Strategies of African indigenous vegetables to cope with phosphorus deficient soils

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HORTINLEA DIVERSIFYING FOOD SYSTEMS

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Background

Food production in smallholder farming systems of Sub Saharan Africa is often constrained by low soil contents of plant-available phosphorus (P). An option to increase food production is cultivation of species with high P efficiency. Plant strategies to improve P acquisition and growth on low P soils include root foraging strategies to improve spatial soil exploitation, P mining strategies to enhance desorption, solubilisation or mineralization of soil P, and improving internal P utilization efficiency (see below).

Plant traits related to high P efficiency (g biomass production per mg soil P supply at low P supply) for different forms of soil P

Plant trait/rhizosphere characteristic	Effective for
Internal use efficiency (biomass formation per unit plant P)	All P forms
Root surface (e.g., root hairs, specific root length)	All P forms
Rhizosphere phytase activity	Organic P
Low rhizosphere pH, release of carboxylates (e.g., citrate)	Calcium-P
High rhizosphere pH, release of carboxylates (e.g., citrate)	Fe-, Al-P

Aims

We measured plant responses to low P availability in soil and assessed variation among African indigenous vegetables (AIV) in their ability to use different P forms to inform farmers about choice of species which are optimally adapted to low P soils.

Methods

Five AIV (see below) and common kale (*Brassica oleracea acephala*, introduced and widely grown in Kenya) were grown on low P substrate, either non fertilized (no P) or fertilized (49 mg P pot^{-1}) with water soluble P (KH_2PO_4), sparingly soluble P ($FePO_4$, Rock P) or organic P (phytate).

Solanum scabrum | *Amaranthus cruentus* | *Vigna unguiculata* | *Cleome gynandra* | *Brassica carinata* | *Brassica oleracea acephala*

Results

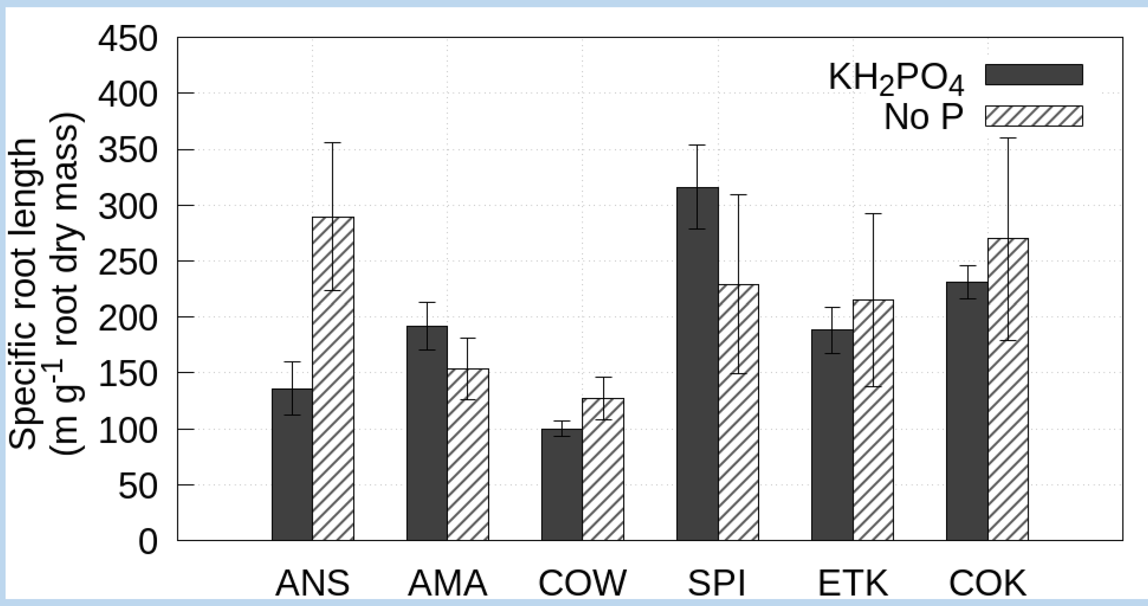
Do species vary in morphology and root trait responses to low soil P supply?

- **Root to shoot ratio**

Supply	ANS	AMA	COW	SPI	ETK	COK
	Root dry mass / shoot dry mass (g/g)					
KH_2PO_4	0.29	0.19	0.21	0.15	0.25	0.23
No P	0.57	0.30	0.31	0.40	0.35	0.33

Under P deficiency all species increased biomass partitioning to roots. This response was particular large in spider plant (SPI) and African nightshade (ANS).

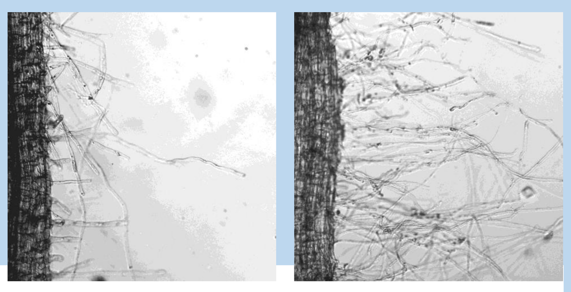
- **Specific root length**

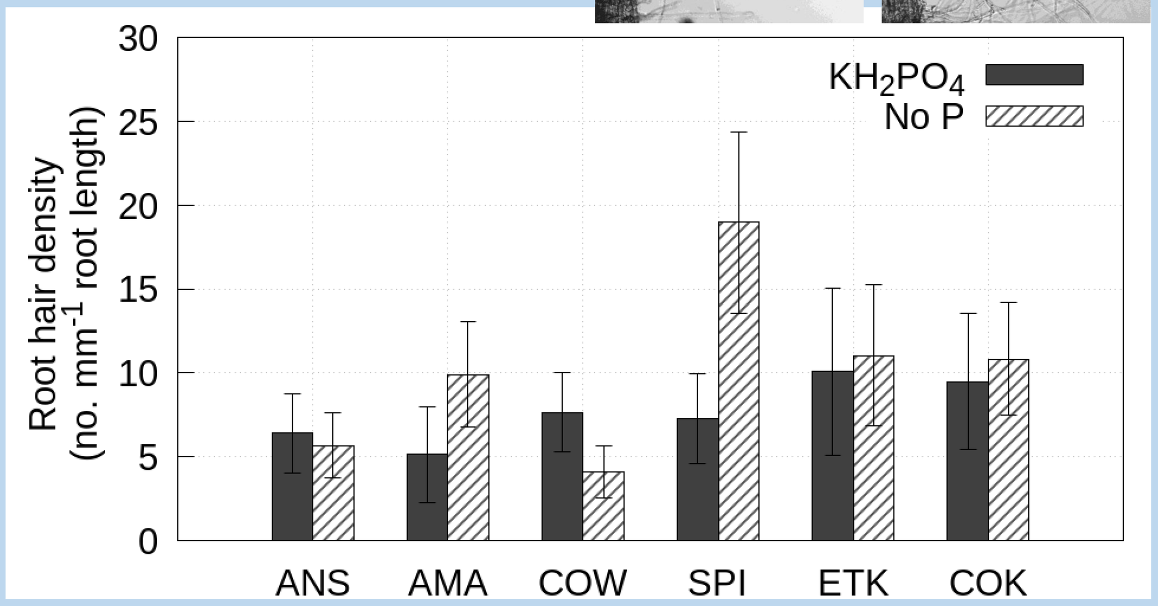


Under P deficiency only African nightshade increased specific root length, and thus, decreased carbon costs for construction of root length.

- **Root hair density (hair no./mm root length)**

Root sections of Spider plant with root hairs:
Left: KH_2PO_4
Right: No P

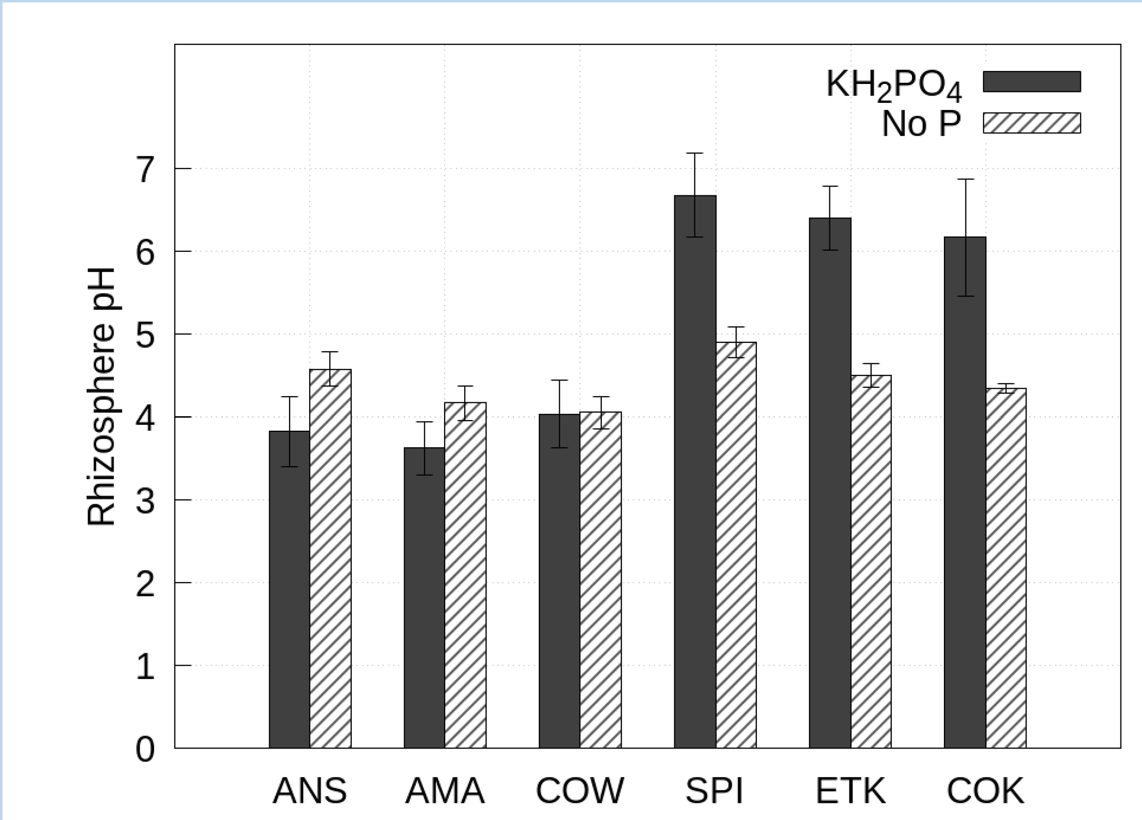




Under P deficiency Spider plant and Amaranthus increased root hair density and length, and thus improved spatial exploitation of soil in the rhizosphere.

Do species vary in their ability for P acquisition from different soil P forms?

- **Rhizosphere pH**



In spider plant (SPI), Ethiopian kale (ETK) and common kale (COK) rhizosphere pH (measured in the leachate before harvest) was higher than in the other species when plants were well supplied with P (black columns). However, under P deficiency (hatched columns), these species decreased rhizosphere pH. This may be taken as adaptive response to increase availability of sparingly soluble calcium-phosphates in soil.

- **P uptake from various P forms**

P form	ANS	AMA	COW	SPI	ETK	COK
	P uptake (mg plant^{-1})					
KH_2PO_4	18.7	18.3	19.7	17.1	18.2	17.1
Phytate	13.6	12.8	12.1	10.1	9.2	8.3
$FePO_4$	1.1	2.6	1.3	0.7	3.2	3.4
Rock-P	3.1	7.6	6.9	0.8	6.7	5.3

P uptake from KH_2PO_4 (plant P of fertilized plants - plant P of non-fertilized plants) was quite similar for all species (17-20 mg P). However, species considerably differed in their ability to acquire P from sparingly soluble P sources. Phytate was better used by ANS, AMA and COW than by SPI, ETK and COK. For utilization of iron phosphate, COK, ETK and AMA were more efficient than the other species. For utilization of rock-P, AMA, COW and ETK were most efficient, whereas SPI could hardly take up any P from rock-P.

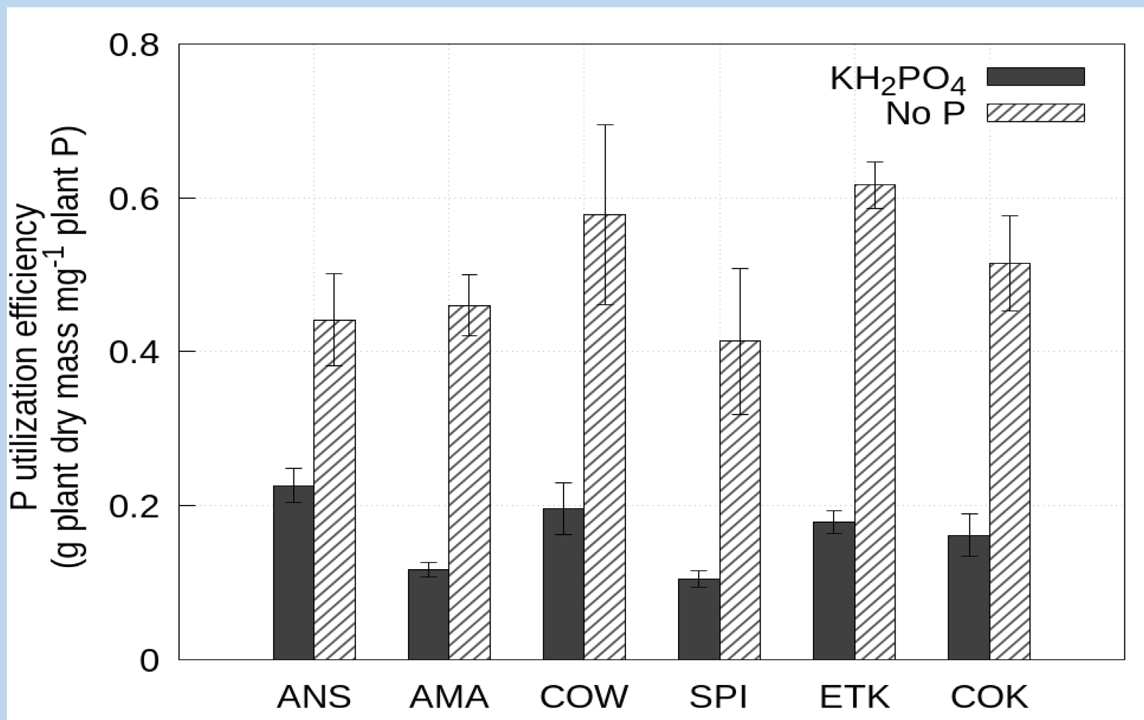
Do species vary in growth and internal P utilization efficiency?

- **Effect of P form on growth**

P form	ANS	AMA	COW	SPI	ETK	COK
	Total plant dry mass (Relative values, KH_2PO_4 = 100)					
KH_2PO_4	100	100	100	100	100	100
Phytate	100	127	98	95	94	103
$FePO_4$	14	55	40	21	60	60
Rock-P	23	82	75	16	77	63

As indicated by similar growth in soil amended with KH_2PO_4 and phytate, all species efficiently used organic P sources for growth. Iron phosphate was most efficiently used by ETK and COK. Rock-P was most efficiently used by AMA (82% of plant DM of KH_2PO_4-supplied plants), COW (75%) and ETK (77% of plant DM of KH_2PO_4-supplied plants). ANS and SPI were least efficient in using sparingly soluble P for growth.

- **Internal P utilization efficiency**



The utilization of plant P for dry mass production was generally much lower when plants were well supplied (black columns) than under P deficiency (hatched columns). This indicates, that in well supplied plants a considerable part of internal P is sequestered in storage compounds and compartments and not used for growth processes (luxury consumption).
When plants were suffering from P deficiency, ETK and COW were most efficient, and SPI least efficient in using internal plant P for dry mass.

Conclusion

The ability of plants to respond to P deficiency by increasing root surface area, and to utilize sparingly soluble or organic P differed among species. African nightshade and spiderplant were least able to acquire P from sparingly soluble iron- and calcium-phosphates, and had the lowest internal P utilization efficiency, and thus, are not recommended for cultivation on P poor soils.

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