Tightly-coupled plant-soil nitrogen cycling and crop productivity on contrasting organic farms across an intensively-managed agricultural landscape

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Objectives and on-farm landscape approach

Soil N cycling

1. depolymerization (rate-limiting step)
2. mineralization
3. immobilization
4. volatilization
5. nitrification
6. leaching
7. denitrification
8. microbial turnover
9. root turnover and labile C exudation
10. faunal grazing

Soil organic matter (SOM)

monomers (DON)

microbes

NH₄⁺

NO₃⁻

leaching

NH₃

NO & N₂O

N₂
Objectives and on-farm landscape approach

- Identify patterns of plant-soil N cycling on organic tomato fields
- Examine biogeochemical indicators of N cycling and a novel approach based on root gene expression
- Use an on-farm landscape approach to capture biophysical variability and growers’ strategies
Landscape survey of organic Roma-type tomato fields

- 8 growers managing 13 fields in Yolo Co., CA
- 4 fresh market and 4 processing growers
- Wide variety of practices (e.g. manure vs. composted green waste; vetch cover crops; commercial organic fertilizers)
- Monitoring study over 2011 growing season
  - biogeochemical indicators of soil N cycling at three keys times: pre-transplant, anthesis, harvest
    - Soil NH$_4^+$ and NO$_3^-$;
    - potentially mineralizable N (PMN)
    - soil organic matter (SOM): total C & total N, DOC, POXC, IR spectra
  - root gene expression
  - plant N status
  - crop yields
3-fold gradient of soil C and N

- Similar texture (10 silt loams, 3 loams) and parent material (mixed alluvium)
- Little variation in pH (6.3-7.2)
Soil inorganic N across fields

- Soil NH$_4^+$ generally low, but large variability in soil NO$_3^-$
  (e.g. 0.2 – 44.9 μg-N g$^{-1}$ soil for mid-season)
Soil inorganic N across fields

- Different NO$_3^-$ dynamics across fields: higher, more variable (red); lower, less variable (blue)
Tomato N status and yields

- At mid-season, 11/13 fields close to critical N
- 9/13 fields above Yolo Co. average for crop yield
Why link root gene expression to soil N processes?

- Plants turn on/off genes involved in N uptake and assimilation – transcription levels in roots may be “plant’s eye view” of soil N cycling
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Root N assimilation linked to soil biology

- Root GTS1 expression better associated with indicators of soil biology than with \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) pools
- Root N assimilation thus may be elevated when soil inorganic N pools are low but when microbial activity is high
Plant-soil-microbial interrelationships via KSOM

- Size of wedge represents relative value of variable for each cluster
- Neighboring clusters more similar than those farther away
N deficiency

N excess

Tightly-coupled N cycling

N deficiency
Activities of C and N cycling soil enzymes show opposing trends:
- C cycling enzymes: greater activity in “N excess” fields
- N cycling enzymes: greater activity in “Tightly coupled N cycling” fields
- High rates of N cycling and turnover mean plants can acquire N even when N pools (NH$_4^+$ and NO$_3^-$) do not build up

Bowles et al. (2014), *Soil Biology and Biochemistry*
Multiple ecosystem services in organic production

- Three N cycling “scenarios” found on organic farms: tradeoffs among yields, N availability, and potential for N retention
  - 1) N deficiency (- - +)
  - 2) N excess (+ + -)
  - 3) Tightly-coupled plant-soil N cycling (+ + +)
Multiple ecosystem services in organic production

- Three N cycling “scenarios” found on organic farms: tradeoffs among yields, N availability, and potential for N retention
  - 1) N deficiency (- - +)
  - 2) N excess (+ + - )
  - 3) Tightly-coupled plant-soil N cycling (+ + +)

- Multiple indicators required to support adaptive management along pathways to tighter N cycling:
  - SOM and biological activity
    - High soil C and N pools, high bioassays of N availability
  - Soil inorganic N pools
    - Low soil NO$_3^-$ (N deficiency OR tightly coupled N cycling) vs. high soil NO$_3^-$ (more potential for N loss)
  - Plant N status
    - Elevated expression of GTS1 indicates higher plant N assimilation even if soil inorganic N pools are low

- Tightly-coupled N cycling comes with slightly reduced yields:
  - Are some tradeoffs inevitable?
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