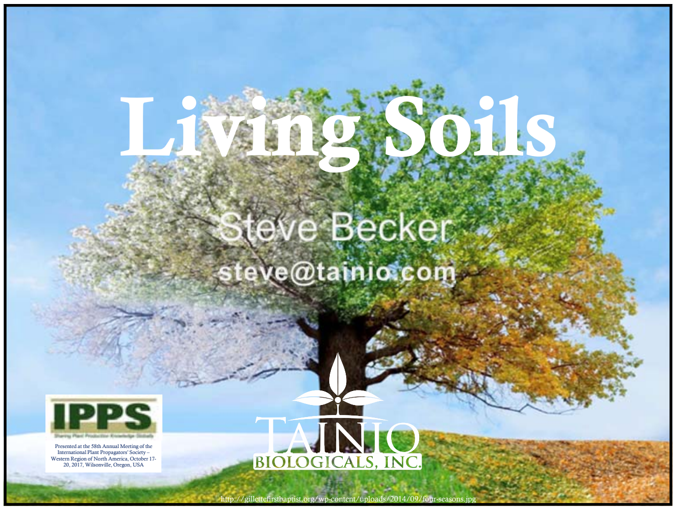
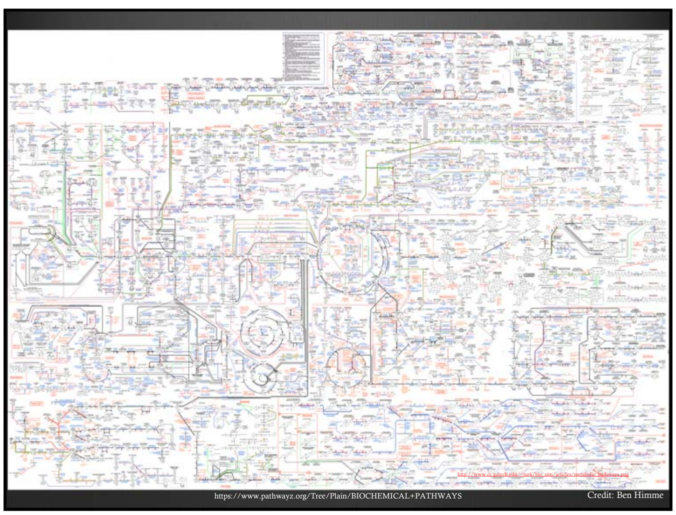
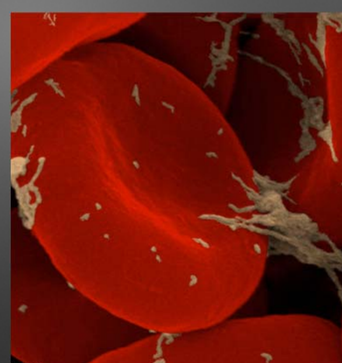




Life is AMAZING!

- Inside of YOU!
- ~2.4 million new RBC/second!
  - 250 million hemoglobin each
    - 600,000,000,000,000 hemoglobin produced-Trill
      - 344,400,000,000,000,000 amino acids-Quad
      - 1,033,200,000,000,000,000 bases read-Quint
- Life is AMAZING!



http://www.boredpanda.com/looking-at-the-world-through-a-microscope-part-i/

Surfaces Scratched:

- Living Soils
- Small Friends
- Exudate Energy
- PGPR Functions
- Examples

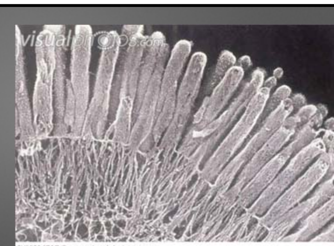
http://www.homeopathy-healing.com/wp-content/uploads/2017/05/Iceberg.png

Pretend your soil is a person…

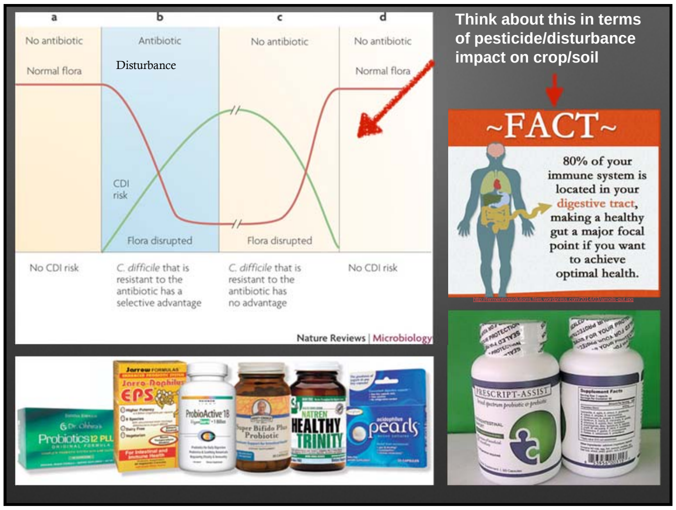
Pretty easy for me…

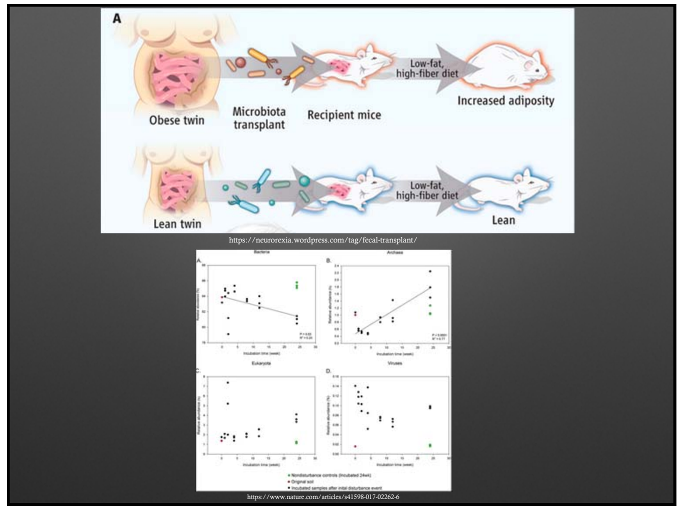
Plant Gut?

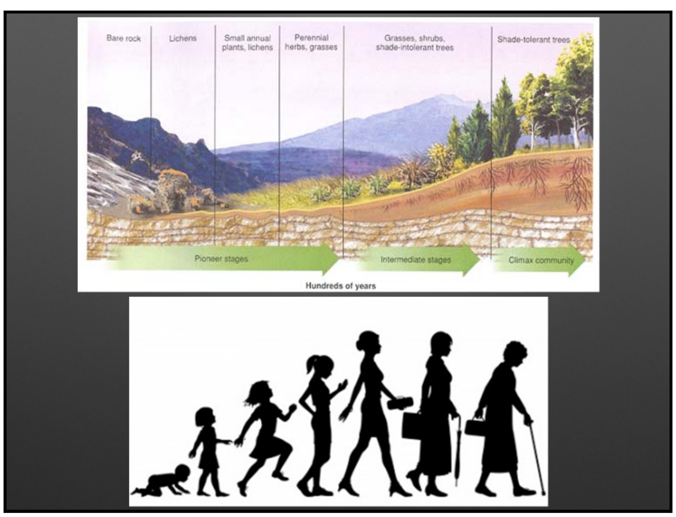
- Berendsen et al. (2012) highlights similarities in importance of microbes between human and plant
  - "[The] complex plant-associated microbial community, also referred to as the second genome of the plant is crucial for plant health."
  - "In humans, the effects of intestinal microbial communities on health are becoming increasingly apparent. Similar functions can be ascribed to microbial communities in the human gut and plant rhizosphere."

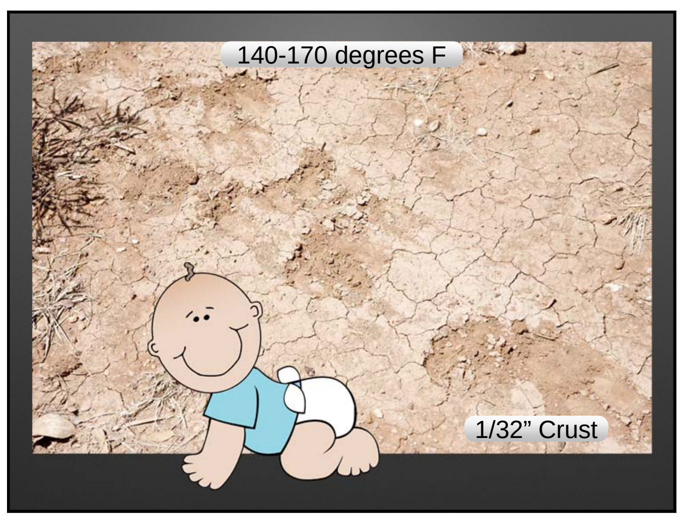


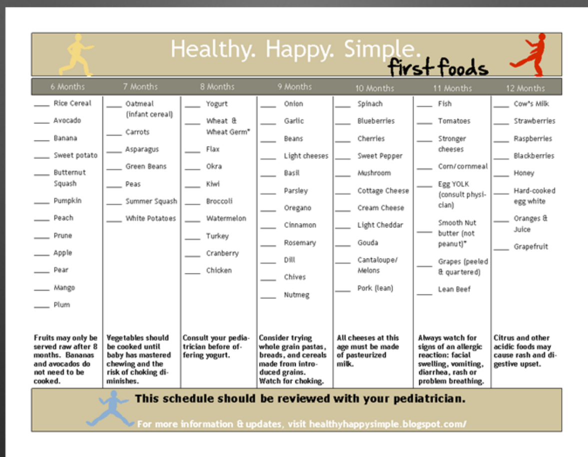
Berendsen et al., 2012. R.L. Berendsen, C.M. Pieterse, P.A. Bakker. The rhizosphere microbiome and plant health. Trends Plant Sci., 17 (2012), pp. 478–486


a
b
c
d
No antibiotic
Antibiotic
No antibiotic
No antibiotic
Normal flora
Disturbance
Normal flora
CDI risk
Flora disrupted
Flora disrupted
No CDI risk
C. difficile that is resistant to the antibiotic has a selective advantage
C. difficile that is resistant to the antibiotic has no advantage
No CDI risk
Nature Reviews | Microbiology
Think about this in terms of pesticide/disturbance impact on crop/soil
~FACT~
80% of your immune system is located in your digestive tract, making a healthy gut a major focal point if you want to achieve optimal health.
Probiotics 12 PLUS
EPS
ProbioActive 18
Super Bifido Plus Probiotic
HEALTHY TRINITY
pearls
PRESCRIPT-ASSIST


A
Obese twin
Microbiota transplant
Recipient mice
Low-fat, high-fiber diet
Increased adiposity
Lean twin
Low-fat, high-fiber diet
Lean
https://neurorexia.wordpress.com/tag/fecal-transplant/
https://www.nature.com/articles/s41598-017-02262-6


Bare rock
Lichens
Small annual plants, lichens
Perennial herbs, grasses
Grasses, shrubs, shade-intolerant trees
Shade-tolerant trees
Pioneer stages
Intermediate stages
Climax community
Hundreds of years


140-170 degrees F
1/32" Crust



Healthy. Happy. Simple. first foods

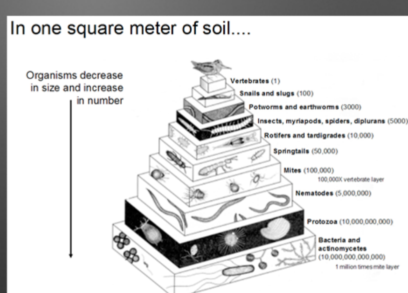
6 Months	7 Months	8 Months	9 Months	10 Months	11 Months	12 Months
___ Rice Cereal	___ Oatmeal (infant cereal)	___ Yogurt	___ Onion	___ Spinach	___ Fish	___ Cow's Milk
___ Avocado	___ Carrots	___ Wheat & Wheat Germ*	___ Garlic	___ Blueberries	___ Tomatoes	___ Strawberries
___ Banana	___ Asparagus	___ Flax	___ Beans	___ Cherries	___ Stronger cheeses	___ Raspberries
___ Sweet potato	___ Green Beans	___ Okra	___ Light cheeses	___ Sweet Pepper	___ Corn/cornmeal	___ Blackberries
___ Butternut Squash	___ Peas	___ Kiwi	___ Basil	___ Mushroom	___ Egg YOLK (consult physician)	___ Honey
___ Pumpkin	___ Summer Squash	___ Broccoli	___ Parsley	___ Cottage Cheese	___ Smooth Nut butter (not peanut)*	___ Hard-cooked egg white
___ Peach	___ White Potatoes	___ Watermelon	___ Oregano	___ Cream Cheese	___ Grapes (peeled & quartered)	___ Oranges & Juice
___ Prune		___ Turkey	___ Cinnamon	___ Light Cheddar	___ Lean Beef	___ Grapefruit
___ Apple		___ Cranberry	___ Rosemary	___ Gouda		
___ Pear		___ Chicken	___ Dill	___ Cantaloupe/ Melons		
___ Mango			___ Chives	___ Pork (lean)		
___ Plum			___ Nutmeg			
Fruits may only be served raw after 8 months. Bananas and avocados do not need to be cooked.	**Vegetables should be cooked until baby has mastered chewing and the risk of choking diminishes.**	**Consult your pediatrician before offering yogurt.**	**Consider trying whole grain pastas, breads, and cereals made from introduced grains. Watch for choking.**	**All cheeses at this age must be made of pasteurized milk.**	**Always watch for signs of an allergic reaction: facial swelling, vomiting, diarrhea, rash or problem breathing.**	**Citrus and other acidic foods may cause rash and digestive upset.**

This schedule should be reviewed with your pediatrician.

For more information & updates, visit healthyhappysimple.blogspot.com/

Who are we feeding?

Organism	Pounds of liveweight/acre
• Bacteria	1000
• Actinomycetes	1000
• Molds	2000
• Algae	100
• Protozoa	200
• Nematodes	50
• Insects	100
• Worms	1000
• Roots	2000



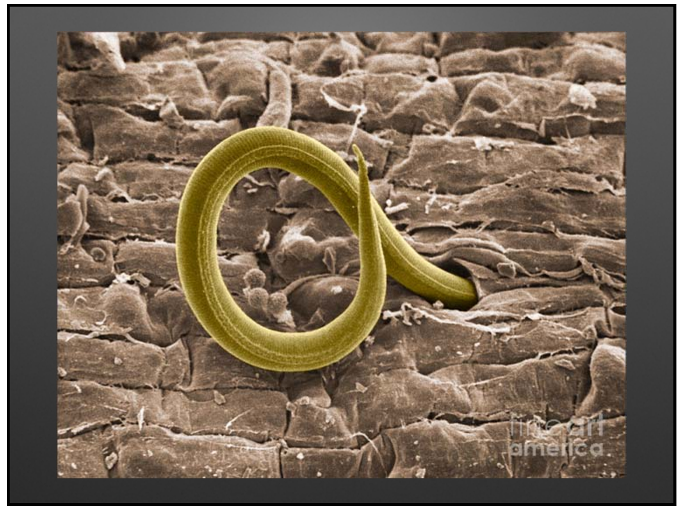
Bollen, Walter B. 1959. Microorganisms and Soil Fertility. Oregon State College. Oregon State Monographs, Studies in Bacteriology, Number 1. 22 p.

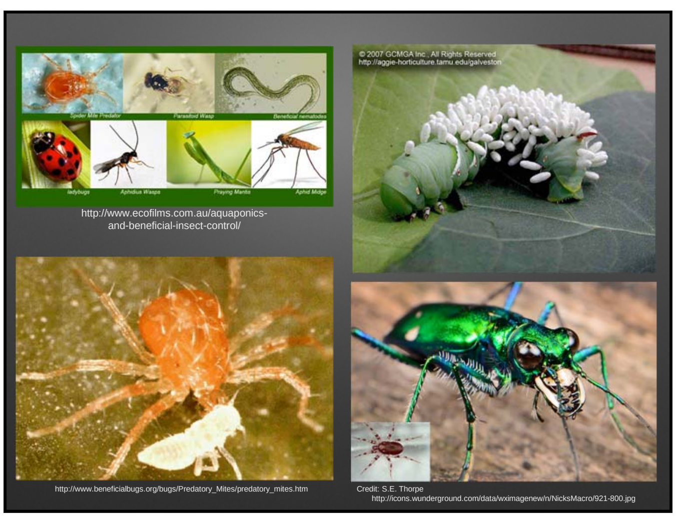
Who Knew?

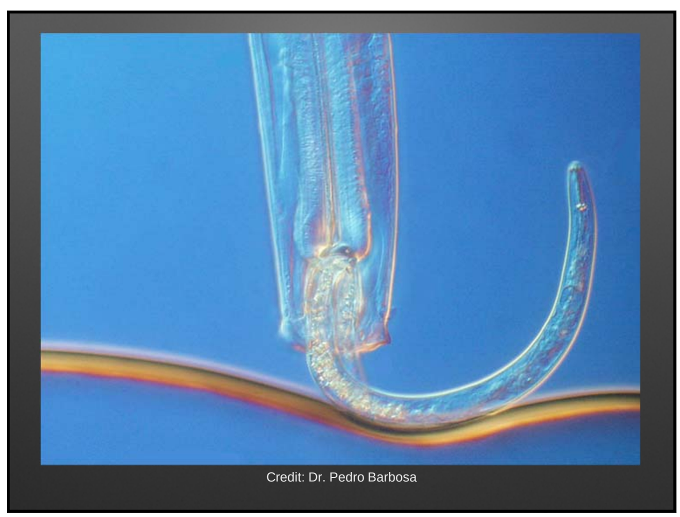
Credit: Val Behan-Pelletier

1 sq. ft., top 2 inches of litter

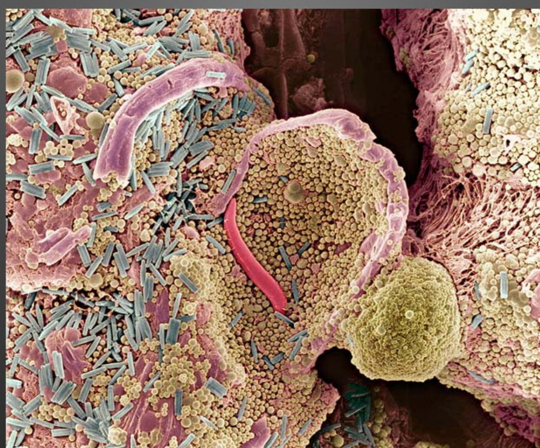

http://scrubmuncher.files.wordpress.com/2012/07/millipede-parasitic-nematodes-low-res.jpg
a b c d e
Nematode Mouth Parts
(a) bacterial feeder, (b) fungal feeder, (c) root feeder, (d) predatory, (e) omnivore.
Figure credit: Ed Zaborski, University of Illinois.
Acrobles ciliatus SEM image
http://nematode.unl.edu/accilsem1.jpg
http://www.nhm.ac.uk/resources-rx/images/1049/osedax-sem_69101_1.jpg




Spider Mite Predator
Parasitoid Wasp
Beneficial nematodes
ladybugs
Aphidius Wasps
Praying Mantis
Aphid Midge
http://www.ecofilms.com.au/aquaponics-and-beneficial-insect-control/
© 2007 GCMGA Inc., All Rights Reserved
http://aggie-horticulture.tamu.edu/galveston
http://www.beneficialbugs.org/bugs/Predatory_Mites/predatory_mites.htm
Credit: S.E. Thorpe
http://icons.wunderground.com/data/wximagenew/n/NicksMacro/921-800.jpg


Credit: Dr. Pedro Barbosa

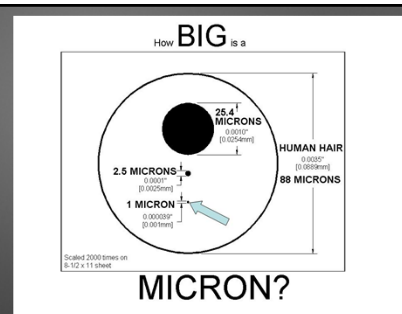
Small Friends



http://fineartamerica.com/featured/1-algae-in-soil-sem-dr-jeremy-burgess.html

Bacteria

- Very Small!
  - So small that by themselves, they can not have an impact on larger organisms
    - But anyone who has been sick or has had an infections knows that this is not the whole story

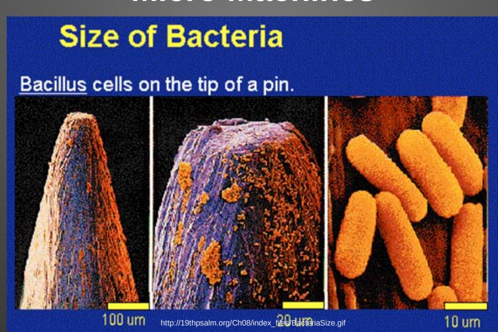


http://www.ctgclean.com/downloads/HowBigisaMicron.jpg

https://mexag.files.wordpress.com/2011/05/090527 170308-large.jpg

http://upload.wikimedia.org/wikipedia/en/b/b2/Broom-Stick_Bunny.jpg

Micro Machines



http://19thpsalm.org/Ch08/index_...iaSize.gif

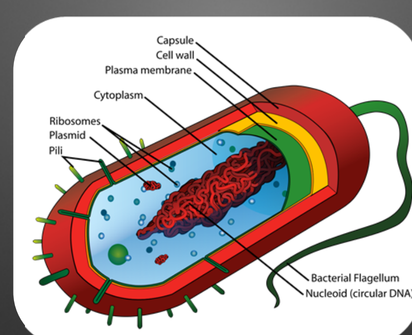
-Based on a quick calculation, a 1 square inch by 1/8th inch colony may have over 5 trillion individuals!

-Earth has 7 billion people

-700x population of people in 1" of bacteria!

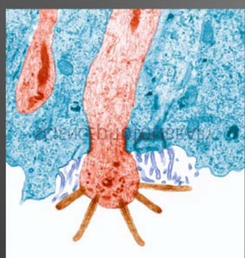
Scale

Just Tiny Blobs?

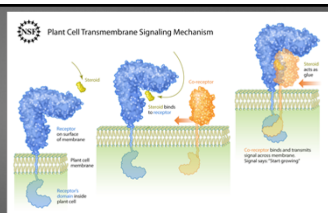


http://upload.wikimedia.org/wikipedia/commons/thumb/5/5a/Average_prokaryote_cell-_en.svg/1258px-Average_prokaryote_cell-_en.svg.png

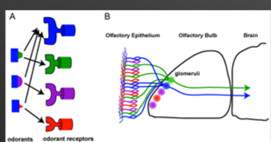
Senses?



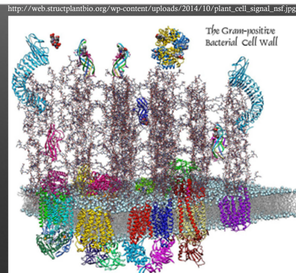
http://www.sciencephoto.com/image/501646/530wm/C0153276-Smell_receptor%2C_TEM-SPL.jpg



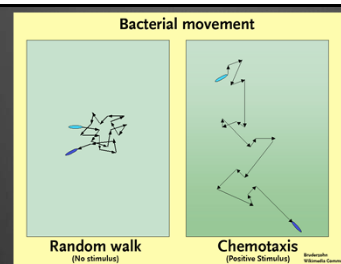
http://web.structplantbio.org/wp-content/uploads/2014/10/plant_cell_signal_nsf.jpg



http://www.mdpi.com/1424-8220/8/10/6303/htm

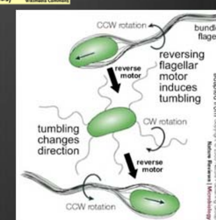


http://www.k-state.edu/bmb/labs/pek/Figures/GramPositiveCellWall2.jpg



https://www.immunology.org/view.image?Id=1508

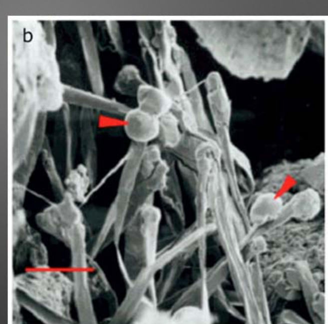
http://static1.squarespace.com/static/52d4acc0e4b086fdf73bb33b/52d74860e4b0281856c412c0/52d74956e4b0429035073c6f/1390498468409/Oh+Piece+of+candy+.jpg



http://virtuallaboratory.colorado.edu/BioFun-Support/labs/Adaptation/graphics/bacterial%20chemotaxis-tumbling.jpg

Follow the food

- Huge quantities of carbon are sent to the roots as exudates
  - Research shows close to 25% of photosynthetic sugar is sent to the root
    - Some research shows 75% during certain plant stages
    - Young seedlings typically exude about 30-40% of their fixed carbon as root exudates (Whipps, 1990)
- That is a LOT of energy
  - If 25%, some crops "dump" over 20,000 lbs of exudate/acre/year



b) Red arrows point to droplets of root exudates released from the tips of root hairs on the surface of broom corn (Sorghum sp.).

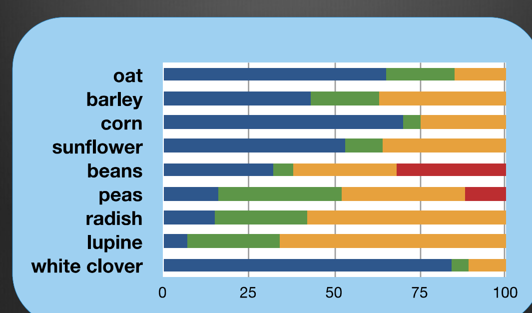
Hutsch B, Augustin J, Merbach W. (2002) Plant rhizodeposition – an important source for carbon turnover in soils. Journal of Plant Nutrition and Soil Science. 165, 4, 397-407

Carvalhais LC, Dennis PG, Fedoseyenko D, Hajirezaei MR, Borriss R, von Wirén N. 2011. Root exudation of sugars, amino acids, and organic acids by maize as affected by nitrogen, phosphorus, potassium, and iron deficiency. Journal of Plant Nutrition and Soil Science 174: 3–11.

Whipps J.M. (1990) Carbon economy. In The Rhizosphere (ed. J.M. Lynch), pp. 59–97. John Wiley & Sons Ltd, Essex, UK.

2012 Nature Education McGully, M. The rhizosphere: the key functional unit in plant/soil/microbial interactions in the field. implications for the understanding of allelopathic effects. Division of Plant Industry. Forth World Congress on Allelopathy. The Regional Institute Ltd.

The percentage of N in the roots as nitrate (blue), amino acids (green), amides (yellow) and ureides (red). These compounds leak from the roots as exudates and are part of the plant's signature to create a unique rhizosphere.



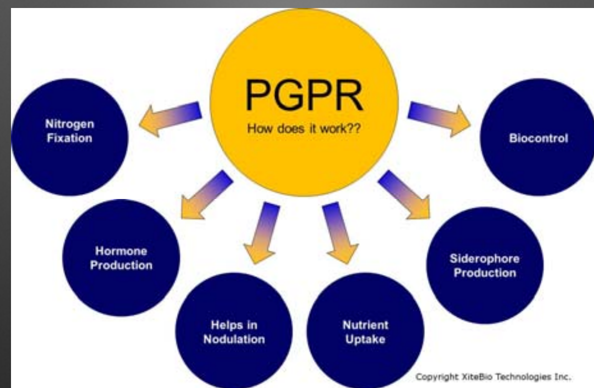
Credit: Dr. Jill Clapperton

Why so much Energy?

- That is a lot of energy being released through the roots
  - Why would a plant do that?
    - ROI?

Credit: Dr. Richard Box Wirelessly lit Fluorescent field

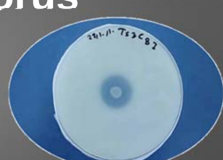
Because Plants Need Help



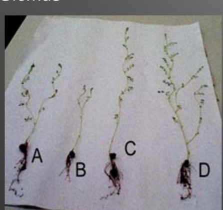
Kloepper, J.W., Schroth, M.N. 1978. Plant grotwh-promoting rhizobacteria in radish. pp 879-882. Proc. 4th Int'l. Conf. Plant Pathogenic Bact. Gilbert-Clarey, Tours, France

Phosphorus

- *Pseudmonas putida*
- *P. fluorescens*
- *Bacillus megaterium*
- *Glomus*

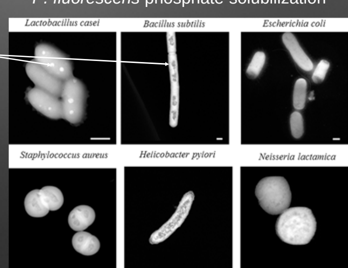


P. fluorescens phosphate solubilization



Pseudomonas

A = Garden soil with zinc phosphate B = Garden soil only C = CMG860 alone without zinc phosphate D = CMG860 with zinc phosphate

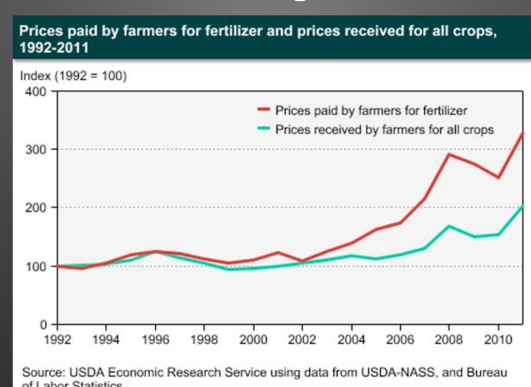


Akhtar, M.S. and Z.A. Siddiqui, 2009. Effects of phosphate solubilizing microorganisms and Rhizobium sp. on the growth, nodulation, yield and root-rot disease complex of chickpea under field condition. African J. Biotechnol., 8: 3489-3496

Noori MSS, Saud HM (2012) Potential Plant Growth-Promoting Activity of Pseudomonas sp Isolated from Paddy Soil in Malaysia as Biocontrol Agent. J Plant Pathol Microb 3:120. doi:10.4172/2157-7471.1000120

http://c431376.r76.cf2.rackcdn.com/24445/fcimb-02-00063-r2/image_m/fcimb-02-00063-g003.jpg

Nitrogen



With these trends, business as usual can not work!

Free-living N Fixers

- Dr. Arden Andersen
  - "University personnel tell farmers that they cannot generate much nitrogen bacteria activity without legumes. However, research in 1942 revealed that "root-nodule bacteria of lucerne grew equally under lucerne and under cotton."
- Azotobacter
- Azospirillum
- Many photosynthetic
  - Rhodospirillum, Rhodobacter, Rhodosphaeroides, etc…
- Don't forget your vitamins!
  - Mg, Fe, Mo, Ni, Co, V

http://www.agrolink.com.br/noticias/NoticiaDetalhe.aspx?codNoticia=94619

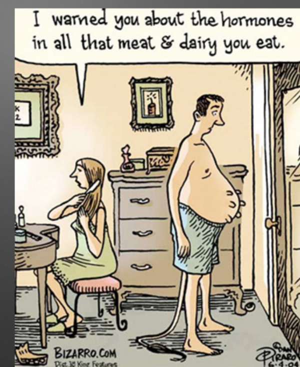
Dobereiner, J. et al. How to isolate and identify diazotrophs of non-leguminous plants. Brasilia: EMBRAPA-SPI: Itajai, RJ: EMBRAPA-CNPAB, 1995.

Biofertilization accounts for approximately 65% of the nitrogen supply to crops worldwide (Bloemberg et al., 2001).

http://popups.ulg.ac.be/1780-4507/index.php?id=7578

Hormones

- Hormones, at their core, are chemical messengers.
- Extremely small quantities.
  - ppm ppb ppt
  - Testosterone and Estradiol will only increase small amounts (roughly 10x) during puberty (a few ppb and ppt)



"China farmers face 'exploding' watermelon problem." -BBC Headline-

- 2011
  - Chinese farmers applied too much plant growth regulator/accelerator
    - Forchlorfenuron
  - When it comes to hormones, a little goes a long way
    - Biofeedback/Nature knows best

http://www.theguardian.com/world/2011/may/17/exploding-watermelons-chinese-farming

http://www.bbc.co.uk/news/world-asia-pacific-13421374

Hormones

Plant Growth Hormones

HORMONE	TYPICAL ACTIVITIES
Abscisic acid	Maintains seed dormancy and winter dormancy; closes stomata
Auxins	Promote stem elongation, adventitious root initiation, and fruit growth; inhibit axillary bud outgrowth and leaf abscission
Brassinosteroids	Promote stem and pollen tube elongation; promote vascular tissue differentiation
Cytokinins	Inhibit leaf senescence; promote cell division and axillary bud outgrowth; affect root growth
Ethylene	Promotes fruit ripening and leaf abscission; inhibits stem elongation and gravitropism
Gibberellins	Promote seed germination, stem growth, and fruit development; break winter dormancy; mobilize nutrient reserves in grass seeds

http://ccbbiology10.wikispaces.com/file/view/t37001.jpg/390885978/t37001.jpg

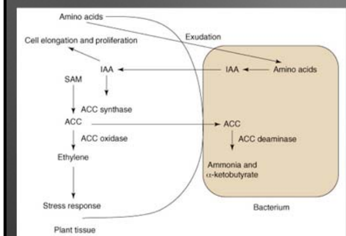
PGPR	PGR	References
Arthrobacter mysorens 7, *Flavobacterium* sp. L30, *Klebsiella* CIAM 880	Indole-3-acelic acid, ethylene	Pishchik *et al.* (2002)
Azotobacter sp.,	Indole-3-acetic acid	Zahir *et al.* (1998a, b 2000), Khalid *et al.* (2001)
Azotobacter chroococcum	Indole-3-acetic acid	Verma *et al.* (2010)
Azospirillum sp.	Gibberellic acid	Lucangeli and Botlini (1997)
Azospirillum sp.	Indole-3-acetic acid	Dobbelaere *et al.* (2001)
Azospirillum sp.	Indole-3-acetic acid	Lambrecht *et al.* (2000)
Bacillus licheniformis	Ethylene	Fukudah *et al.* (1989)
B. licheniformis	Physiologically active gibberellins	Gutierrez-Manero *et al.* (2001)
B. pumilus	Physiologically active gibberellins	Gutierrez-Manero *et al.* (2001)
B. subtilis	Ethylene	Mansouri and Bunch 1989)
Bacillus megaterium BHUPSB14	Indole-3-acetic acid	Verma *et al.* (2010)
Pseudomonas sp.	Auxins.	Pal *et al.* (2000)
Pseudomonas aeruginosa	Ethylene	Mansouri and Bunch (1989)
Pseudomonas fluorescens	Ethylene	Swanson *et al.* (1979)
Pseudomonas fluorescens G20-18	Isopentyl adenosine, *t*-zeatin ribose, dihydrozeatin riboside	Garcia de Salamone *et al.* (2001)
Pseudomonas fluorescens BHUPSB06	Indole-3-acetic acid	Verma *et al.* (2010)
Pseudomonas putida	Ethylene	Pazout *et al.* (1981), Fukudah *et al.* (1989)
Pseudomonas syringae	Ethylene	Sato *et al.* (1997), Swanson *et al.* (1979)
Pseudomonas tabaci	Ethylene	Swanson *et al.* (1979)
Rhizobacterial isolates	Auxins	Asghar *et al.* (2000, 2002)
Rhizobium sp.	Isopentyl adenine, isopenty) adenosine	Sturtevant and Taller (1989)
R. leguminosarum	Indole-3-acetic acid	Badenoch-jones *et al.* (1982a), Dazzo *et al.* (2000)
R. leguminosarum	Indole-3-acetic acid	Wang *et al.* (1993)
R. leguminosarum	Isopentyj atlenosine, zeatin, methylthiozeatin	Taller and Sturtevant (1991)
Rhizobium sp.	Indole-3-acetic acid	Verma *et al.* (2010)

Research shows that gut flora impact hormone levels

Jay Prakash Verma, Janardan Yadav, Kavindra Nath Tiwari, Lavakush and Vimal Singh, 2010. Impact of Plant Growth Promoting Rhizobacteria on Crop Production. International Journal of Agricultural Research, 5: 954-983.

Credit: Saraswoti Nepuane

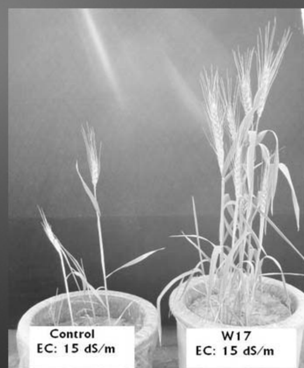
"Rhizobacteria Capable of Producing ACC-deaminase May Mitigate Salt Stress in Wheat"



http://www.cell.com/cms/attachment/584358/4421744/gr1.jpg

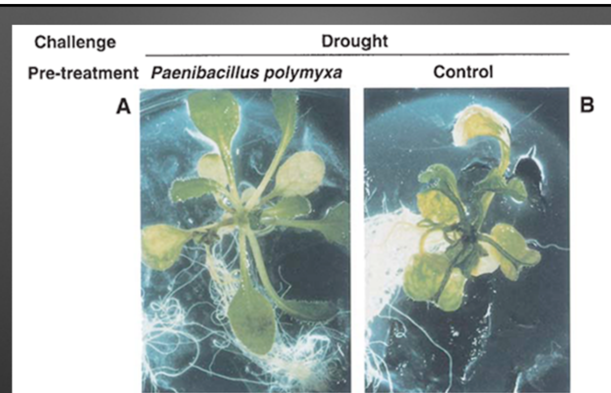
SAM = S-adenosylmethionine

ACC = 1-aminocyclopropane-1-carboxylic acid



P. fluorescens and P. putida

Nadeem S., et. al. 2010. Rhizobacteria Capable of Producing ACC-deaminase May Mitigate Salt Stress in Wheat Soil Sci. Soc. Am. J. 2010. 74:533–542.



P. polymyxa B2 inoculated plants (A) survived drought stress two weeks longer than untreated control plants (B). Image after three day drought exposure is shown. Plants were grown and inoculated and subsequently exposed to drought stress as described by Timmusk and Wagner (1999).

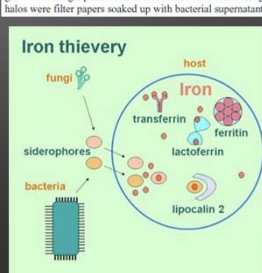
Timmusk, S. , Timmusk, K. , & Behers, L. (2013). Rhizobacterial Plant Drought Stress Tolerance Enhancement: Towards Sustainable Water Resource Management and Food Security. Journal of Food Security, 1(1), 6-9.

Iron

- Siderophores chelate iron
  - Plant feeding
  - Pathogen control

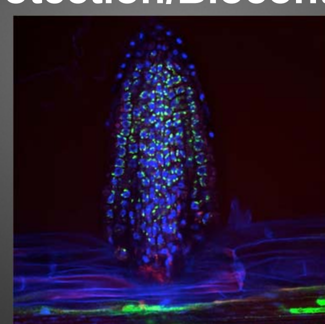
http://www.alive.com/articles/view/21560/clean_up_with_chelation

Figure 1. Screening of siderophore-producing bacterial isolates using CAS agar plates. The arrows indicated the isolates PC-1012 (the left one), and G-2-17-1 (the right one) which couldn't grow on CAS agar plates. The circles in the center of the orange halos were filter papers soaked up with bacterial supernatant.



Bakker, P.A.H.M., J.G. Lamers, A.W. Bakker, J.D. Marugg, P.J. Weisbeek and B. Schippers, 1986. The role of siderophores in potato tuber yield increase by Pseudomonas putida in a short rotation of potato. Eur. J. Plant Pathol., 92: 249-256

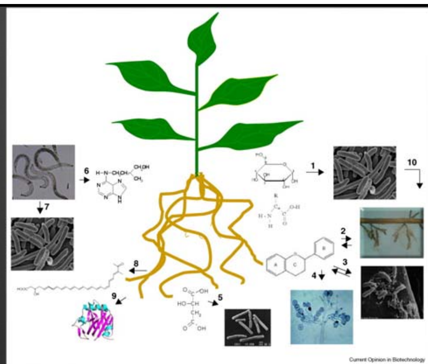
Protection/Biocontrol



"If you have a healthy soil, you will not need soil fumigants."

- G.W. Bird MSU

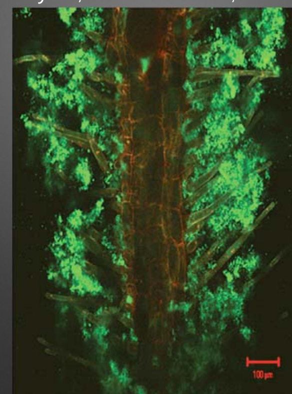
Published in Lundberg, D.S., Lebeis, S.L., Paredes, Yourstone, S., Gehring, J., Malfatti, S., Tremblay J., Engelbrektson A., Kunin V., Glavina del Rio, T., Edgar., R.C., Eickhorst, T., Ley, R. E., Hugenholtz, P., Tringe, S.G., and Dangl, J.L. 2012. Nature 488: 86-90



Plant roots secrete a wide range of compounds, among those sugars and amino acids are engaged in attracting (chemotaxis) microbes (1), flavonoids act as signaling molecules to initiate interactions with mycorrhiza (AM fungi) (2), rhizobium (3) and pathogenic fungi (oomycetes) (4), aliphatic acids (e.g. malic acid) are involved in recruiting specific plant growth promoting rhizobacteria (Bacillus subtilis) (5), nematodes secrete growth regulators (cytokinins) that are involved in establishing feeding sites in plant roots (6) and nematodes secrete other compounds (organic acids, amino acids and sugars) involved in attracting bacteria and in bacterial quorum sensing (7). Knowledge of the roles of other types of compounds, such as fatty acids (8) and proteins (9), secreted by roots in the rhizosphere and other multi-partite interactions (10) remains unknown.

http://www.sciencedirect.com/science/article/pii/S0958166909001281-

"When under attack, plants can signal microbial friends for help" - Bryant, Univ. Delaware, 2008-



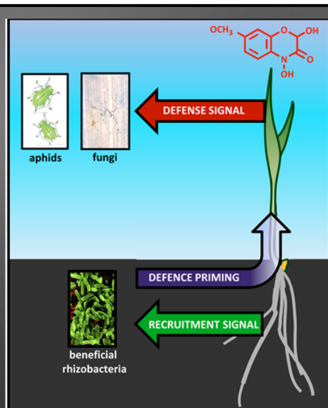
A plant root surrounded by a film of Bacillus subtilis (green fluorescence) in response to an infection by a plant pathogen.
(Thimmaraju Rudrappa, University of Delaware)

McNear Jr., D. H. (2013) The Rhizosphere - Roots, Soil and Everything In Between. Nature Education Knowledge 4(3):1

http://www.udel.edu/udaily/2009/oct/bais101708.html

Double Whammy

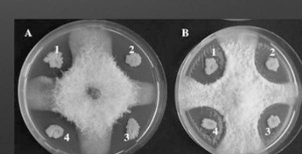
- Benzoxazinoids can act as powerful antibiotics
  - Protects the plant directly
  - Research has shown P. putida is attracted
    - Once attracted, help protect the plant



Neal, A. et. al. found a corn antibiotic (benzoxazinoid) to encourage chemotaxis and growth of Pseudomonas putida.

EPA Biopesticides

- Partial List:
  - Bacillus thuringiensis
  - B. sphaericus
  - B. subtilis
  - B. cereus
  - B. pumilus
  - B. firmus
  - B. amyloliquefaciens
  - Pseudomonas fluorescens
  - Streptomyces griseoviridis
  - S. lydicus
  - Trichoderma harzianum

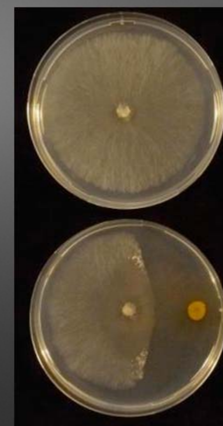


Crop	Disease/pathogen/insect	PGPR	References
Barley	Powdery mildew	*B. subtilis*	Schobeck *et al.* (1980)
Beans	Halo blight	*Pseudomonas fluorescens* strain 97	Alstrom (1991)
	Sclerotium rolfsii	*Pseudomonas cepacia*	Fridlender *et al.* (1993)
Carnation	*Fusarium* wilt	*Pseudomonas* sp. (WCS 417r)	Van Peer *et al.* (1991)
Cotton	Damping off	*Pseudomonas flourescens*	Howell and Stipanovic (1979, 1980)
	Meloidogyne incognita, M. Arenaria	*B. subtilis*	Sikoraa (1998)
	Rhizoctonia solani	*Pseudomonas cepacia*	Fridlender *et al.* (1993)
	Helicoverpa armigera	*Pseudomonas gladioli*	Quingwen *et al.* (1998)
Cucumber	*Cucumber anthracnose*	*Pseudomonas putida* (89B-27), *Serratia marcescens* (90-166)	Wei *et al.* (1991, 1996)
	Pythium ultimum	*Pseudomonas cepacia*	Fridlender *et al.* (1993)
	Bacterial wilt	*Pseudomonas putida* (89B-27), *S. marcescens* (90-166)	Kloepper *et al.* (1993)
	Bacterial angular leaf spot	*P. putida* (89B-27). *Flavomonas oryzihabitans* INR-5. *S. marcescens* (90-166). *Bacillus pumilus* (INR-7)	Kloepper *et al.* (1993)
	Cucumber mosaic virus	*P. putida* (89B-27). *S. marcescens* (90-166)	Raupach *et al.* (1996)
	Striped Cucumber beetle	*P. putida* (89B-27), *Flavomonas oryzihabitans* INR-5,	Zehnder et at., (1997a)
Green gram	*Aspergillus* sp., *Curvularia* sp., *Fuxarium oxysporum, Rhizoctonia solani*	*Pseudomonas* sp.	Sindhu *et al.* (1999)
Mung bean	Root rot. Root knot	*P. aeruginosa. B. subtilis*	Siddiqui *et al.* (2001)
Rice	Rice sheath blight	*Streptomyces* spp. and *Bacillus cereus* in combination with *Ps. fluorescens* and *Burkholderia*	Sung and Chung (1997)
	Rice sheath blight	Combination of *P. fluorescens* strains Pf1 and Fp7	Nandakumar (1998)
	Rhizoctonia solani (sheath blight pathogen)	*P. fluorescens* Strains Pf 1 and Fp7	Vidhayasekaran and Muthamilan (1999)
	Blue mold	*S. marcescens* 90-1 16. *B. pumilus* SE 34, *Ps. fluorescens* 898-6 1 . *B. pumilus T4, B. pasteurii* C-9	Zhang *et al.* (2002)
Tomato		*B. subtilis strain* 1N 937b	
	Tomato mottle virus	B. *amyloliquifacians* strain 1N 937a. B. *subtilis* strain 1N 937b	Murphy *et al.* (2000)
Wheat	Take till disease	*Bacillus. pseudomonas, Penicillium. Beauveria, Rhodococcus*	Renwick *et al.* (1991)
		Mixture of *Pseudomonas* sp.	Pierson and Weller (1994)

Jay Prakash Verma, Janardan Yadav, Kavindra Nath Tiwari, Lavakush and Vimal Singh, 2010. Impact of Plant Growth Promoting Rhizobacteria on Crop Production. International Journal of Agricultural Research, 5: 954-983.

Botrytis

- *Bacillus brevis*
- *Bacillus subtilis*
- *B. pumilus*

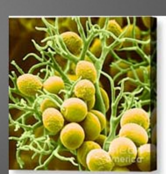


Lefiert C, Li H, Chidburee S, Hampson S, Workman S,Digel D, Epton HAS, Harbour A (1995). Antibiotic production and biocontrol activity by Bacillus subtilis CL 27 and Bacillus pumilus CLAS. J Appl Bacteriol78: 97-108

Edwards S.G., 1993. Biological control of Botrytis cinerea by Bacillus brevis on protected Chinese cabbage. PhD thesis, University of Aberdeen, UK.

Downy Mildew

- *Bacillus subtilis*
- *Pseudomonas fluorescens*
- *Streptomyces lydicus*
- *Trichoderma harzianum*

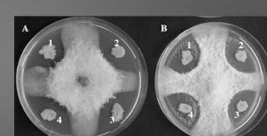


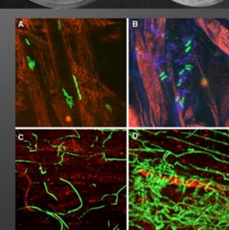
Niranjan-Raj, S., Shetty, N. P., and Shetty, H. S., 2004, Seed bio-priming with Pseudomonas fluorescens isolates enhances growth of pearl millet plants and induces resistance against downy mildew. Intern. J. Pest Manag. 50: 41–48

http://extension.psu.edu/pests/plant-diseases/all-fact-sheets/organic-and-biological-control-of-plant-diseases

Fusarium

- *Azospirillum brasilense*
- *Bacillus subtilis*
- *Pseudomonas fluorescens*
- *Trichoderma harzianum*





Reddy KRN, Choudary KA and Reddy MS. 2007. Antifungal metabolites of Pseudomonas fluorescens isolated from rhizosphere of rice crop. J Mycol Pl Pathol 37(2):

UNLAP C. A., SCHISLER D. A., PRICE N. P., VAUGHN F. Cyclic lipopeptide profile of three Bacillus subtilis strains; antagonists of Fusarium head blight. J. Microbiol. 49, (4), 603, 2011

Cao Y, Zhang Z, Ling N, Yuan Y, Zheng X, Shen B, Shen Q (2011) Bacillus subtilis SQR9 can control Fusarium wilt in cucumber by colonizing plant roots. Biol Fertil Soils 47:495–506

Chen L, Huang X, Zhang F, Zhao D, Yang X, Shen Q (2012) Application of Trichoderma harzianum SQR-T037 bio-organic fertilizer significantly controls Fusarium wilt and affects the microbial communities of continuously cropped soil of cucumber. J Sci Food Agric 92:2465–2470

Bashan Et al,. 2010. How the Plant Growth-Promoting Bacterium Azospirillum Promotes Plant Growth—A Critical Assessment Advances in Agronomy, Volume 108

Benhamou, N., Bélanger, R. R., and Paulitz, T. C., 1996b, Induction of differential host responses by Pseudomonas fluorescens in Ri T-DNA-transformed pea roots after challenge with Fusarium oxysporum f. sp. pisi and Pythium ultimum. Phytopathology, 86:1174–1185.

Phytophthora

- *Bacillus amyloliquefaciens*
- *B. cereus*
- *B. subtilis*
- *Pseudomonas fluorescens*
- *Streptomyces griseovirdis*
- *Trichoderma*

T. virens

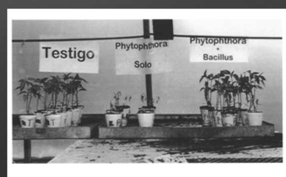


FIG. 1

Agustí L, Bonaterra A, Moragrega C, Camps J, Montesinos E. Biocontrol of root rot of strawberry caused by phytophthora cactorum with a combination of two pseudomonas fluorescens strains. J Plant Pathol. 2011;93(2):363-72.

Valois, D., Fayad, K., Barbasubiye, T., Garon, M., Déry, C., Brzezinski, R., and Beaulieu, C., 1996, Glucanolytic actinomycetes antagonistic to Phytophthora fragariae var. rubi, the causal agent of raspberry root rot. Appl. Environ. Microbiol. 62: 1630–1635

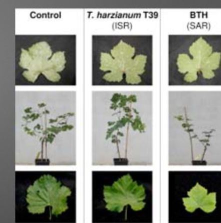
Diby, P., Saju, K.A., Jisha, P.J., Sarma, Y.R., Kumar, A., Anandaraj, M., 2005. Mycolytic enzymes produced by *Pseudomonas fluorescens* and *Trichoderma* spp. *against Phytopthora capsici*, the foot rot pathogen of black pepper (*Piper nigrum* L.). Annals of Microbiology 55, 129-133
Patent #6589524

Smith, V. L., Wilcox, W. F., and Harman, G. E. 1990. Potential for biological control of Phytophthora root and crown rots of apple by Trichoderma and Gliocladium spp. Phytopathology 80:880-885

Powdery Mildew

- *Bacillus subtilis*
- *Streptomyces lydicus*
- *Trichoderma harzianum*

BTH = benzothiadiazole



http://www.sciencedirect.com/science/article/pii/S1049964411000909

Sample	Dilution ratio and concentration (μg/mℓ)	Control value (%)	
		The 1st Exp.	The 2nd Exp.
Bacillus subtilis EB120	1:10 diluent	86±5.8	94±3.3
	1:25 diluent	84±5.0	91±2.7
	1:50 diluent	76±11	86±3.0
	1:100 diluent	21±9.2	84±6.7
	1:200 diluent	16±5.8	72±20
Topseed	1:10 diluent	87±3.8	92±5.4
	1:25 diluent	60±7.8	82±6.7
	1:50 diluent	56±9.3	48±11
	1:100 diluent	32±23	14±39
	1:200 diluent	26±13	45±20
Flusilazole	10 μg/mℓ	97	97
	30 μg/mℓ	99	99

Patent: WO 2005090553 A1

Schobeck, F., H.W. Dehne and W. Beicht, 1980. Untersuchungen zur Aktivierung unspezifisher resistenz mechanismen in Pflanzen. Z. Pflk. Pflschutz, 87: 654-666

http://extension.psu.edu/pests/plant-diseases/all-fact-sheets/organic-and-biological-control-of-plant-diseases

Pythium

- *Azospirillum brasilense*
- *Bacillus amyloliquefaciens*
- *Bacillus subtilis*
- *Bacillus cereus*
- *Pseudomonas fluorescens*
- *Trichoderma harzianum*

T. harzianum parasitizing Pythium

Bashan Et al,. 2010. How the Plant Growth-Promoting Bacterium Azospirillum Promotes Plant Growth—A Critical Assessment Advances in Agronomy, Volume 108

Loper, J. E., 1988, Role of fluorescent siderophore production in biological control of Pythium ultimum by a Pseudomonas fluorescens strain. Phytopathology, 78: 166–172.

Benhamou N., Bélanger R. R., and Paulitz T. C., 1996a, Pre-inoculation of Ri T-DNA-transformed pea roots with Pseudomonas fluorescens inhibits colonization by Pythium ultimum Trow: an ultra structural and cytochemical study. Planta, 199: 105–117

Benhamou, N., Bélanger, R. R., and Paulitz, T. C., 1996b, Induction of differential host responses by Pseudomonas fluorescens in Ri T-DNA-transformed pea roots after challenge with Fusarium oxysporum f. sp. pisi and Pythium ultimum. Phytopathology, 86:1174–1185.

Chang H., Chen J., Handelsman J., Goodman R.M., 1999. Behavior of Pythium torulosum zoospores during their interaction with tobacco roots and Bacillus cereus. Current Microbiology 38: 199-204

Abo-Elnaga HIG (2006). Bacillus subtili as a biocontrol agent for controlling sugar beet damping-off disease Egypt J Phytopathol 34: 51-59.

Fiddaman, P.J. and Rossall, S. 1993. The production of antifungal volatile by Bacills subtilis . J. Appl. Bacteriol., 74: 119-126

Gurusiddaia, S., Weller, D.M., Sarkar, A., Cooks, J.R. 1986. Characterization of an antibiotic produced by a strain of Pseudomonas fluorescens inhibitory to Gaeumannomyces graminis var. tritici and Pythium spp. Antimicrob. Agents Chemother. 29: 488-495

Rhizoctonia

- *Azospirillum brasilense*
- *Bacillus subtilis*
- *Pseudomonas putida*
- *Streptomyces griseus*
- *Trichoderma harzianum*

Antagonistic activity of Pseudomonas putida strain BHUPSB04 (accession number GU124834) against Rhizoctonia solani

S. Abeysinghe , 2009. Effect of Combined Use of Bacillus subtilis CA32 and Trichoderma harzianum RU01 on Biological Control of Rhizoctonia solani on Solanum melongena and Capsicum annuum. Plant Pathology Journal, 8: 9-16.

Elad, Y., Chet, I., & Katan, J. (1980). Trichoderma harzianum: A biocontrol agent effective against Sclerotium rolfsii and Rhizoctonia solani. Journal of Phytopathollogy 70, 119-121

Nagarajku mar, M., Bhaskaran, R., Velazha ha n, R., 2004. Involve me nt of secondary metabolites a nd ext racellular lytic e nzy mes produced by *Pseudomonas fluorescens* in inhibition of *Rhizoctonia solani*, the rice sheath blight pathogen. Microbiological Research, 159, 73-81

Merriman, P.R., R.D. Price, J.F. Kollmorgen, T. Piggott and E.H. Ridge, 1974. Effect of seed inoculation with Bacillus subtilis and Streptomyces griseus on the growth of cereals and carrots. Aust. J. Agric. Res., 25: 219-226.

Asaka O, Shoda M (1996). Biocontrol of Rhizoctoniasolani damping-off of tomato with Bacillus subtilis RB14. Appl Environ Microbiol 62: 4081-4085.

Nandakumr, R., Babu, S., Radjacommare, R., Raguchander, T., Samiyappan, R., 2002. *Pseudomonas fluorescens* mediated antifungal activity against *Rhizoctonia solani* causing sheath blight in rice. Phytopathologia Mediterranea 41, 109-119

Fiddaman, P.J. and Rossall, S. 1993. The production of antifungal volatile by Bacills subtilis . J. Appl. Bacteriol., 74: 119-126
Bashan Et al,. 2010. How the Plant Growth-Promoting Bacterium Azospirillum Promotes Plant Growth—A Critical Assessment Advances in Agronomy, Volume 108.

Sclerotium

- *Azospirillum brasilense*
- *Bacillus subtilis*
- *Trichoderma harzianum*

- Dancing- Ergot/St. Anthony's Fire - 1518

Moustafa E. Shalaby, Kamal E. Ghoniem, Mohamed A. El-Diehi Biological and fungicidal antagonism of Sclerotium cepivorum for controlling onion white rot disease December 2013, Volume 63, Issue 4, pp 1579-1589

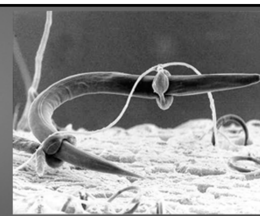
Bashan Et al,. 2010. How the Plant Growth-Promoting Bacterium Azospirillum Promotes Plant Growth—A Critical Assessment Advances in Agronomy, Volume 108.

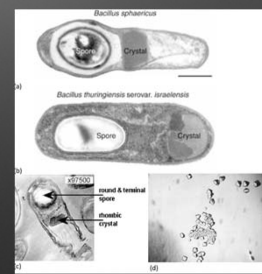
Elad, Y., Chet, I., & Katan, J. (1980). Trichoderma harzianum: A biocontrol agent effective against Sclerotium rolfsii and Rhizoctonia solani. Journal of Phytopathollogy 70, 119-121

And More…

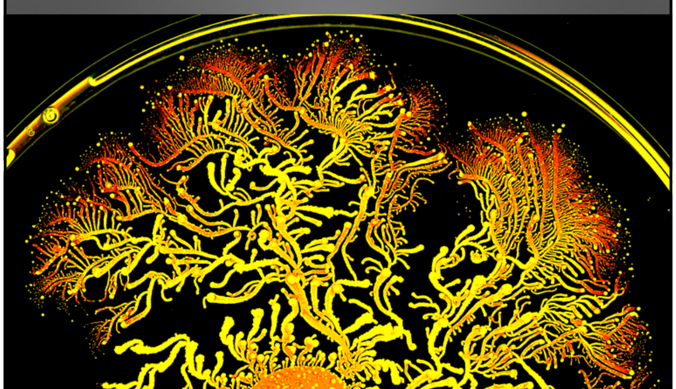
- Fungicidal
- Bactericidal
- Nematicidal
- Insecticidal
- Antiviral
- Etc…

- Long story short, these beneficial organisms have a major impact on plant nutrition, growth and health



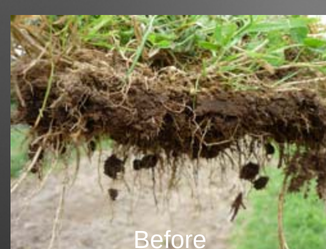


Examples of PGPR in the Field:

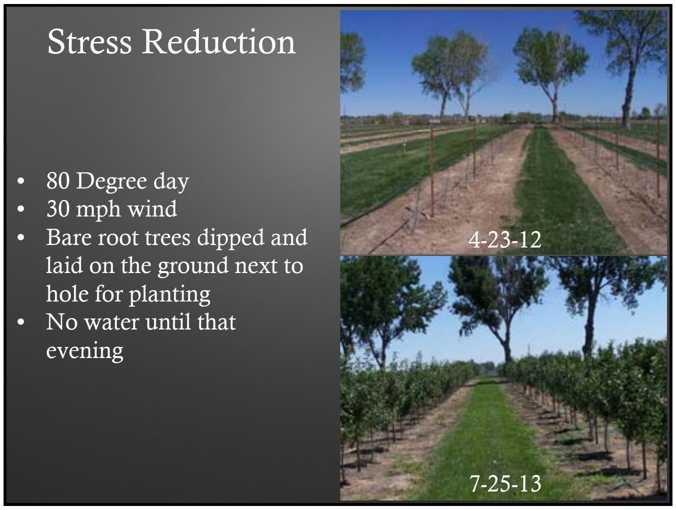


Credit: Eshel Ben-Jacob

Established fescue side by side comparison shows results 3 weeks post application



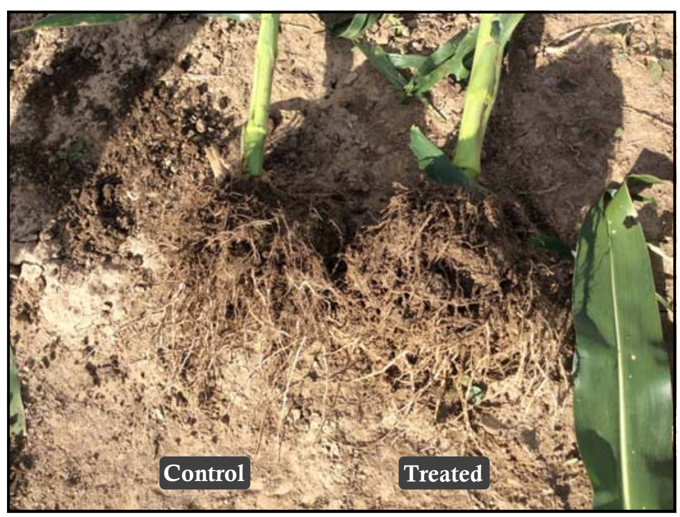
Result is improved: soil/plant digestive system, plant stress management, nutrient retention, water retention, biodiversity, and the list goes on…


Stress Reduction
• 80 Degree day
• 30 mph wind
• Bare root trees dipped and laid on the ground next to hole for planting
• No water until that evening
4-23-12
7-25-13


Control
Treated


Root dip MycoGenesis
Planted 4-28-2014
Root dip MycoGenesis 9-17-14
99.9% Success Rate


Treated:
~10 skips
Control:
~50 skips


Control
Treated


Treated
Control

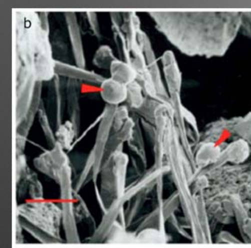

treated vs untreated


Making Friends…
Photo: Colin Ingham
C. J. Ingham, O. Kalisman, A. Finkelshtein, E. Ben-Jacob. Mutually facilitated dispersal between the nonmotile fungus Aspergillus fumigatus and the swarming bacterium Paenibacillus vortex. Proceedings of the National Academy of Sciences, 2011; DOI: 10.1073/pnas.1102097108


More Friends…
FISH- Azospirillum brasilense
100 µm
http://www.bashanfoundation.org/gmaweb/pics/azospirillumdetection.jpg
McNear Jr., D. H. (2013) The Rhizosphere - Roots, Soil and Everything In Between. Nature Education Knowledge 4(3):1
…More Options!

Lessons from an Efficient "Farmer"

- Earth worms:
  - Consume low to no protein leaves
    - Process in gizzard
      - Mix with mucilage
        - Regurgitate
          - Have now created microbe "agar"
            - Microbes grow on "agar"
              - Microbes have a 5:1 C:N
                - Worms have taken low to no protein food and created a protein food source for themselves!



b) Red arrows point to droplets of root exudates released from the tips of root hairs on the surface of broom corn (Sorghum sp.).

Andrew L. Neal, Shakoor Ahmad, Ruth Gordon-Weeks, and Jurriaan Ton. (2012). Benzoxazinoids in Root Exudates of Maize Attract Pseudomonas putida to the Rhizosphere. PLoS ONE. doi:10.1371/journal.pone.0035498

2012 Nature Education McGully, M. The rhizosphere: the key functional unit in plant/soil/microbial interactions in the field. implications for the understanding of allelopathic effects. Division of Plant Industry. Forth World Congress on Allelopathy. The Regional Institute Ltd. All rights reserved

http://www.bashanfoundation.org/gmaweb/pics/azospirillumdetection.jpg

FISH- *Azospirillum brasilense*

Indirect: ISR

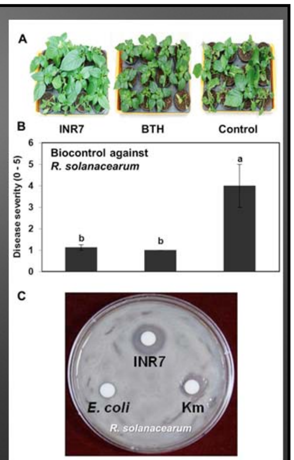
- "The term induced resistance is a generic term for the induced state of resistance in plants triggered by biological or chemical inducers, which protects non-exposed plant parts against future attack by pathogenic microbes and herbivorous insects." - Pieterse, Utrecht Univ.

http://www.annualreviews.org/eprint/7gPVpKemTHwpZXUWfRZ8/full/10.1146/annurev-phyto-082712-102340

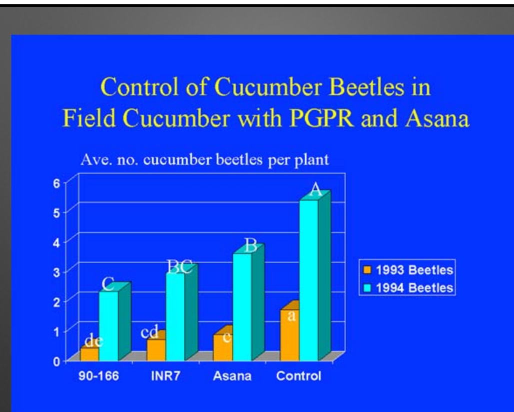
Ryu CM, Farag MA, Hu CH, Reddy MS, Wei HX, Paré PW, Kloepper JW (2003) Bacterial Volatiles Promote Growth in Arabidopsis. Proc Natl Acad Sci USA 100:4927–4932

Ryu CM, Farag MA, Hu CH, Reddy MS, Kloepper JW, Paré PW (2004a) Bacterial volatiles induce systemic resistance in Arabidopsis. Plant Physiol 134:1017–1026

Ryu CM, Murphy JF, Mysore KS, Kloepper JW (2004b) Plant growth-promoting rhizobacteria protect systemically Arabidopsis thaliana against Cucumber mosaic virus by a salicylic acid and NPR1-independent and jasmonic acid dependent signaling pathway. Plant J 39:381–392

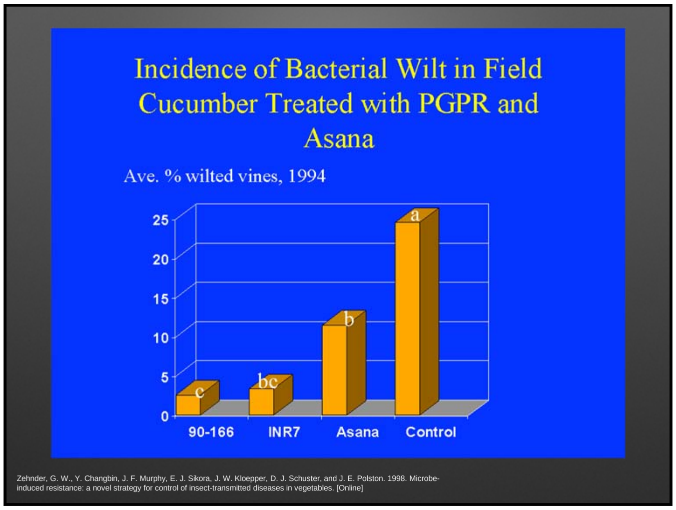


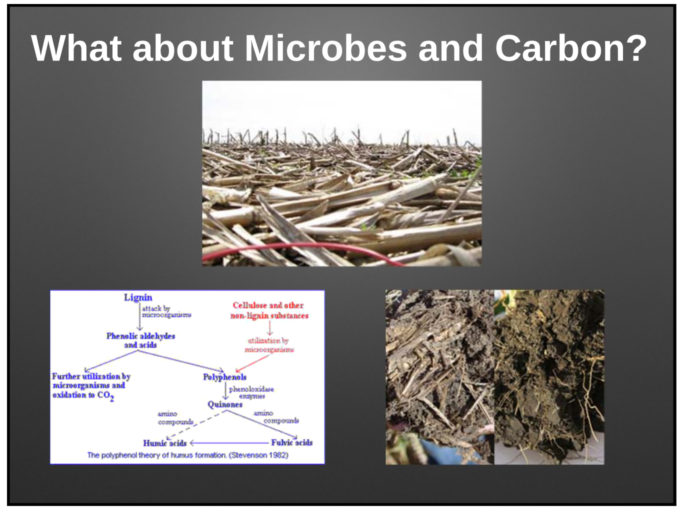
http://journal.frontiersin.org/Journal/10.3389/fpls.2013.00122/full

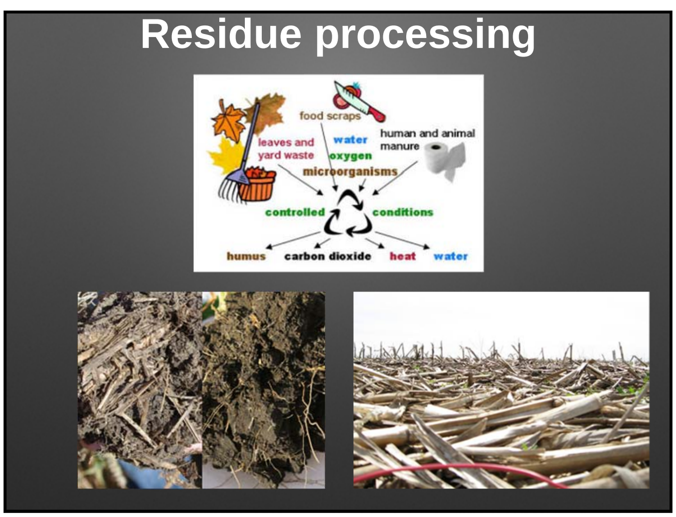


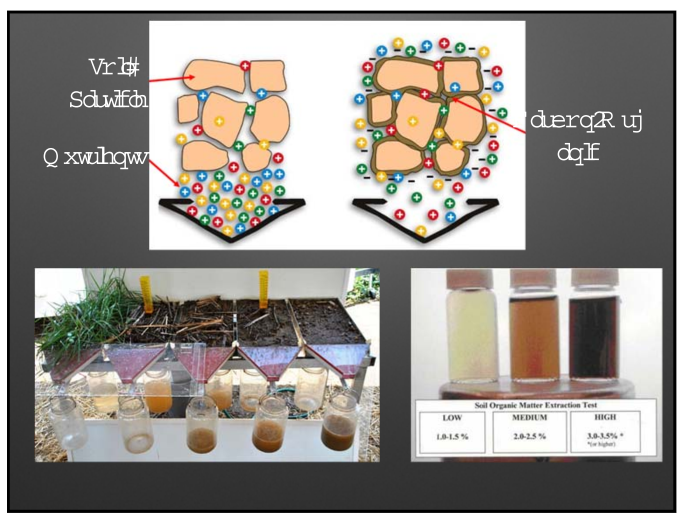
B. pumilus

Zehnder, G. W., Y. Changbin, J. F. Murphy, E. J. Sikora, J. W. Kloepper, D. J. Schuster, and J. E. Polston. 1998. Microbe-induced resistance: a novel strategy for control of insect-transmitted diseases in vegetables. [Online]


Incidence of Bacterial Wilt in Field Cucumber Treated with PGPR and Asana
Ave. % wilted vines, 1994
25
20
15
10
5
0
c
bc
b
a
90-166
INR7
Asana
Control
Zehnder, G. W., Y. Changbin, J. F. Murphy, E. J. Sikora, J. W. Kloepper, D. J. Schuster, and J. E. Polston. 1998. Microbe-induced resistance: a novel strategy for control of insect-transmitted diseases in vegetables. [Online]

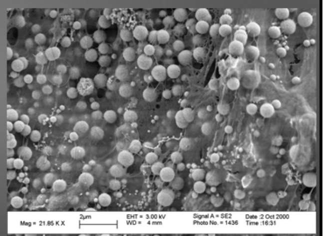

What about Microbes and Carbon?
Lignin
Cellulose and other non-lignin substances
Phenolic aldehydes and acids
Further utilization by microorganisms and oxidation to CO2
Polyphenols
Quinones
Humic acids
Fulvic acids
The polyphenol theory of humus formation. (Stevenson 1982)

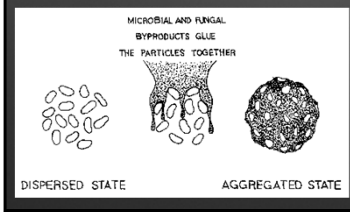

Residue processing
food scraps
leaves and yard waste
water
oxygen
human and animal manure
microorganisms
controlled
conditions
humus
carbon dioxide
heat
water

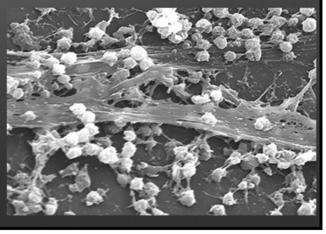

Soil Organic Matter Extraction Test
LOW
MEDIUM
HIGH

Microbe “glue”

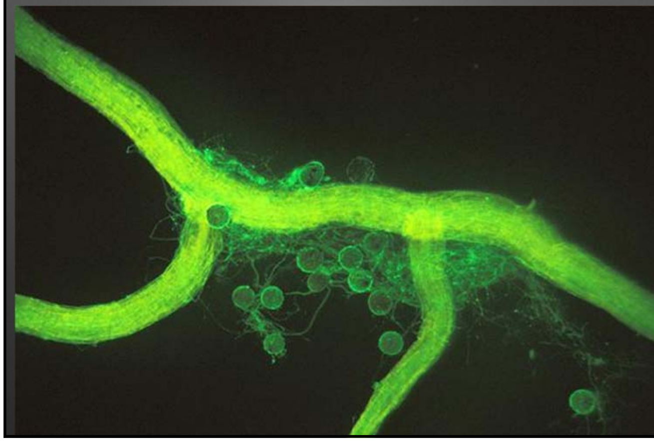
- Microbes produce a wide variety of materials that help bind soil together
  - Aggregation = gas exchange and water storage
  - Mucilaginous carbohydrates (EPS), biofilms mycelium, hyphae, etc… all help hold soils together





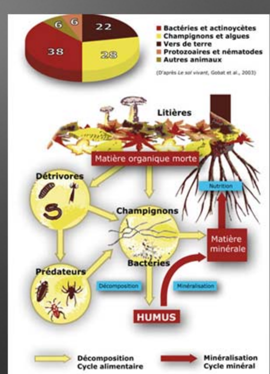


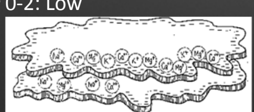
Glomalin



Organic Matter

- OM Levels:
  - CEC of 100 or more
  - Organic matter is important for the microbes as a source of carbon and nutrients
    - 4 or more: Can mean slow microbial breakdown or low microbial counts
    - 3-4: Often times Ideal levels
    - 2-3: Good Level
    - 0-2: Low





Carbon:Nitrogen

- C:N “microbial suitability” and sustainability
  - 30:1+ High levels of Carbon
    - Dr. Clapperton’s research is suggesting high C:N can have long term support characteristics
  - 20:1 to 30:1 Excellent
  - 15:1 to 19:1 Some Carbon needed
  - 1:1 to 14:1 High quantities of Carbon needed
    - Depending upon form, remember that C is necessary for N storage
- Photosynthesis and exudates = long term building


11-354-0066
Dec 29, 2011 1234
Dec 20, 2011

Midwest Laboratories Inc.

PAGE 1/1

CARBON NITROGEN RATIO REPORT

Sample Id	Total Carbon	Total Nitrogen	C/N Ratio
1 N	1.90 %	0.20 %	9.3

Drop Test

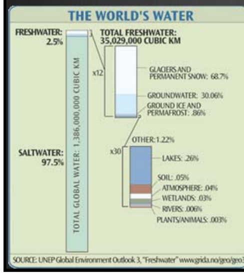
Graham Shepherd VSA Vol. III

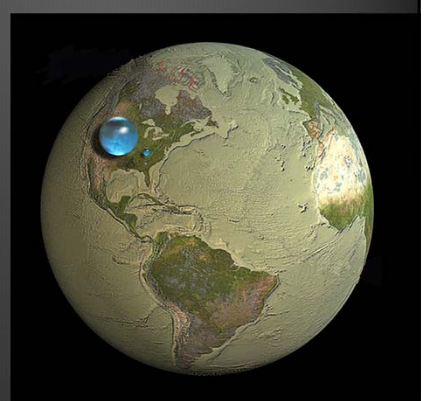
Porosity

Graham Shepherd VSA Vol. III

What's the big deal about Carbon?

- All the water in the world (1.4087 billion cubic kilometers) including sea water, ice, lakes, rivers, ground water, and clouds
  - 860 mile

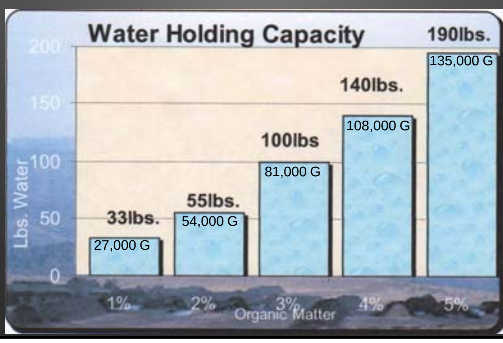


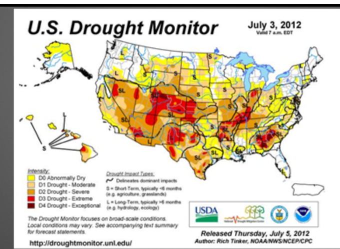


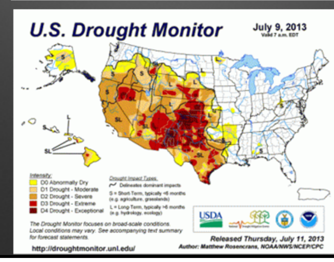
NRCS:

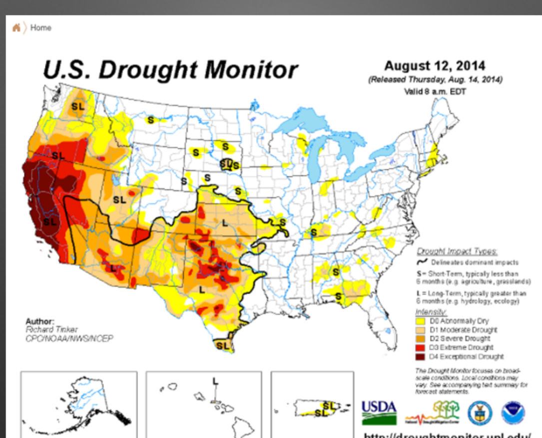
Organic matter builds as tillage declines and plants and residue cover the soil. Organic matter holds **18-20 times** its weight in water and recycles nutrients for plants to use.

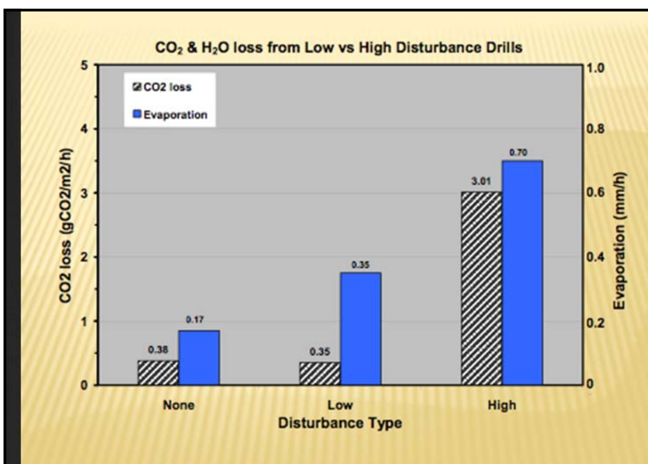
One percent of organic matter in the top six inches of soil would hold approximately **27,000 gallons** of water per acre!



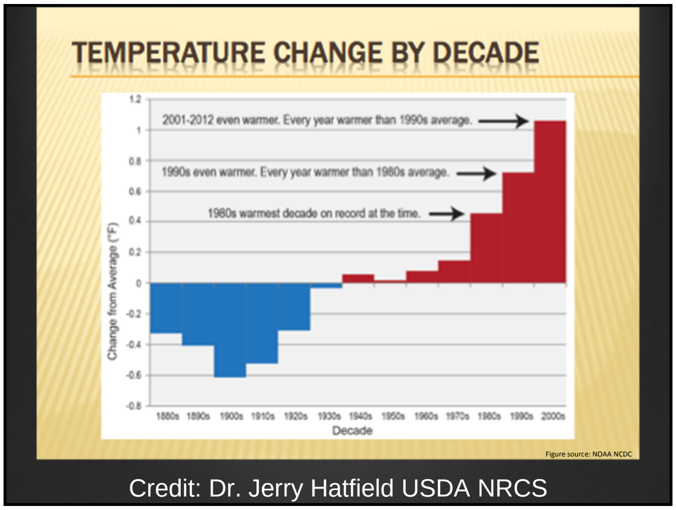


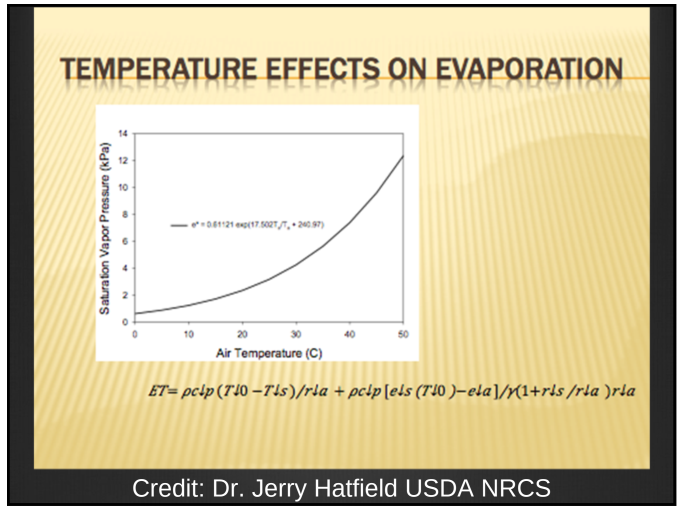


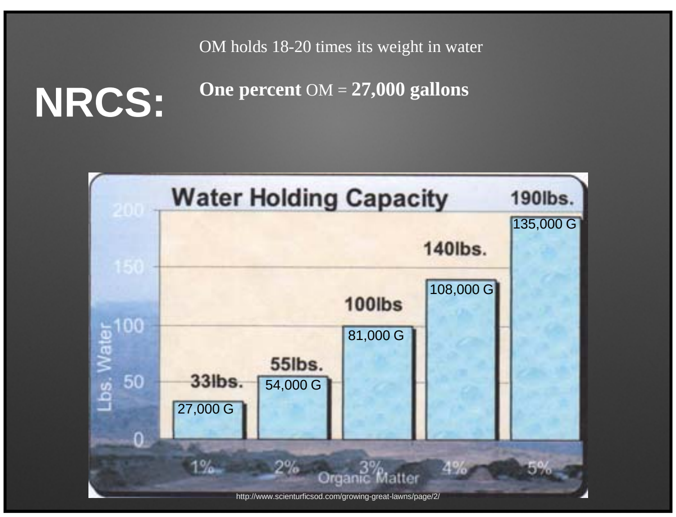


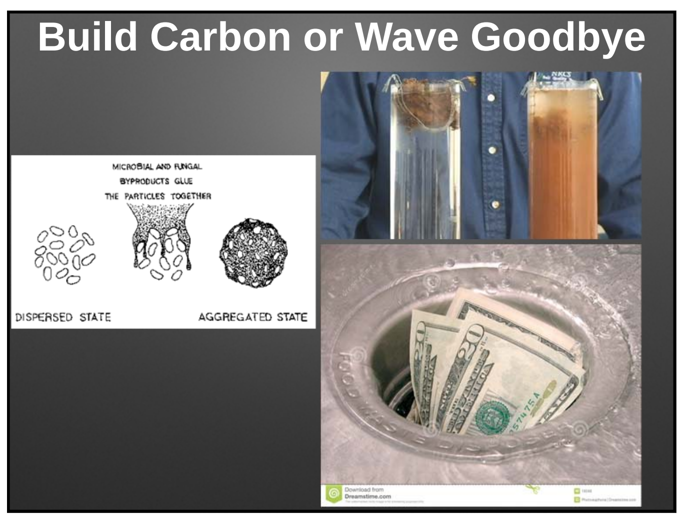


Credit: Dr. Jerry Hatfield USDA NRCS

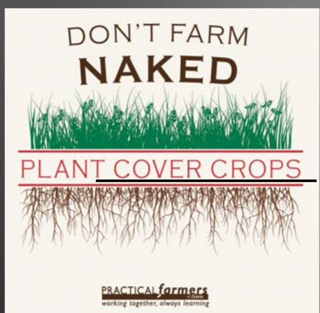

TEMPERATURE CHANGE BY DECADE
2001-2012 even warmer. Every year warmer than 1990s average.
1990s even warmer. Every year warmer than 1980s average.
1980s warmest decade on record at the time.
Change from Average (°F)
Decade
1880s 1890s 1900s 1910s 1920s 1930s 1940s 1950s 1960s 1970s 1980s 1990s 2000s
Figure source: NOAA NCDC
Credit: Dr. Jerry Hatfield USDA NRCS

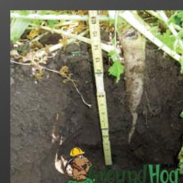

TEMPERATURE EFFECTS ON EVAPORATION
Saturation Vapor Pressure (kPa)
Air Temperature (C)
Credit: Dr. Jerry Hatfield USDA NRCS


NRCS:
OM holds 18-20 times its weight in water
One percent OM = 27,000 gallons
Water Holding Capacity
Lbs. Water
33lbs.
27,000 G
55lbs.
54,000 G
100lbs
81,000 G
140lbs.
108,000 G
190lbs.
135,000 G
1% 2% 3% 4% 5%
Organic Matter
http://www.scienturficsod.com/growing-great-lawns/page/2/


Build Carbon or Wave Goodbye
MICROBIAL AND FUNGAL BYPRODUCTS GLUE THE PARTICLES TOGETHER
DISPERSED STATE
AGGREGATED STATE

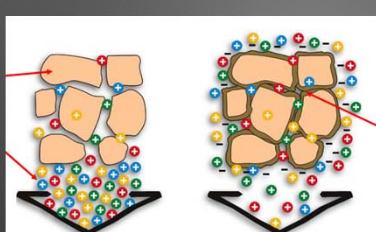
Tools to build Carbon:

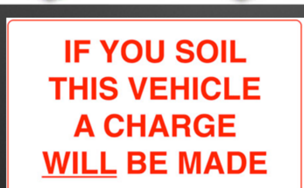


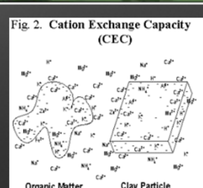


Credit: Dr. Jerry Hatfield USDA NRCS

Carbon Fertilizer

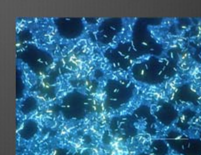


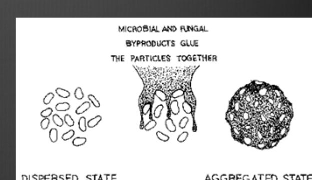




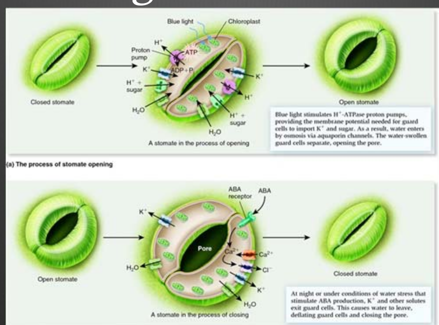
Microbes, Carbon, and Water

- Biological soils help both plant and soil during drought times:
  - Pore spaces
  - Aggregation
  - Humus/Soil Carbon
  - Hormones
  - Nutrient Osmotic Control





Ring the Alarm!

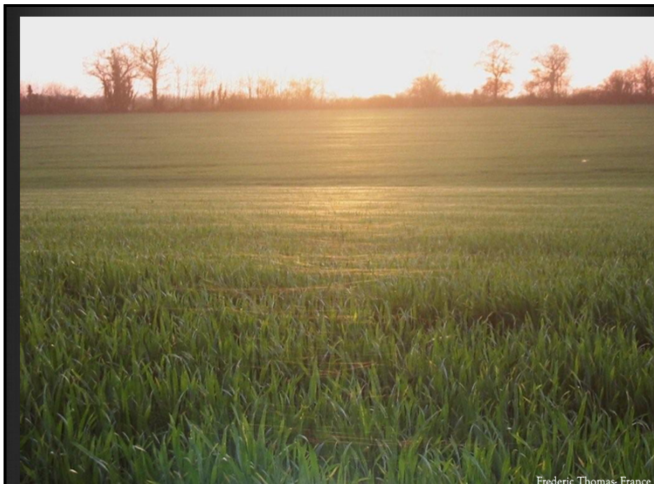


http://biology-forums.com/index.php?action=gallery;sa=view;id=1030

- PGPR produce plant hormones that help control plant growth.
  - During drought, the abscisic acid (ABA) is produced which translocates to leaves to regulate stomata.

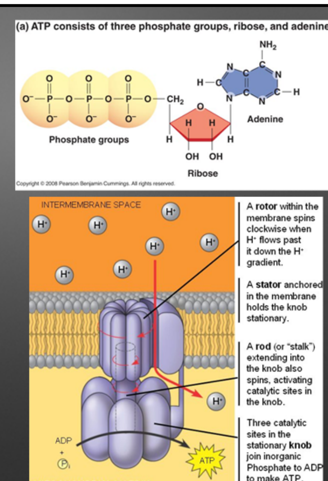
How do we build Carbon and maintain moisture?

Short answer…
On Purpose



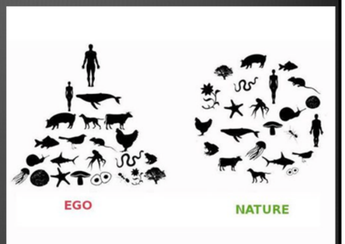
Mighty Mito

- Mitochondria turnover approximately 60 kg of ATP per day/healthy adult.
  - 507.18 g/mol
    - 6.022 x 10^23 molecules or atoms per mole
    - 118.3 moles of ATP turned over
    - 7,124,026,000,000,000,000,000,000 (Sept.)



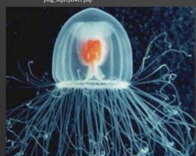
People are incredible, but…

- Pretty much everything humans can do, a creature in nature can do better.



http://24.media.tumblr.com/7c78dcffc758a1c99c4cbe1ba9417ebc/tumblr_mew6lzoGtf1qhh6n0o1_500.jpg

http://www.buzzle.com/img/articleImages/582945-0816-14.jpg



http://www.blastr.com/2011/06/8_jaw_dropping_superpower.php

http://www.shapeways.com/wordpress/wp-content/uploads/2014/12/tardigrade.jpg

How Sensitive are Living Systems?

Silent Mutations

ATG	GAA	GCA	CGT
Met	Glu	Ala	Gly
ATG	GAG	GCA	CGT
Met	Glu	Ala	Gly

- Pain sensitivity is affected by a silent mutation as are 50+ other human disorders,
- bun—patty—cheese—pickle—mustard—ketchup— lettuce—bun

  Different than
- bun—patty—cheese—-pickle—mustard—ketchup— lettuce—bun

https://www.sciencenews.org/article/not-so-silent-mutation-alters-protein-not-its-components

Vibrio fischeri

- Marine Bacteria
- Symbiotic
  - Bobtail Squid
    - Bioluminescence

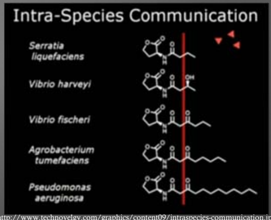
/www.redorbit.com/media/uploads/2013/04/bobtail-squid-shutterstock_128992328-617x416.jpg

http://www.marengel.ch/Projekte/Vibrio-fischeri/Vibriofischeri1.jpg

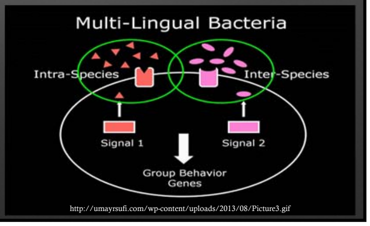
To Glow or not to Glow

- " Instead of language, bacteria use signalling molecules which are released into the environment." -Atkinson-
- Quorum sensing enables bacteria to co-ordinate their behavior.
- As environmental conditions often change rapidly, bacteria need to respond quickly in order to survive.
- These responses include adaptation to availability of nutrients, defense against other microorganisms which may compete for the same nutrients and the avoidance of toxic compounds potentially dangerous for the bacteria.
- Autoinducers
- Bonnie Bassler

http://www.nottingham.ac.uk/quorum/what.htm



http://www.technovelgy.com/graphics/content09/intraspecies-communication.jpg



http://umayrsufi.com/wp-content/uploads/2013/08/Picture3.gif

Erwinia carotovora

- Quorum sensing
  - Waits until sufficient numbers are present and then… attack!
    - Emits virulence factor
    - Spits out enzymes to create wound/infection site
    - Simultaneously releases protective molecules to keep all other pathogens away

http://rem-learn-images.s3.amazonaws.com/1352055721.sneak-attack.jpg

Long Term

- Dr. James Collins - Boston Univ.
- “In studying the development of antibiotic-resistant strains of bacteria, the researchers found that the populations most adept at withstanding doses of antibiotics are those in which a few highly resistant isolates sacrifice their own well being to improve the group's overall chance of survival.”
  - Indole — Signal Flare
    - Encourages biofilm and stationary phase
    - Hurts/costs individual
  - Over 85 species have been found
    - “Single shot” approaches may miss “sleepy” individuals
    - Biological approach

https://experiencelife.com/wp-content/uploads/2011/11/Sep11_Bact1.jpg

http://thewestchesterview.com/files/2009/07/TeamworkSuccessPicnik.jpg

Lee J. H. & Lee J. (2010). Indole as an intercellular signal in microbial communities. FEMS Microbiology Reviews 34(4):426-44.

Boston University College of Engineering. "'Charitable' behavior found in bacteria." ScienceDaily. www.sciencedaily.com/releases/2010/09/100901132157.htm (accessed January 28, 2015).

Henry H. Lee, Michael N. Molla, Charles R. Cantor, James J. Collins. Bacterial charity work leads to population-wide resistance. Nature, 2010; 467 (7311): 82 DOI: 10.1038/nature09354