Shifting the shape of soil and plant microbiomes in modern agriculture

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AAFC Saskatoon

Canola Innovation Day
December 7, 2017

What is soil health?

soil health ⟷ soil quality

"the continued capacity of a soil to function as a vital living ecosystem that sustains plants, animals and humans"

USDA, 2016

What is soil health?

soil health ⟷ soil quality

"Soil health…. ***Healthy soils maintain a diverse community of soil organisms*** that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots; recycle essential plant nutrients; improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production" (FAO, 2008)

What are the biota doing?

Ecosystem services
Decomposition & cycling of organic matter
Regulation of nutrient availability
Suppression of pests and disease
Maintenance of soil structure & hydrology
Gas exchange and carbon storage
Soil Detoxification
Plant growth control

Estimated value: \$1.5 trillion y^{-1} (FAO)

Supporting soil microbial communities

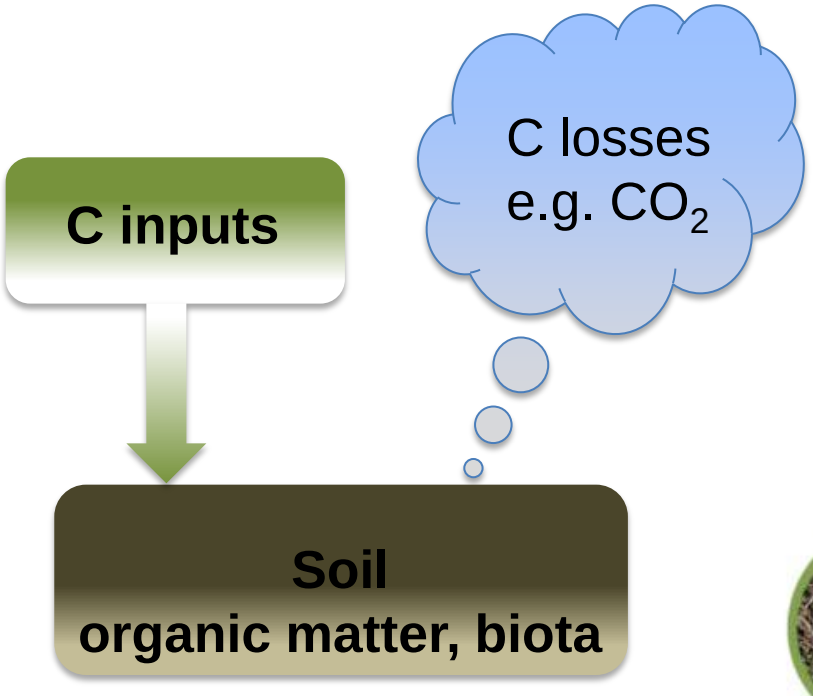
Management practice
*Reduced physical disturbance
*Continuous cropping
*Diverse cropping rotations
Cover cropping
Balanced nutrient management
Organic amendment application
Use of inoculants

Increased microbial abundance and diversity

Improved soil functioning

Soil Organic Matter

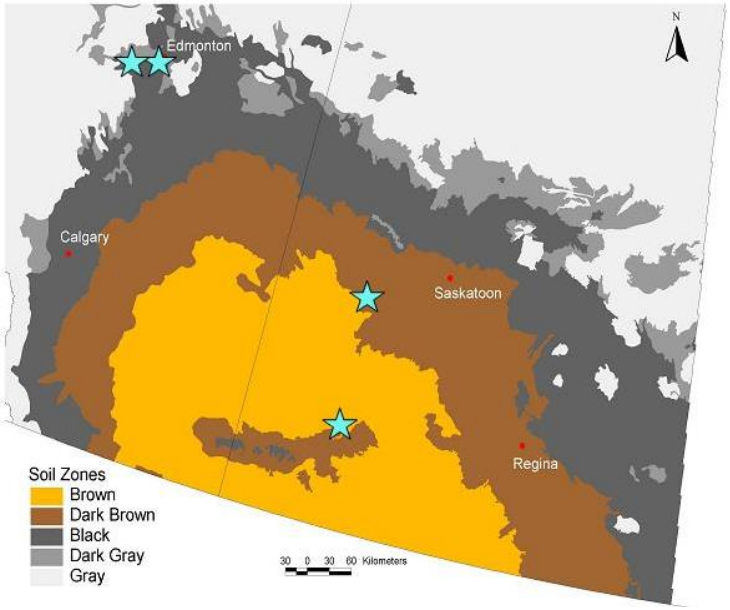
is vital for healthy soils!



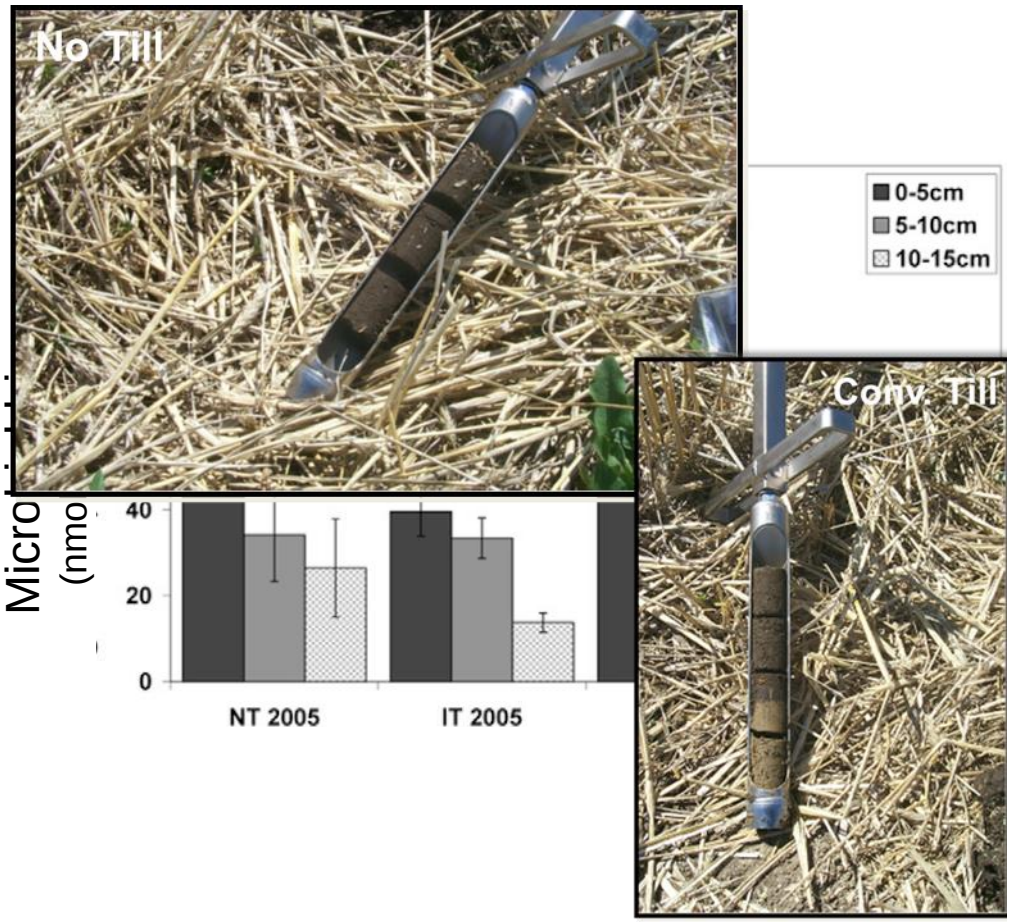
https://www.quartoknows.com/blog/quartohomes/2015/04/22/sustainable-gardens-and-organic-matter/

Reduced physical disturbance

Increased microbial biomass (0-5cm) 8 to 202%



NT vs CT
Long term sites (~25yr)
4 locations
2 years

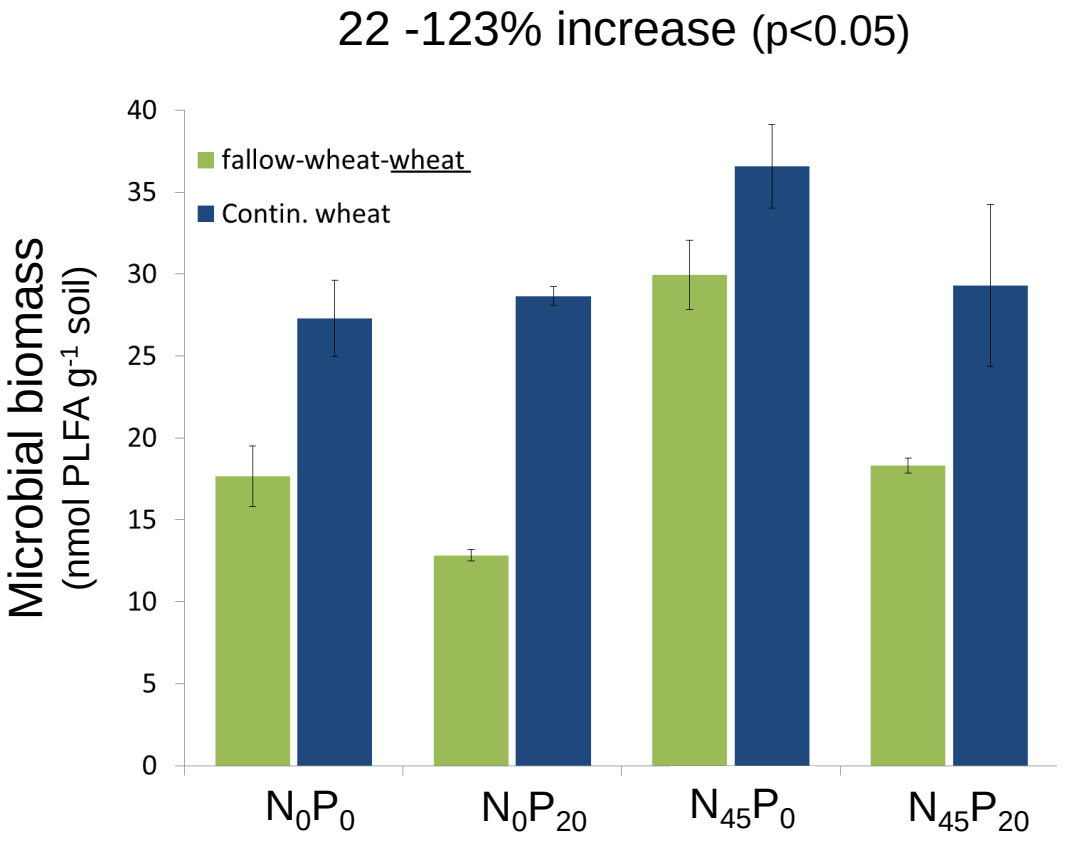


Helgason et al. 2009 SSSAJ

Continuous cropping

increases microbial biomass, even when nutrients are limiting

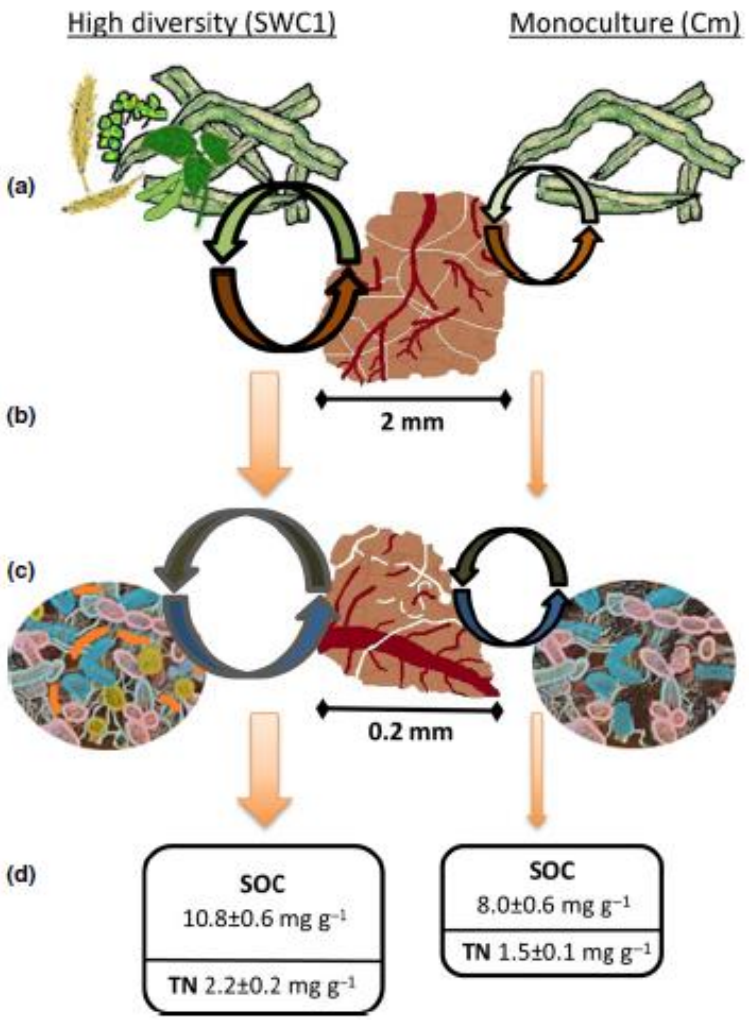
Rotation ABC est. 1910
Rot. A: continuous wheat
Rot. C: wheat-wheat-fallow

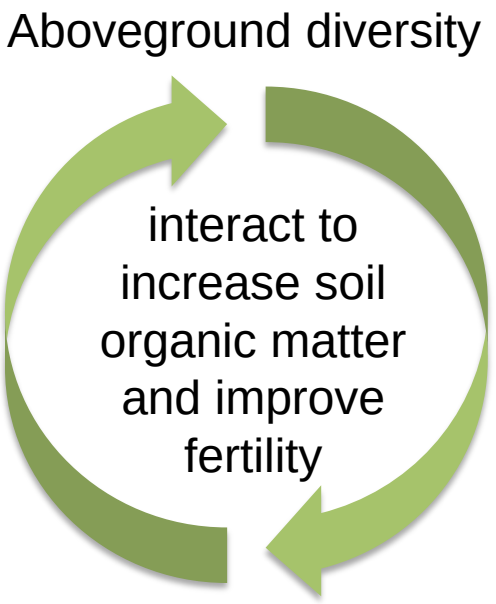


1967: 45 kg ha^{-1} N
1972: 20 kg ha^{-1} P

Increased crop rotation diversity

enhances microbial activity, aggregation, soil C and N

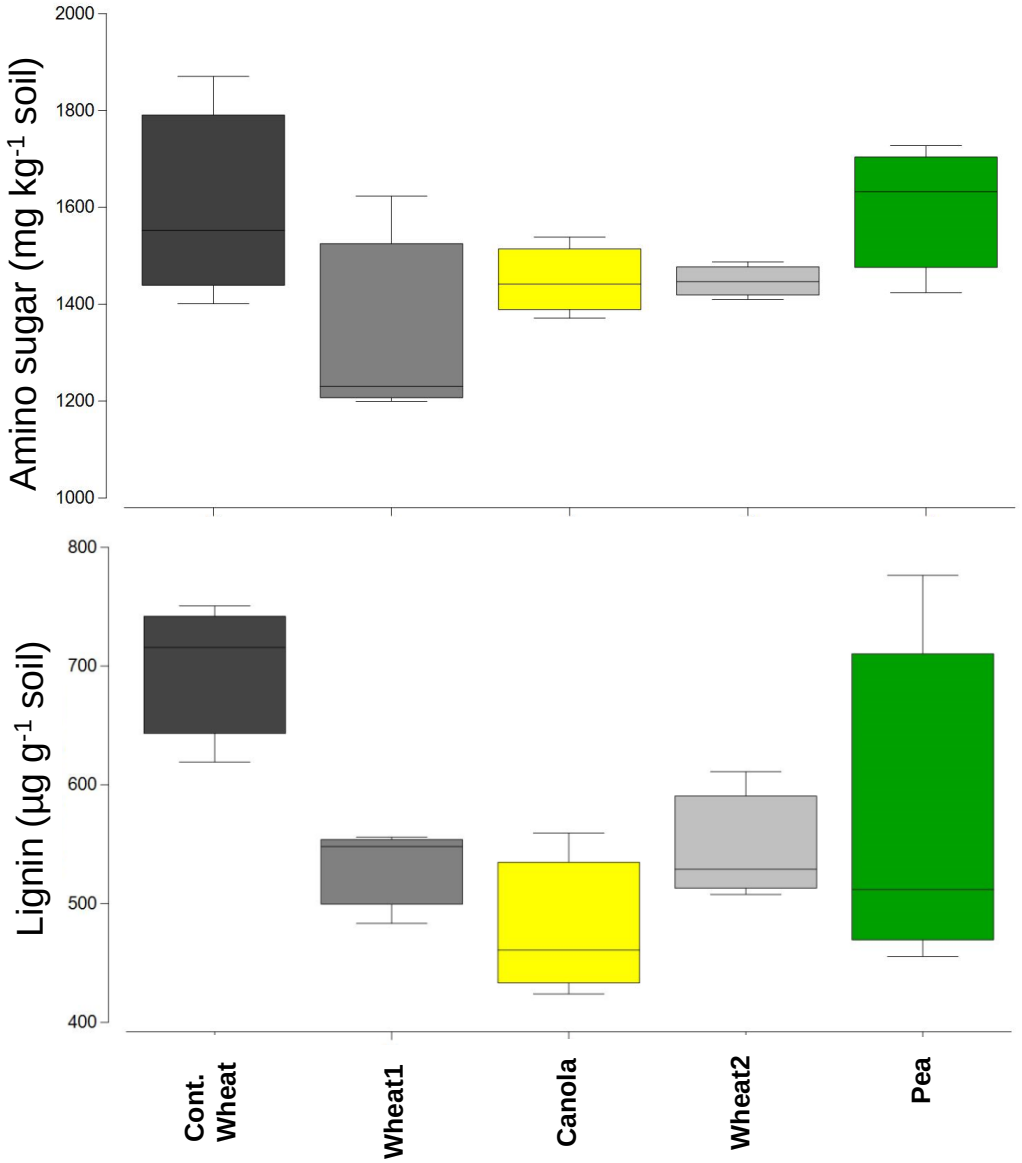


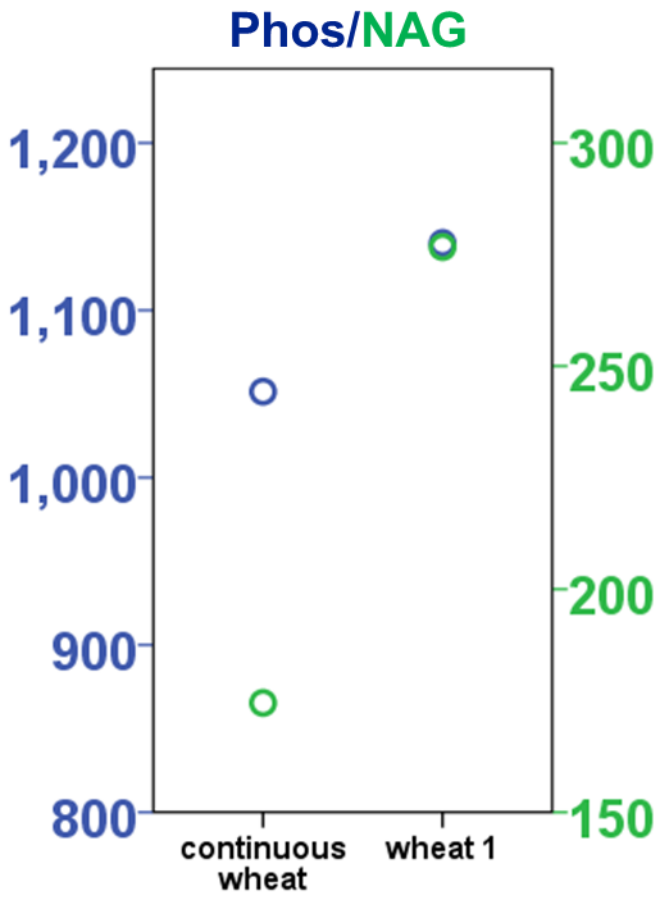


Tiemann et al. 2015 Ecology Letters

AAFC New Rotation Experiment (Swift Current)

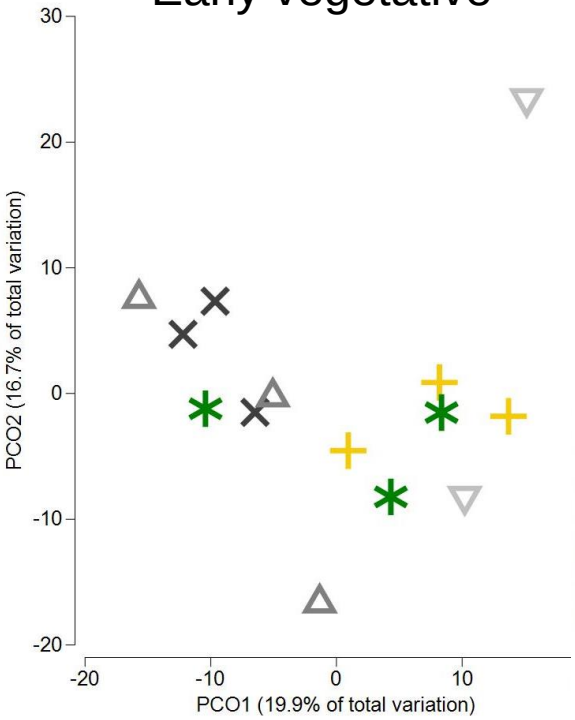
continuous wheat vs. wheat-canola-wheat-pea



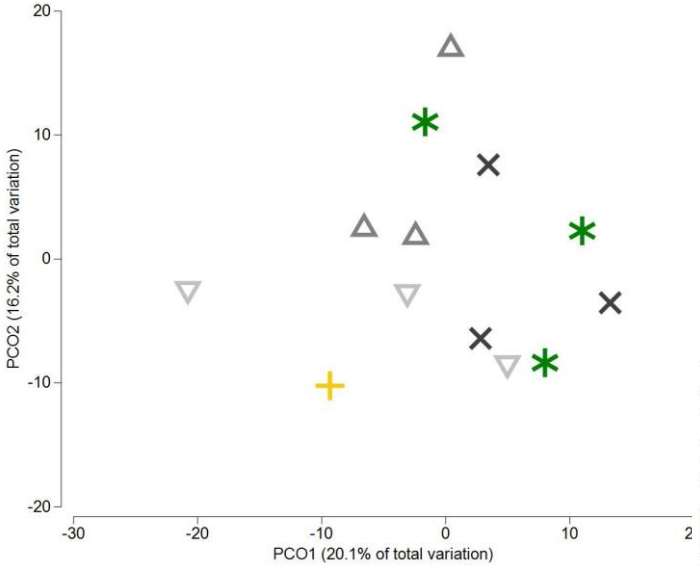


Soil microbiome – temporal changes

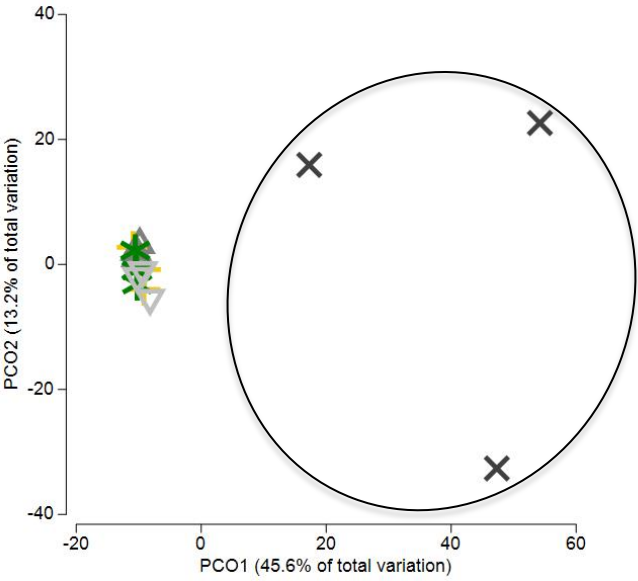
Early vegetative

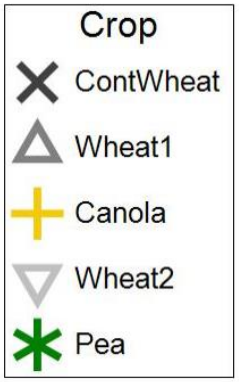


Anthesis



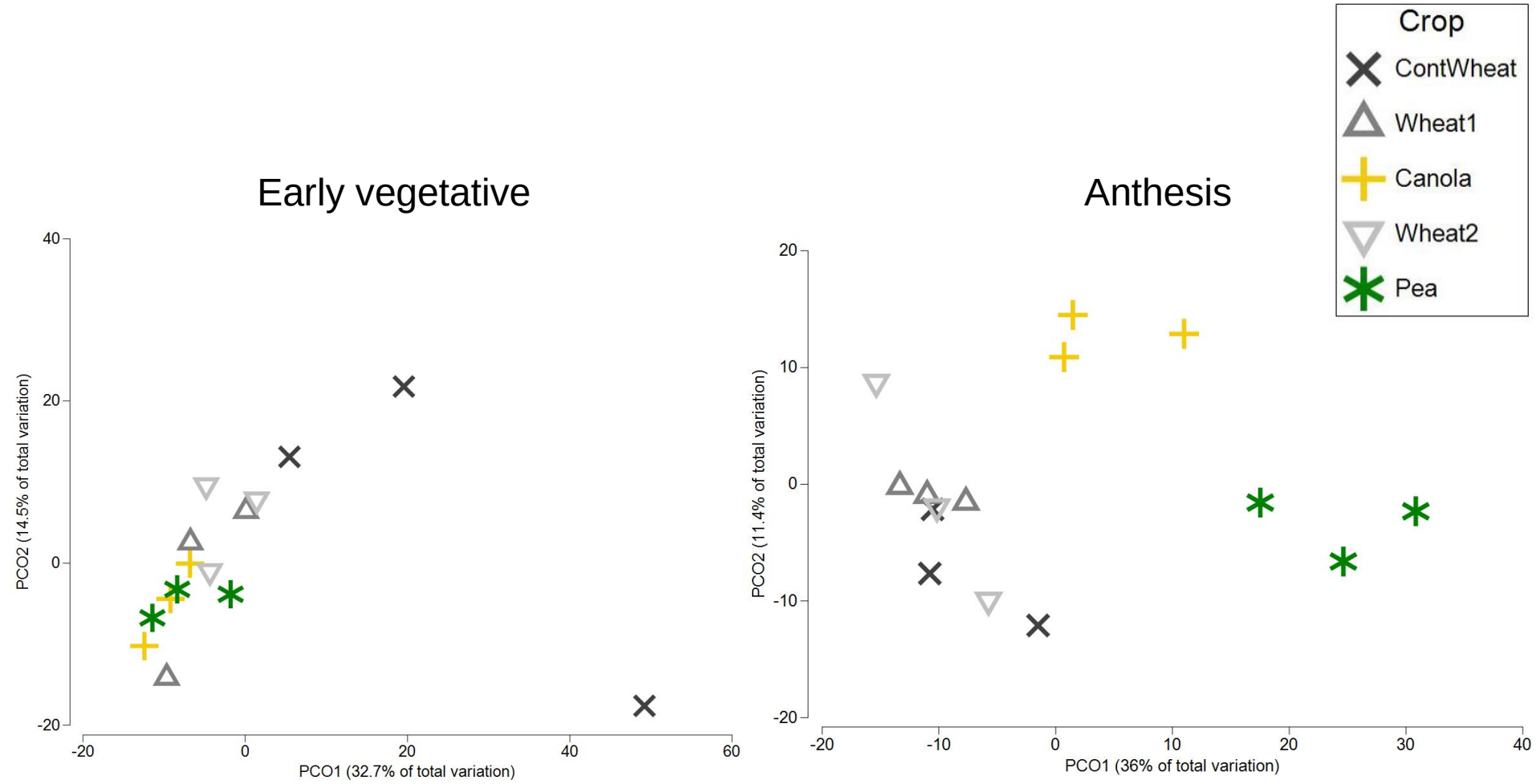
Post-Harvest





Rhizosphere microbiome

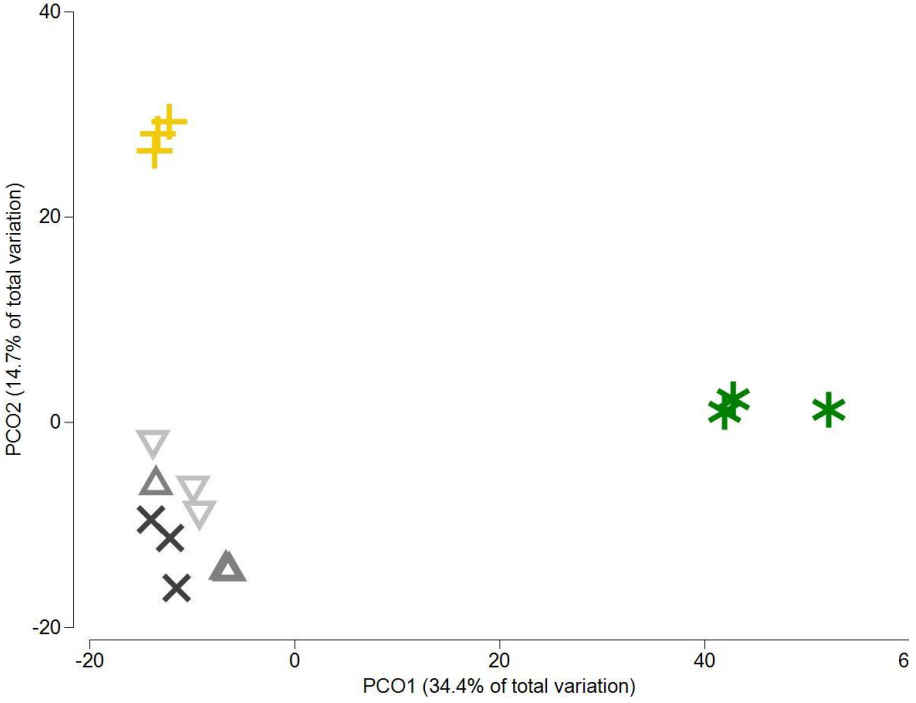
- Differences between crops were more pronounced at anthesis



Root microbiome (bacteria)

- Differences in root microbiome can be see ca. 4 wks after planting.
- Continuous wheat vs. rotation wheat are similar

Early vegetative



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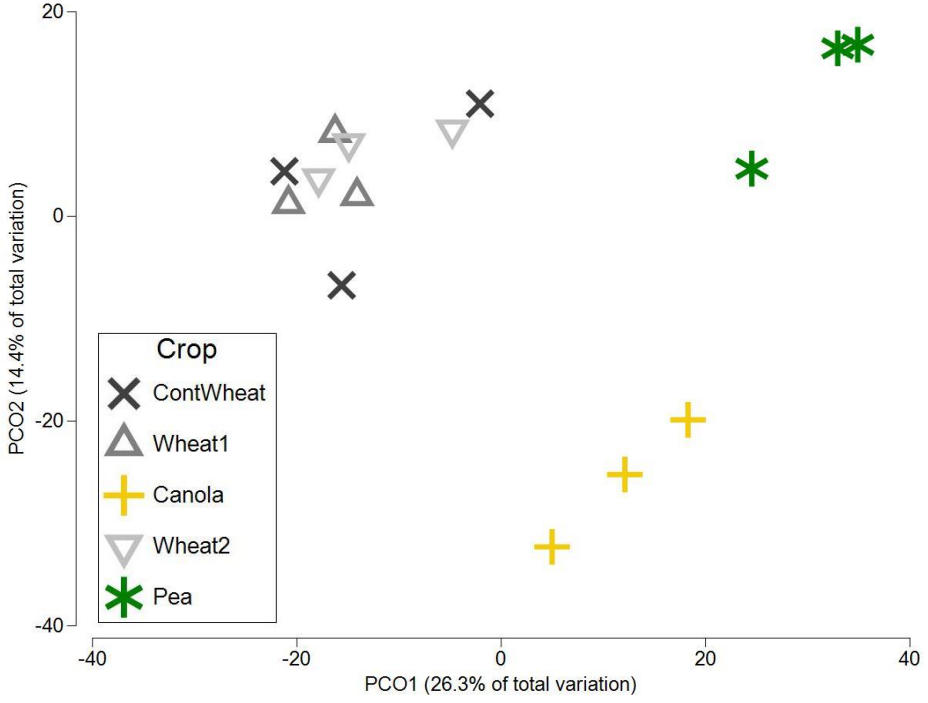
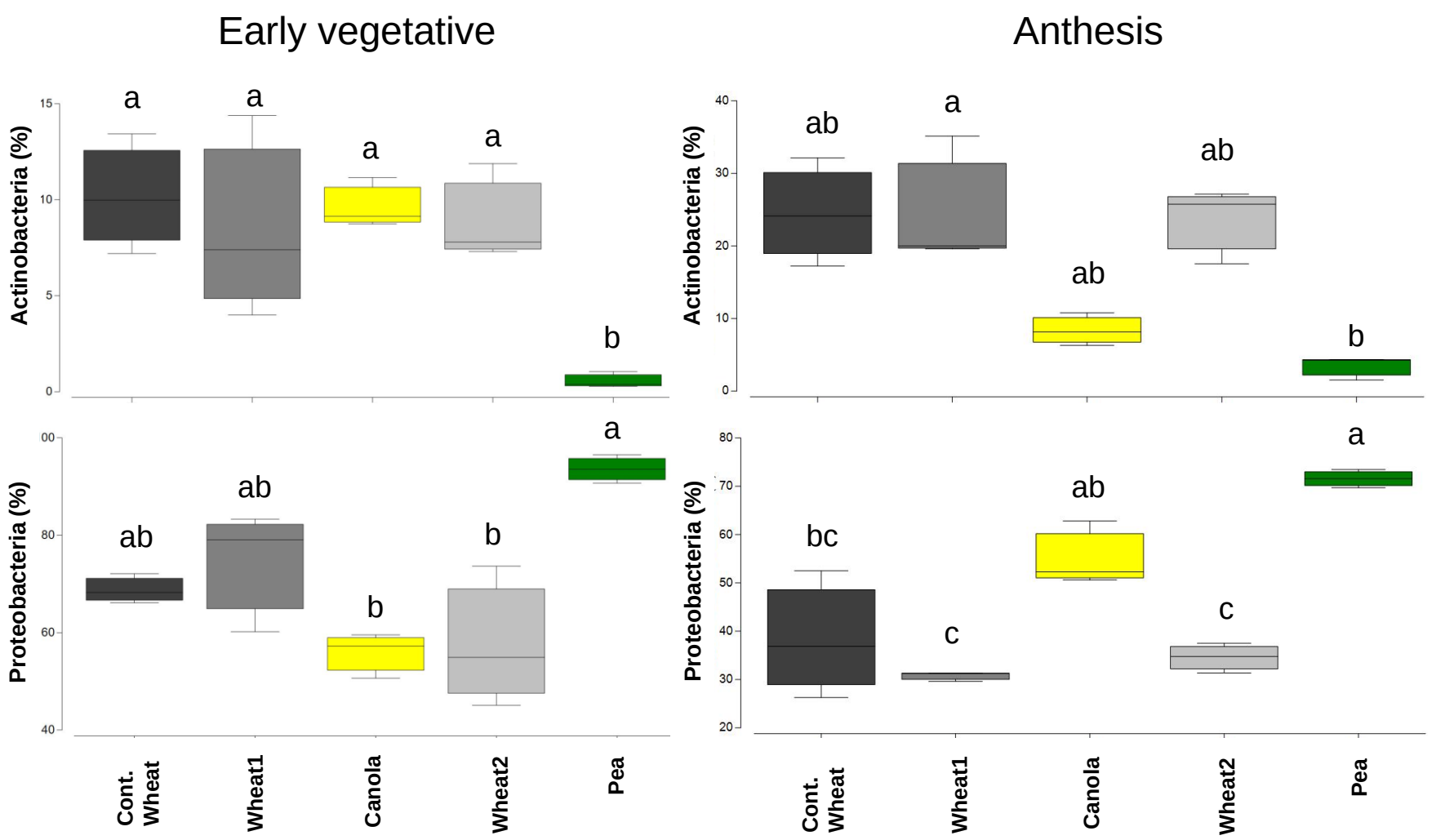
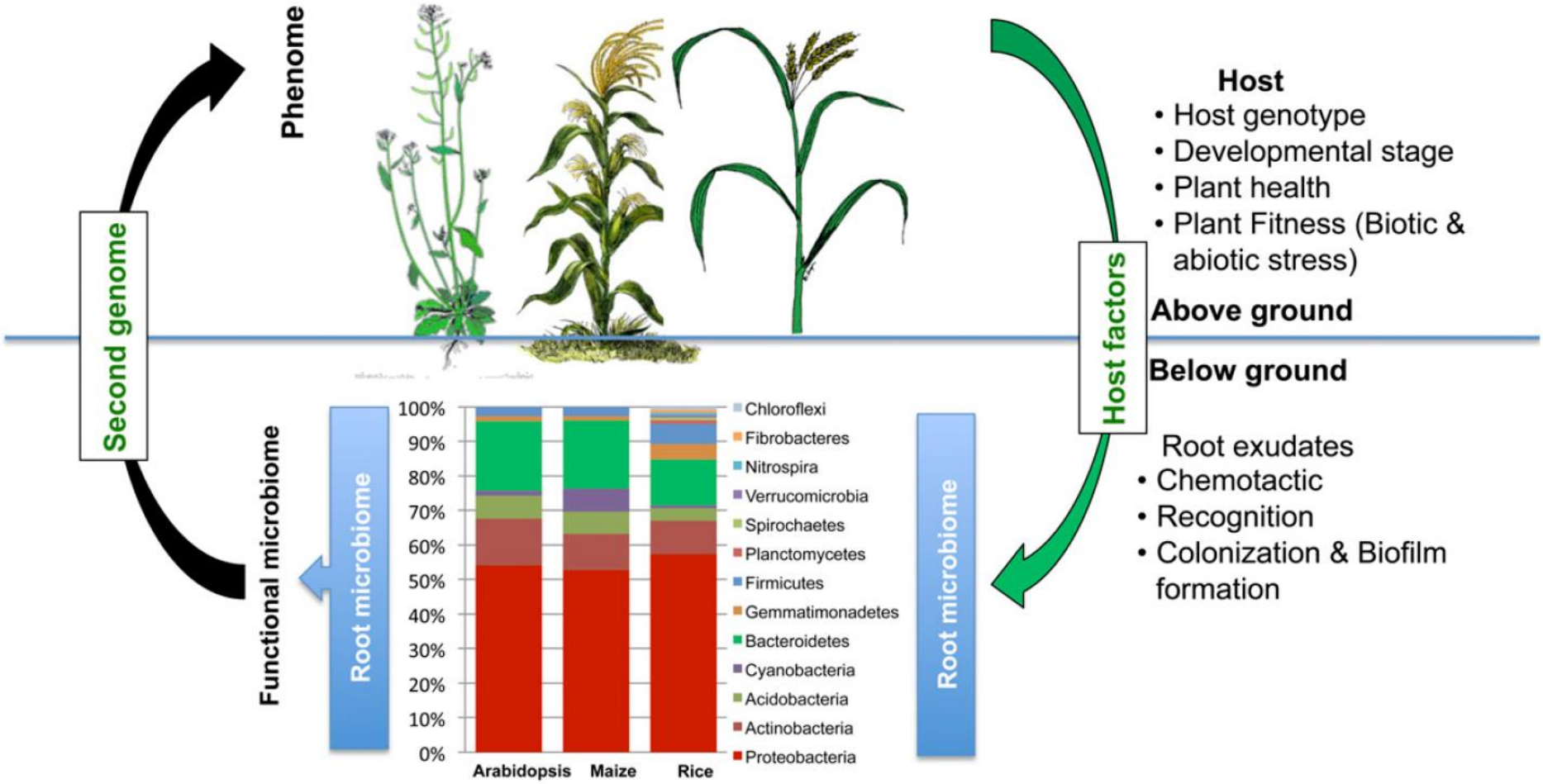


Root Microbiomes:

continuous wheat vs. wheat-canola-wheat-pea



Root-microbe-soil interactions



Lakshmanan et al. 2014. Functional soil microbiome: belowground solutions to an aboveground problem. Plant Physiol 166:689-700.

Plant-microbial interactions

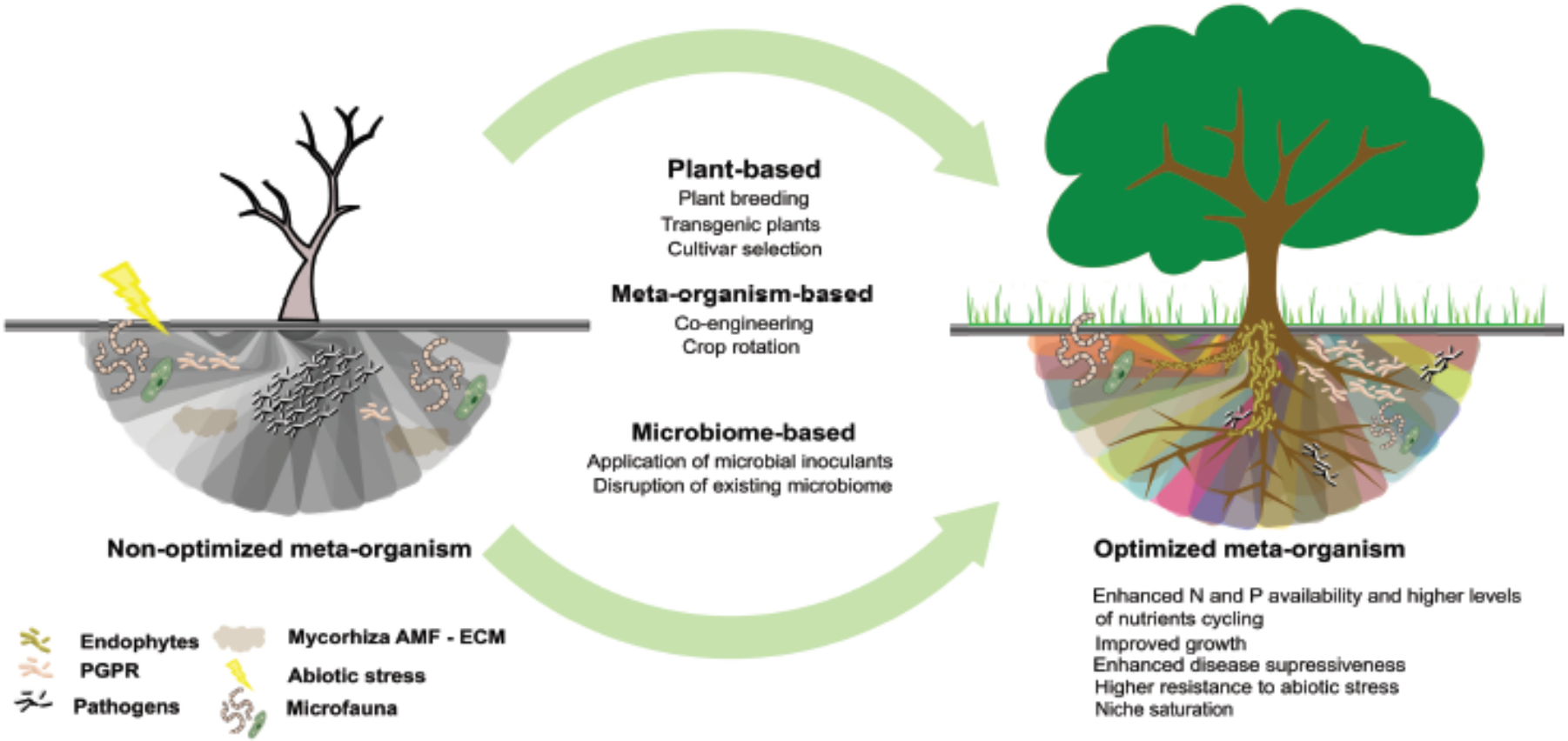


FIGURE 2 | Different approaches to rhizosphere microbiome engineering used to bring the microbiome from a low diversity and vulnerable state, with limited functions and productivity to a diverse and resilient state with high functional redundancy and consistent functioning across variable environments and increased resistance to pathogen invasion.

Quiza et al. 2015. Harnessing phytomicrobiome signalling for rhizosphere microbiome engineering. Front Plant Sci

Plant Pedological Phenotyping

S. Siciliano, B. Helgason
M. Arcand, J. Germida, E. Lamb, M. Links

Research Associate: S. Mamut (C. Norris)

Research Technicians: A. Schebel, M. Donkuru

PhD students: J. Bell, S. Williams-Johnson, Z. Morales, Z. Taye
MSc students: F. Lalany, T. Dowhy

Summer research assistants

Plant Pedological Phenotyping

Understanding the plant microbiome

How are plant microbiomes assembled?

- assess different genotypes (**canola**, wheat, lentil)

What are major microbiome disruptors?

- repeat across time and in different environments (GxE)

Beyond the soil: leaf and seed microbiomes

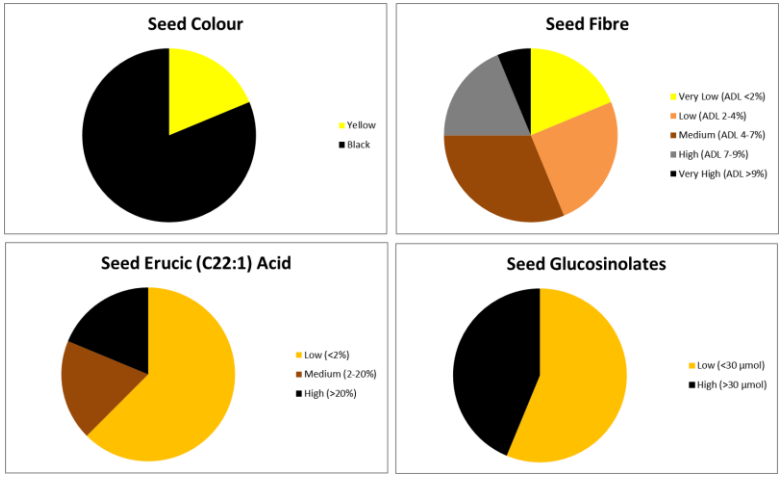
Bioinformatics – emerging approaches and tools for microbial ecologists; collaboration with computer scientists

Plant Pedological Phenotyping

B. napus L. nested association mapping (NAM) population

16 lines (n=3)

- glucosinolate content
- black vs. yellow seeded



S. Vail, et al. AAFC Saskatoon

Sampled for 10 weeks

(June 14 – August 16, 2016)

(June 20 – August 22, 2017)

Plant Pedological Phenotyping

								North					
						Plan		54m					
		8	6	2	6	6	6	2	6	6	6	2	6
		8m swath	6m plot	2m	6m plot	6m swath	6m plot	2m	6m plot	6m swath	6m plot	2m	6m plot
				rep1				rep2				rep3	
		2m	Guard		Guard		Guard		Guard		Guard		Guard
			1101		1129		1201		1229		1301		1329
			1101		1129		1202		1229		1302		1330
			1102		1130		1203		1230		1302		1330
			1102		1130		1203		1230		1303		1331
			1103		1131		1204		1231		1303		1332
West			1104		1132		1205		1232		1304		1333
			1105		1133		1206		1233		1305		1333
			1106		1134		1207		1234		1306		1334
			1107		1135		1207		1235		1307		1335
56 + 16			1108		1136		1208		1236		1308		1336
Total 72			1108		1136		1208		1236		1308		1337
Canola exp			1109		1137		1209		1237		1309		1337
			1109		1137		1210		1237		1309		1338
		West	1110		1138		1211		1238		1310		1339
Stake Colours			1111		1139		1211		1239		1311		1340
Phenotyping Plots			1112		1140		1212		1240		1312		1340
AAFC Sampling Plots			1113		1141		1213		1241		1313		1341
			1114		1142		1214		1242		1314		1342
1000 = Canola			Guard		Guard		Guard		Guard		Guard		Guard
#00 = rep #			1115		1143		1215		1243		1315		1343
xx = variety			1115		1143		1215		1244		1316		1343
			1116		1144		1216		1244		1316		1344
			1116		1144		1217		1245		1317		1345
			1117		1145		1218		1245		1318		1346
			1118		1146		1218		1246		1319		1346
			1119		1147		1219		1247		1319		1347
			1120		1148		1220		1248		1320		1348
			1121		1149		1221		1249		1321		1349
			1122		1150		1222		1250		1322		1350
			1122		1150		1223		1251		1322		1351
			1123		1151		1224		1252		1323		1352
			1123		1151		1225		1252		1324		1353
			1124		1152		1225		1253		1325		1354
			1125		1153		1226		1254		1326		1355
			1126		1154		1227		1255		1327		1355
			1127		1155		1228		1255		1327		1356
			1128		1156		1228		1256		1328		1356
			Guard		Guard		Guard		Guard		Guard		Guard

Transdisciplinary collaboration

Paired plots:

a) Destructive sampling ✓

b) Phenotyping

Plant Pedological Phenotyping

Amplicon based surveys (16S rRNA and ITS genes)

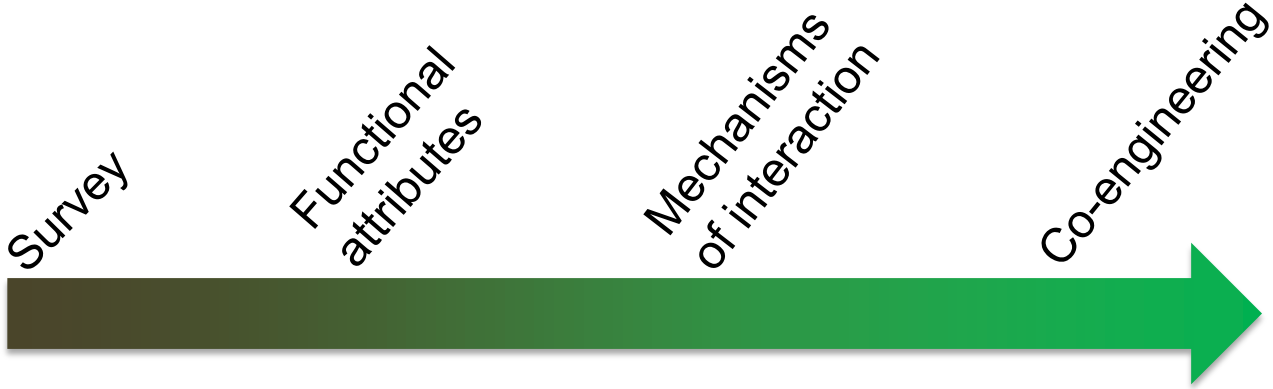
- Who's there and how do communities differ between lines and over time?

Metagenomic analysis

- Putative functional potential

Root exudation characterization

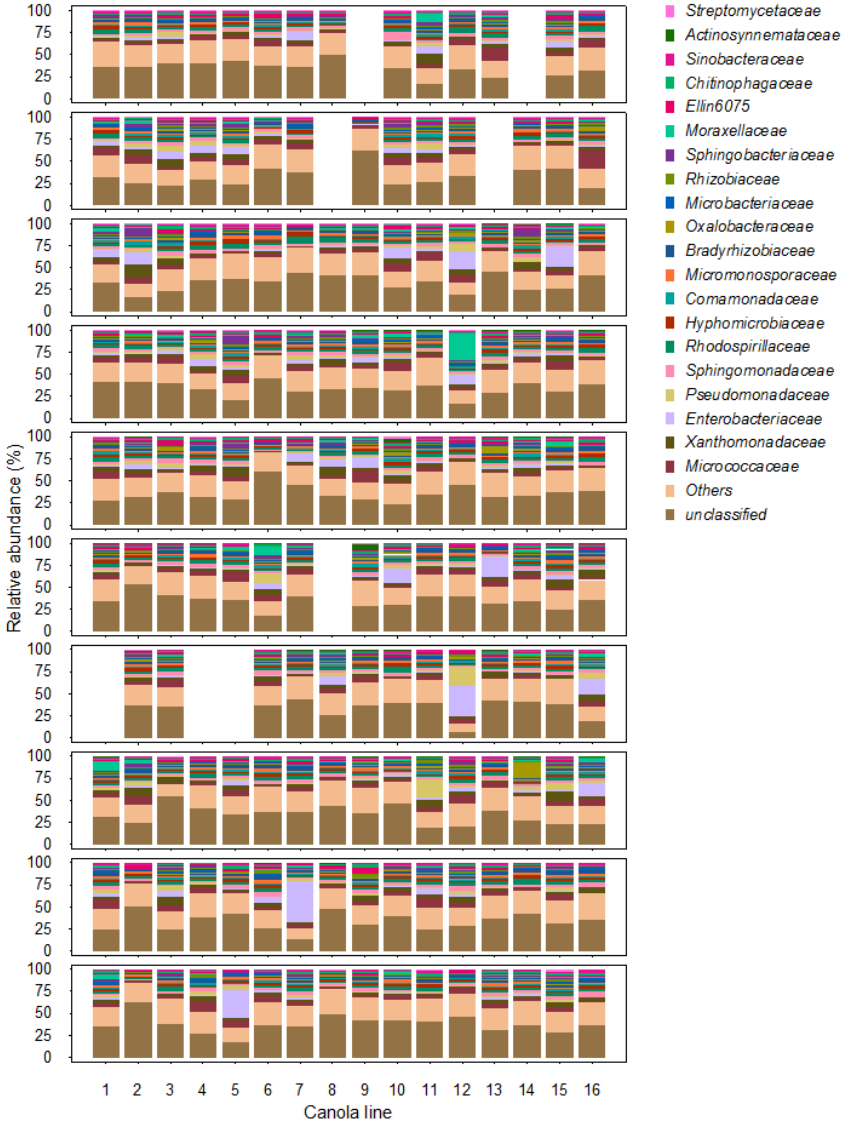
- Are there plant mechanistic controls?



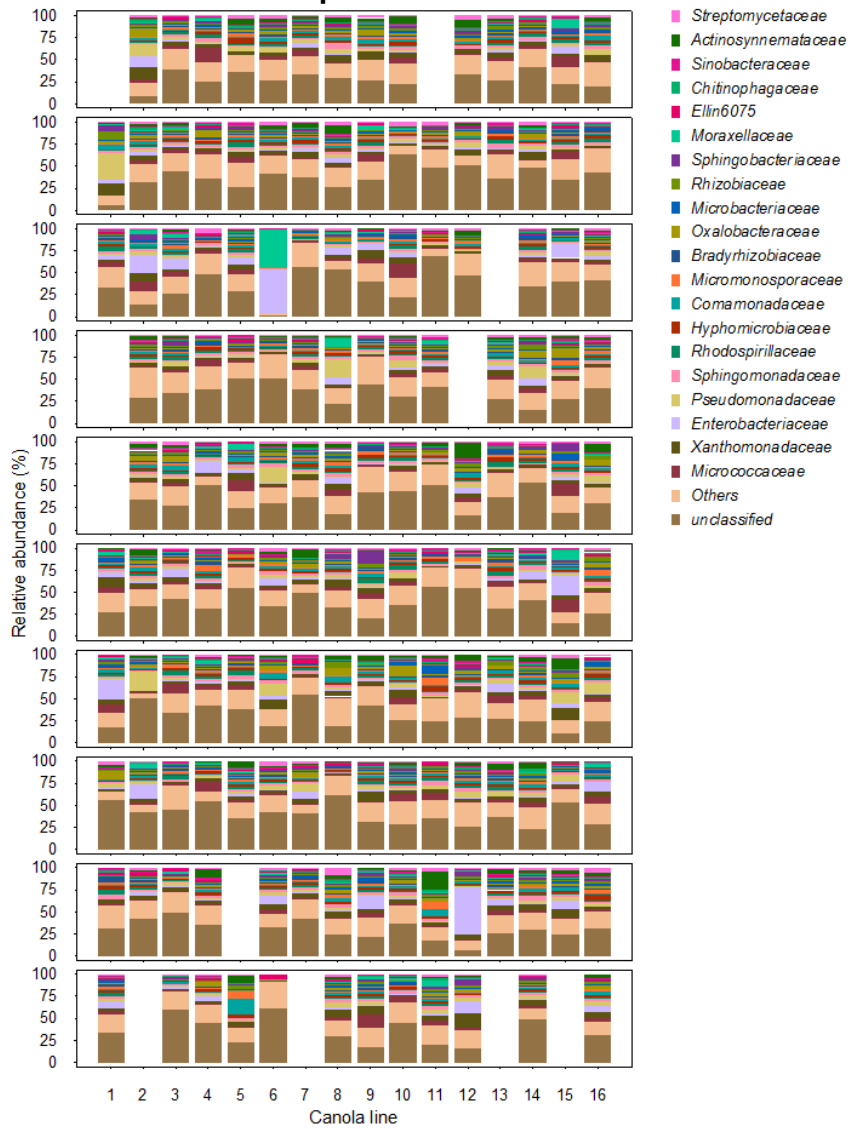
Quiza et al. 2015 Front Plant Sci

Canola genotype microbiomes

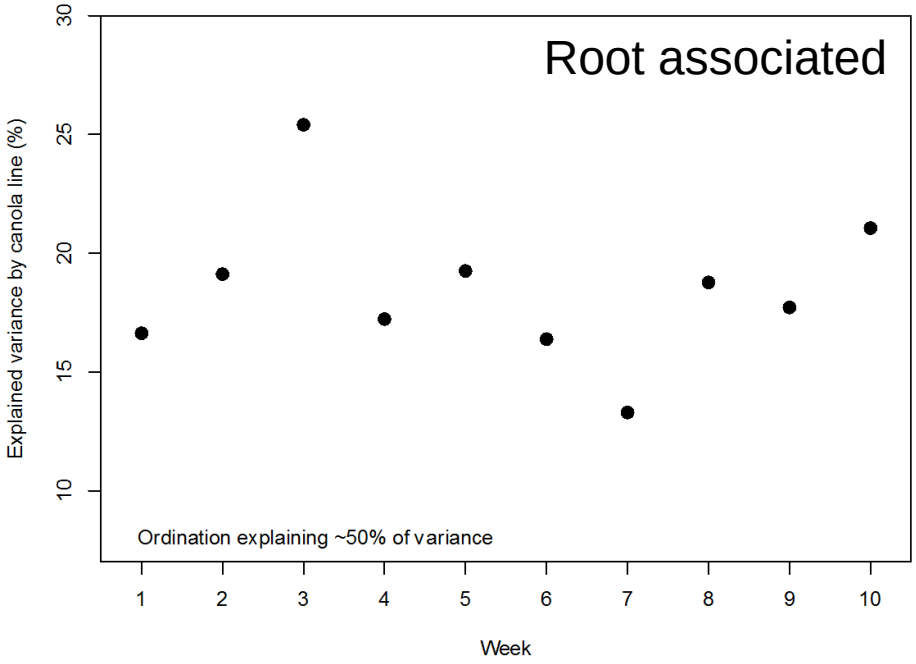
Root

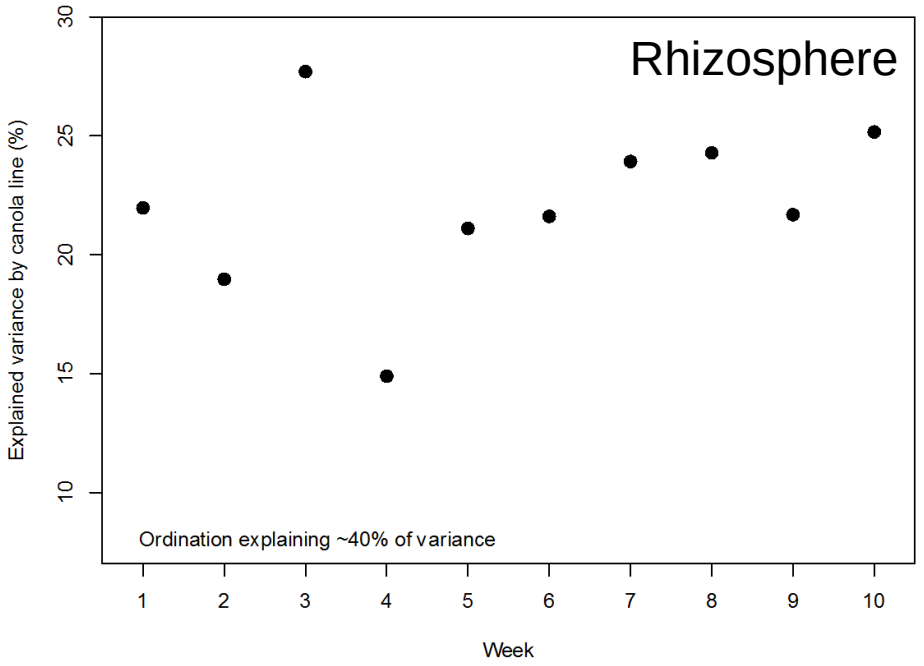


Rhizosphere soil

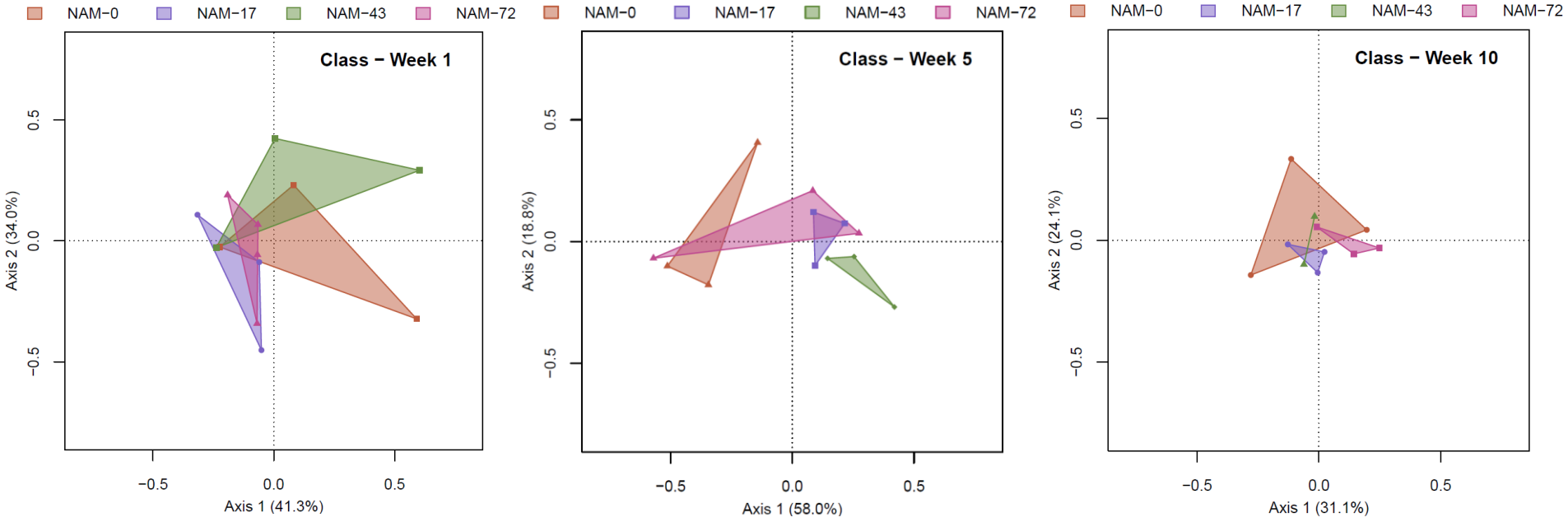


Temporal changes in bacterial microbiomes

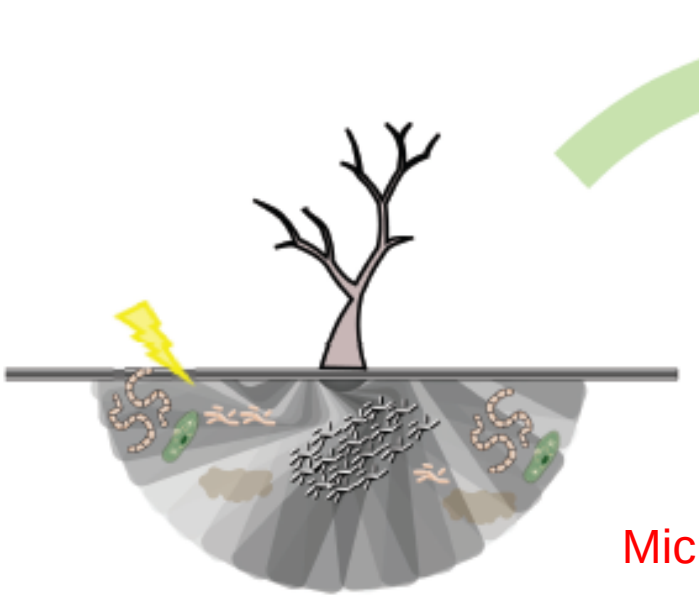




Temporal changes in bacterial microbiomes



Plant-microbial interactions



Non-optimized meta-organism

Plant-based
Plant breeding
Transgenic plants
Cultivar selection

Meta-organism-based
Co-engineering
Crop rotation

Microbiome-based
Microbiome disruption

Optimized meta-organism

Enhanced N and P availability and higher levels of nutrients cycling
Improved growth
Enhanced disease supressiveness
Higher resistance to abiotic stress
Niche saturation

Endophytes
PGPR
Pathogens
Mycorhiza AMF - ECM
Abiotic stress
Microfauna

FIGURE 2 | Different approaches to rhizosphere microbiome engineering used to bring the microbiome from a low diversity and vulnerable state, with limited functions and productivity to a diverse and resilient state with high functional redundancy and consistent functioning across variable environments and increased resistance to pathogen invasion.

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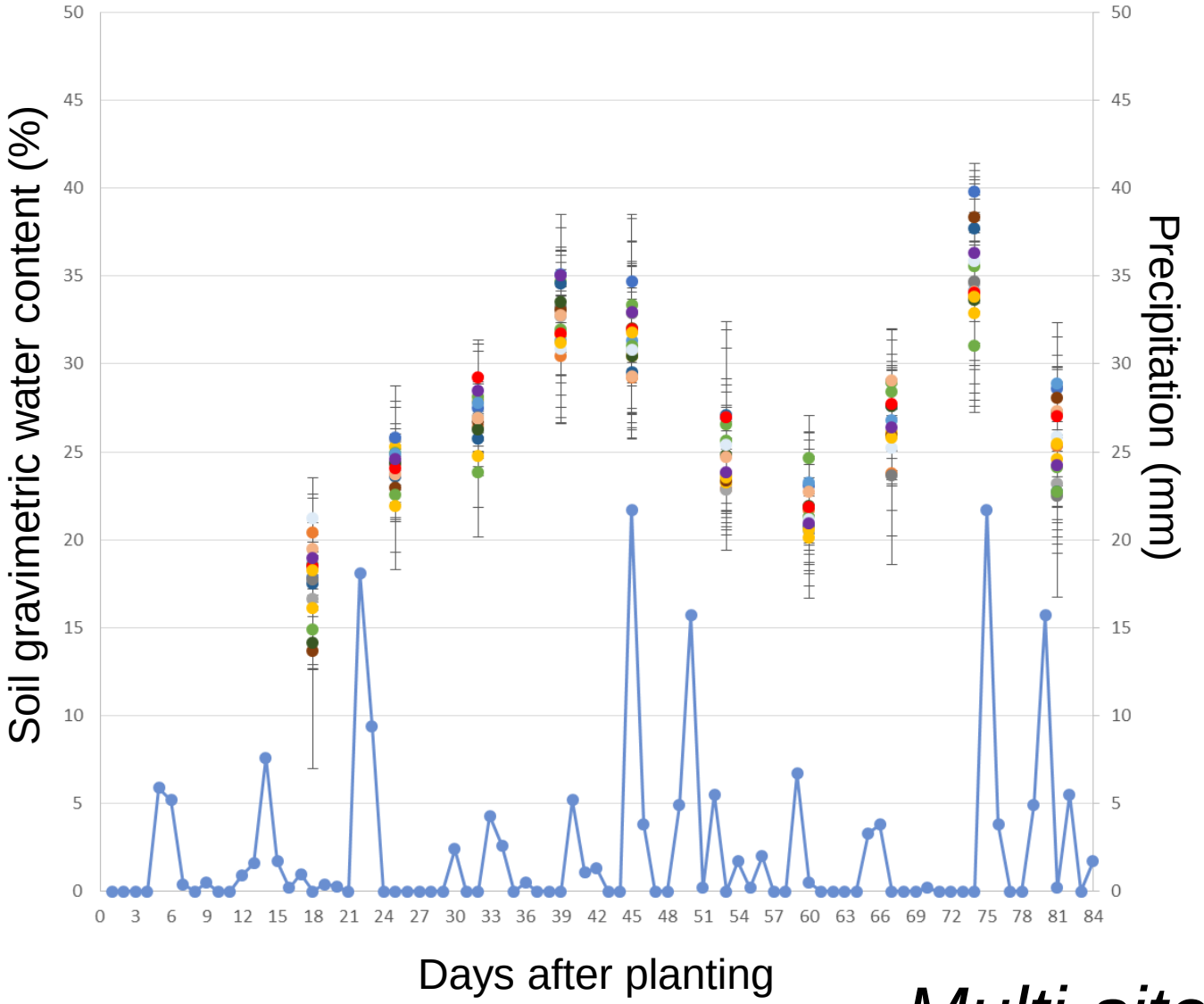
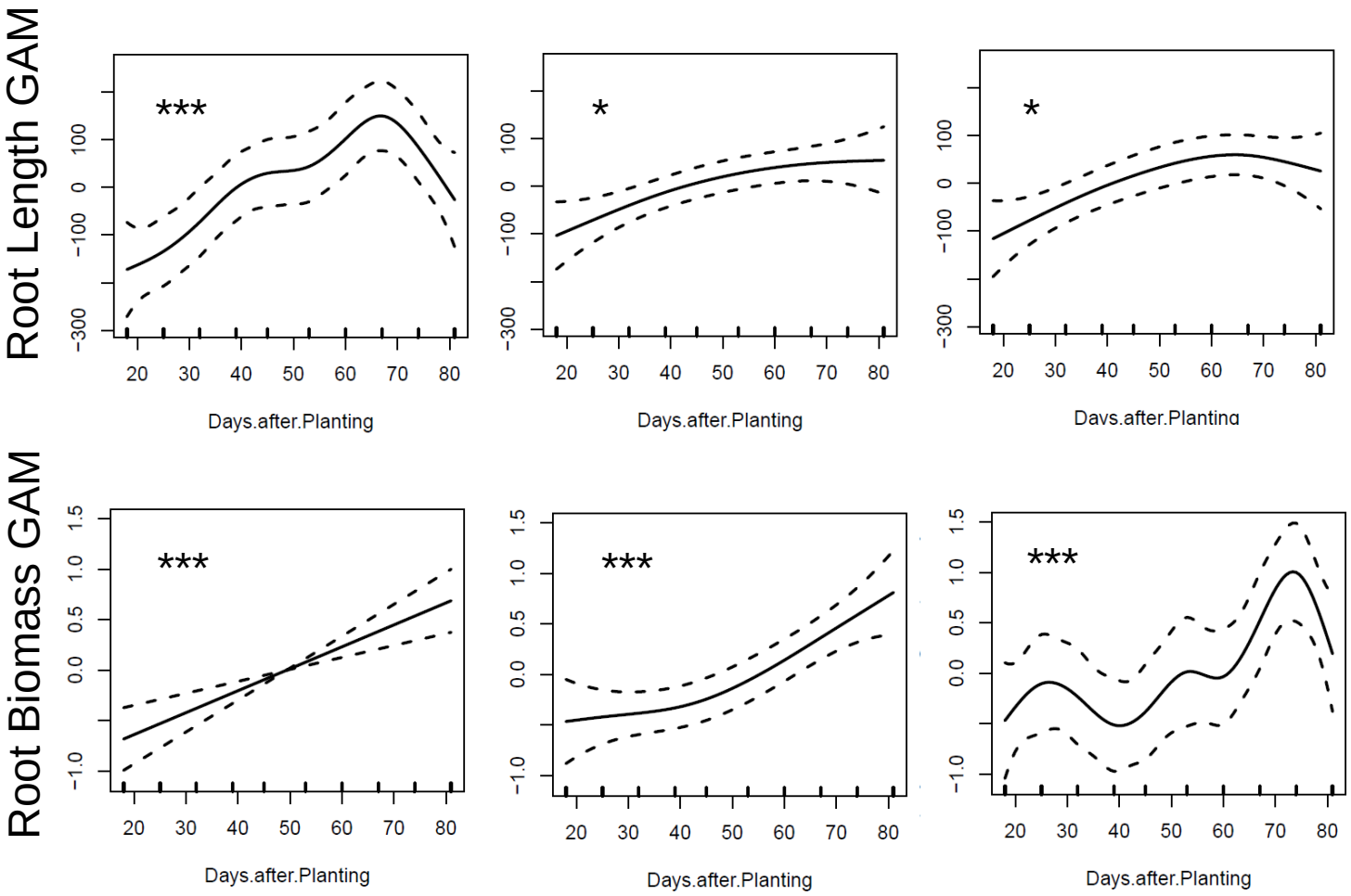
Microbiome disruptors: environmental conditions



Multi-site comparisons

Microbiome disruptors: root phenotype



advanced imaging

Thank you!

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In cooperation with Tourism Saskatoon and the Global Institute for Food Security, the University of Saskatchewan is excited to announce that Saskatoon has been selected to host Rhizosphere 5. This international conference takes place every 4 years to highlight the latest advances in our understanding of the below ground world of plant roots and their interactions with the environment.

Rhizosphere 5

"Shining light on the world beneath our feet"

Saskatoon, Saskatchewan, Canada

7 - 11 July 2019

www.rhizo5.org

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