Dynamic Roots in ALM
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**Objective**

**Background:**
Roots are responsible for water and nutrient uptake and therefore couple above and below-ground systems. Roots respond to their environment with foraging strategies to maximize resource acquisition. In order to allow ecosystems to respond to changes in environment from climate change, roots must be allowed to adapt to heterogeneity of water and nitrogen in the soil.

ALM has fixed rooting depth and distribution similar to the exponential distribution of Jackson et al. (1996). The exponential distribution of roots agrees well with global observations, but does not allow changes in root distribution from changes in water or nutrients, nor does it capture the rooting profile of ecosystems in arctic or arid regions. Furthermore, crops undergo rapid root development under short timescales which is not reflected in ALM and can result in an over- or under estimate of crop productivity. At a minimum, root profiles should include time varying structure.

The goal of this study is to develop a new approach for root representation to resolve the horizontal structure of roots. This allows plasticity of roots under non-uniform profiles of water and nitrogen, influencing the above ground vegetation dynamics.

The dynamic roots model is designed to optimize root distribution for both water and nitrogen uptake, but with a priority given to plant water demands.

**Approach**

**Root Distribution:**
The model is initialized with the default root profile, but fine root carbon in each soil layer is updated each timestep as:

$$\rho_j = C \cdot fr + C_{new} \cdot \left(1 - w_{limit}\right) \cdot \frac{rs}_{wa} \sum rs_{wa} + w_{limit} \cdot \frac{rs_{mn}}{\sum rs_{mn}}$$

Where $w_{limit}$ is the water availability in the root zone:

$$w_{limit} = \sum \frac{\log(minpsi)}{\log(maxpsi)} \cdot fr$$

And the water ($rs_{wa}$) and nitrogen($rs_{mn}$) availability in each soil layer ($j$) are:

$$rs_{wa} = \frac{\log(minpsi)}{\log(maxpsi)}$$

$$rs_{mn} = sminn \cdot vr_j$$

The new root fraction ($fr$) is then:

$$fr = \frac{\rho_j}{\sum \rho_j}$$

**Root Depth (crops only):**
- Initial root depth is ~ 4 cm
- Roots grow linearly with Growing Degree Days (GDDs)
- Max depth reached at grain fill:
  - Maize: 1.2 m, Wheat: 0.9 m, Soybean: 1.6 m

**Impact**

**Root Depth (crops only):**
- Percent change in soil water content (proxy for water uptake) between the default ALM root representation and the dynamic root model. The global average soil water decreases -0.85%.
- Percent change in GPP between the default ALM root representation and the dynamic root model. The global average GPP increases 4.3%.

**Root Fraction:**
- Density of roots in each soil layer over the growing season for maize crop.

**Impact:**
- Percent change in nitrogen uptake between the default ALM root representation and the dynamic root model. The global nitrogen uptake increases 1.2%.

**Impact:**
- Percent change in crop yield between the default ALM root representation and the dynamic root model. The global average yield increase 4.7%.

**Left:** Same as above except for 95% root biomass, with a mean depth of 1.28 m. Regions with higher precipitation result in deeper depth where 95% root biomass is found. In general the depth decreases with increasing latitude. Dry tropical savannahs have a majority of root biomass found in deeper soil depths.

**Right:** Same as above except for 95% root biomass. The largest changes in depth of 95% root biomass are along precipitation gradients – higher precipitation results in a deepening of the root profile. The largest increases in depth of 95% root biomass are in the dry tropics and in the Mediterranean regions. In arctic, most root biomass is found at shallower depths with dynamic roots.