal{A}} Q(s', a'; \theta_i^-) - Q(s, a; \theta_i) \right]$$

Results

- Reward = 0.158*Yield - 0.79*Fertilizer- 1.1*Irrigation (Economic Profit)

Method	N Fertilizer (kg/ha)	Irrigation (L/m^2)	N Leaching (kg/ha)	Yield (kg/ha)	Cumulative Reward
Baseline	360	393.7	212.6	10771.5	984.4
Trained Policy 1	240	156	38.5	10998.0	1376.5

- Reward = 0.158*Yield - 0.79*Fertilizer- 0*Irrigation

Method	N Fertilizer (kg/ha)	Irrigation (L/m^2)	N Leaching (kg/ha)	Yield (kg/ha)	Cumulative Reward
Baseline	360	393.7	212.6	10771.5	1417.5
Trained Policy 2	240	594	69.2	11291.8	1594.5

- Reward = 0.158*Yield - 0.79*2*Fertilizer- 1.1*Irrigation

Method	N Fertilizer (kg/ha)	Irrigation (L/m^2)	N Leaching (kg/ha)	Yield (kg/ha)	Cumulative Reward
Baseline	360	393.7	212.6	10771.5	700.0
Trained Policy 3	160	108	41.9	10116.7	1226.8

- Reward = 0.2*Yield - 1*Fertilizer- 1*Irrigation- 5*Nitrogen Leaching (Economic & Environmental Consideration)

Method	N Fertilizer (kg/ha)	Irrigation (L/m^2)	N Leaching (kg/ha)	Yield (kg/ha)	Cumulative Reward
Baseline	360	393.7	212.6	10771.5	337.6
Trained Policy 4	200	138	39.2	10926.1	1651.0

- **For each trained policy, with the corresponding reward function design, it has the highest cumulative reward among all trained policies**

Experiment Settings

Region	Crop Type	Year	Crop Management
Florida	Maize	1982	Fertilization & Irrigation

Conclusions

1. We present a framework for crop management (fertilization and irrigation) with deep reinforcement learning (RL) and crop simulations based on DSSAT.
2. The proposed framework is shown to outperform standard management practices in Florida.
3. Our work demonstrates the potential of deep RL in optimizing crop management for more sustainable and resilient agriculture.