Hawaii Tropical Fruit Growers

Back to Our Roots

Soil Culture, Soil Health and Food Quality in Hawaii

Bob Shaffer, agronomist
Soil Culture Consulting™
SOIL CULTURE

- Object is:
  - Use cultural practices to elevate soil health, in preference to treatments, rescue of crops and environmental damage in the act of raising food.
  - Soil health preserves environmental health and function.
  - High quality food production and prevention of disease.
Farm management systems designed to employ cultural practices which closely imitate nature and natural ecosystems
An effective, simple and economical system for creating healthy soils comprised of three (3) groups cultural practices has become apparent
3 essential groups of SOIL cultural practices

1. Organic matter management
   a) Cover crops
   b) Compost
   c) Mulch

2. Mineral and nutrient management
   a) Balance and Availability

3. Tillage management
   a) Beneficial disturbance
Management systems which value ecological principles are based on:

- Worker health, safety and working conditions
- Recycling
- Soil health
- Minimize loss by management of soil and canopy layers
- Diversification, enhancement of biological environment
Prevailing philosophy

“Specific pests, nutrient deficiencies and others are the cause of low productivity”

(Carroll et al. 1990)
Holistic philosophy

“Pests or nutrients only become limiting if conditions in the agroecosystem are not in equilibrium”

(Carroll et al. 1990)
Holistic philosophy

“Limiting factors only represent symptoms of a more systemic disease inherent to imbalances within the agroecosystem”

(Altieri et al. 1983; Altieri 1994; Altieri 1987; Altieri and Nicholls 2004)
Long term research

• 119 year long trial, A.C. Magruder, at Oklahoma State University

• 118 year long trial, Sanborn Field at the University of Missouri campus

• 170 year long trial, Rothamsed Experiment Station, England
Mid term research

• 30 year farming systems trials at Rodale Institute
• 28 year study or Swiss Research Institute of Organic Agriculture (DOK), comparison of organic, biodynamic and conventional
• 27 year Sustainable Agriculture Farming Systems (SAFS) project at UC Davis, CA on Russell Ranch studying organic, conventional and low input for crop rotations typical to Sacramento Valley
• 23 year old, Long Term Research on Agricultural Systems (LTRAS) project. UC Davis, California. One hundred (100) acres
• Reganold 2001 published in Nature a 6 year study on apples showed comparable yield and many advantages to conventional and higher profit
Local current research

• Performance and Plant-Available Nitrogen (PAN) Contribution of Cover Crops in High Elevations in Hawaii
  Archana Pant, Theodore Radovich, Koon-Hi Wang, NV Hue

• Building the Future on a Foundation of Soil Health
  Susan Kubo, USDA NRCS Pacific Islands Area
Local current research

- Enhancing Phytonutrient Content, Yield and Quality of Vegetables with Compost Tea in the tropics
  Theodore Radovich, University of Hawaii, 2011

- Improving and extending the superhero status of the sunn hemp to other growers in need of help
  Dr. Cerruti Hooks, University of Maryland, 2009
Australia current research

- Soil health survey in Macadamia orchards in NSW
  Van-Zwieten, Kingston, Cox, Walker, Hotson, Morris

- Macadamia husk compost improves soil health in sub-tropical horticulture,
  Cox, Van-Zwieten, Ayres and Morris, 2001
Developing a sustainable and preventative farming system

- Transition rather than instant change
- Integrate all cultural practices
- Focus on soil health
- Feed the soil (and the plant)
- Grow large volumes of plant biomass
- Diversity and Rotate
- Relentless learning
- Recognize opportunity in the
- Accepting change and practicing tolerance
SOIL HEALTH
Healthy soil characteristics

- Erosion free, TILTH, pores, aggregation, crusts
- Soil life diverse, high populations, active
  Earthworms, 9 major soil surface dwelling animals, smell
- Reliably, ripens the highest quality crops
- Nutrient recycling obvious
  9 major animals present, residues from last crop decompose rapidly and fully
- SOM levels are 4 – 15 % + site specific, active inputs?
  0-7 inch depth, Walkley-Black method, Dichromate-sulfuric acid 90 minutes at 90°C, Spectrophotometer
- Minerals balanced
- Disease suppressive
- Crops show resistance-tolerance
  Pests present but damage is minimal
Soil diversity
Biodiversity

Above and below ground, from cover crops, leads to soil health
Species contained within *The Plant List* belong to 620 plant families and 16,167 plant genera.

*The Plant List* includes 1,040,426 scientific plant names of species rank.

Of these 298,900 are accepted species names

www.theplantlist.org
Bacteria 10,000 species
Fungi 500,000 species
Nematode 50,000 species
Protozoa 100,000 species

NRCS national soil tilth lab
Primary effects:
- Enhanced microbial functions such as N fixation, decomposition, etc.
- Production of humic substances
- As food source, increases soil faunal and microbial diversity and activity
- Production of polysaccharide and other nonhumic compounds

Secondary effects:
- Increased buffering capacity
- Increased water holding capacity
- Increased ion adsorption capacity
- Darker soil color
- Production of burrows, macropores
- Increased aggregate stability, macro porosity
- Increased mineralization

Subsequent effects on soil:
- Increased supply of available N, P, S and micronutrients
- Increased availability of Fe, Mn, Cu, Zn
- Reduced toxicity of aluminum
- Increased water availability to plants

Environment effects:
- Inactivation of toxins, pesticides
- More stable soil pH
- More retention of Ca, Mg, K, and micronutrients
- Greater absorption of organic compounds
- Cooler soil in daytime, summer
- Warmer soil, on average
- Warmer soil at night, in winter

Red shows LMB 7 functions

A Complex Food Web

Figure 4

* Earthworms are generalists that feed on many smaller soil organisms.
Soil food web showing energy flow

- **Protozoa**
- **Nematode**
- **Fungi**
- **Bacteria**
- **Mycorrhizal Fungi**
- **Saprophytic Fungi**
- **Plant-feeding Nematodes**
- **Fungal-Feeding Mites**
- **Predatory Nematodes**
- **Predatory Mites**
- **Flagellates**
- **Amoebae**
- **Ciliates**
- **Heterotrophic Fungi**
- **Organic Matter**
- **Dead Material (from all boxes)**
- **Shoots**
- **Roots**
- **Algae**
- **P-Bacteria**
- **Lichen**

From all boxes

Root knot
Lesion
Dagger
Fungi feeding nematode
Bacteria feeding nematode
Potential threat of loss of biodiversity weighting (%)

65%  Human intensive exploitation
63%  Soil organic matter decline
60%  Habitat disruption
60%  Soil sealing
60%  Soil pollution
59%  Land use change
58%  Soil compaction
56%  Soil erosion
48%  Habitat fragmentation
45%  Climate change
38%  Invasive species
35%  GMO
Diversity provided by cover crops

Ultimate soil diversity is from soil microorganism secondary materials and decomposition breakdown products.

And this huge diversity is the foundation on which SOIL HEALTH, environmental health and FOOD QUALITY is based.
What is soil health?

• Health as commonly understood
• Soil capacity to sustain quality crops
• Holistic biological, chemical, physical
• Life force in soil
• Living total soil biomass
  All soil animals and plant ROOTS
• Living soil micro-fauna biomass
  actinomycetes, bacteria, fungi, nematodes, protozoa
• Living soil macro-fauna biomass
  algae, insects, micro-arthropods, worms
hyū-məs / hyuməs  [hyoo-muhs or, yoo-]  
noun

The dark organic material in soils, produced by the decomposition of vegetable or animal matter and essential to the fertility of the earth

• **Origin**  
  1790–1800; < L: earth, ground; akin to Gk chamaí on the ground, chthn earth, Skt kṣam-, Lith žėmė, Serbo-Croatian zèmlja ground, earth; cf.
Biological character of healthy soil

- Soil life diverse, high populations, active
- Soil is disease suppressive
- Nutrient cycling is obvious
- Crops show resistance-tolerance
- Pests present but crops loss is minimal
Philosophy, design and strategy
Living microbial biomass functions in soil

- Decomposition of organic matter
- Retain minerals from OM decomposition
- Recycling of immobilized minerals
- Plant growth promotion
- **Plant disease prevention**
- Aggregation of soil particles
- Decomposition of toxins
Living microbial biomass provides plants

- Controlled release of Nitrogen
- Stress relief from salts and toxins
- Release of nutrients in available forms
- **Natural suppression against pests**
  Antibiosis-Competition-Hyperparasitism ANTAGONISM to PEST
  Systemic acquired resistance TOLERANCE – RESISTANCE- host
- **Improved physico-chemical soil aspects**
  Humus development is a microbe process
  Structure development is a microbe process
ORGANIC MATTER
MANAGEMENT
COVER CROP
ORGANIC MATTER
MANGWEMENT
Plants (and lichen, moss, algae, photosynthetic bacteria) are the primary producers of organic matter on land and in the sea (fixed carbon) and are the base of the food chain.
Cover crops are a high quality source of organic matter which provides energy for the soil organisms which provide perform seven (7) essential functions for the crop and soil that cannot be practically or economically provided otherwise.
Diversity provided by ground covers

Diversity from polycultures of ground cover roots which EXUDE secondary metabolites by the thousands of types
Advantages of cover crops

- Prevention of soil erosion
- Diversity
- Soil health
- Nitrogen
- Beneficial habitat for life
- Field access
- Beauty
- Safety and comfortable work site
4,400,000,000 tons of carbon (C) has been lost from farming soils

NRCS national soil tilth lab
By 1936 there was 41% of land in the U.S. had moderate soil erosion and 12% had severe soil erosion and 3% was essentially destroyed.

55% of the total land mass eroded by 1936.

Benefits of cover crops

• Simple
  • Complex effects derived
  • Management increases benefits
  • Management and skill building
  • Increases benefits and decreases risk
  • Synergistic
Benefit of ground covers

• Inexpensive
  • Placement of carbon deep into soil
• Renewable
• Reliable
• Effective and simple
Barley and Oats: 60#/A; moderate rate of establishment; needs water; not great weed competition; good mulch source

Examples of barley-vetch mix: right is clean part of field; lower left has weeds; both pictures from March 2007; lower right shows mowed field planted with mangos in August 2007
Rye grass. Oregon annual seeded at 30#/acre;
Grows best in winter with cooler and wetter weather
Good weed competition
Good fibrous roots for erosion control

Left: Rye grass after 8 weeks in winter; inset above shows soil surface after heavy rain with soil retention by fibrous rye roots after mowing, rototilling, and overseeding with buckwheat (10 day old seedlings)
Buckwheat: 40#/acre; fast germination and canopy closure; excellent insectiary; fast to flower (30 days); good in summer or winter; will reseed; easy to kill with mowing only.
Biological fumigation

Winfred turnip
Brassica

Biological fumigation
Coffee

Amaranth

Coffee
Daikon radish on compacted high clay soil
Insectary Plants, Intercropping and Biological Control

By William Quarles and Joel Grossman

Diverse crop plantings can lead to fewer pests, more beneficial insects, and fewer pesticide applications. This article discusses increased diversity through field insectary plantings and strip intercropping. An earlier Practitioner article called "IPM and Farmscaping" (IPMP 13(10):1-12) reviewed the use of boundary plantings. "Agriforestry and IPM" (IPMP 14(4):1-12) discussed the interplanting of crops and trees.

Large monocultures may cause many of the problems associated with conventional agriculture. Extensive unbroken acreage of the same crop, such as corn or cotton, encourages arthropod pests (insects and mites) that specialize in these crops (Root 1973; Elton 1958; Andow 1991a). Because pests that specialize expand more rapidly than beneficial populations in these situations, broad-spectrum pesticides are applied. These pesticides then cause problems such as target pest resistance, pest resurgence, and secondary pest outbreaks that are all too familiar (see Quarles 1999; DeBach and Rosen 1991).

If it is true that monocultures encourage pests, then fewer pests should be seen when there is an increase in crop diversity (Andow 1991a; Pimentel 1961; Elton 1958). Generally, diversity does lead to lower pest densities. When the published literature was reviewed in 1991, about 52% of pest insects and mites studied had lower population densities in diverse plantings than in monocultures, while only 15% had higher densities. In 20% of the cases effects were variable [sometimes lower, sometimes higher], and in 12% of the cases, there was no effect. Most of the studies conducted in this review were on various kinds of intercropping (Andow 1991a).

Traditional farmers in other countries have long intercropped beans, corn, squash and other subsistence crops to make maximum use of their land (Francis 1986; Funes et al. 2002). There are several different ways to intercrop, and these are discussed in Box A. Published studies on intercropping since 1991 confirm the trend of lower pest densities in intercrops versus monocultures. For instance, in the 38 studies of intercropping and pest abundance cited in CAB Abstracts between 2000 and 2002, about 86% (33) showed lower pest densities with intercropping. Of these, 24% (9) intercropped a veg-

White flowering alyssum, Lobularia maritima, has been planted on the edge of this commercial lettuce field. Alyssum has abundant pollen and nectar to help feed beneficial insects that provide biological control.
Benefits of cover crops

• Effective

  • Prevents movement of soil
  • Elevates level of soil health
  • Develops Humus
  • Increases water infiltration, storage
  • Simple and inexpensive!
MULCH ORGANIC MATTER MANGWEMENT
Soil loss is principally due to water and wind erosion, both heightened by practices that reduce surface cover.

Australian Government department of the environment
Mulch

- Elevates level of soil health
- Food and habitat
- Prevent soil erosion and surface crusts
- Reflects light, cools soil surface
- Prevents soil compaction
- Tillage reduced
- Genes activated in crops growing with mulch

Soil organisms creating suppressive soil, resistant crops
“tomatoes cultivated in vetch mulch have reduced disease”

“disease tolerance of mulched tomatoes is linked to increased expression of specific genes and accumulation of their products”
9 soil surface dwelling animals

- Wood louse
- Springtail
- Orbatid mite
- Fly larva
- Millipede
- Enchytraeid worm
- Beetle larva
- Termite
- Earthworm
COMPOST ORGANIC MATTER MANAGEMENT
Compost
Definitions of compost

- By process: thermal compost or vermipost
- By feedstock: pumice or council greenwaste compost
- By age: immature or mature compost
- By biology: bacteria or fungi dominated compost
- By QUALITY: stability, curing, amended
- By Use: soil amendment
Definitions of compost

Aerobic microbial processes produces:

- Heat
- Water vapor
- Carbon dioxide
- HUMUS
Three (3) essential SOIL cultural practices

1. Organic matter management
   a) Cover crops
   b) Compost
   c) Mulch

2. Mineral management
   a) Balance minerals

3. Tillage management
   a) Beneficial disturbance
MINERAL MANAGEMENT
Legume roots
Soil Nutrient Bioavailability

A MECHANISTIC APPROACH

SECOND EDITION

STANLEY A. BARBER
Biological Nitrogen Fixation Associated with Rice Production

Editors
S.K. Dutta
Charles Sloger
Nutrient Quantity or Nutrient Access?
A New Understanding to Maintain Soil Fertility in the Tropics
Dr. Roland Bunch
Association of Consultants for a Sustainable Ecological and People-Centered Agriculture (COSECHA)
http://ppathw3.cals.cornell.edu/mba_project/moist/Rolandpd

The Management of Soils (Spanish)
Dr. Ana Primavesi
Soil life and chemical fertilizers
Types of Biological Nitrogen Fixation

- **Cyanobacteria**
- **Azospirillum**
- **Lichen**
Environment or climate
SOM strongly impacts soil environment
Minerals create larger plant biomass
Humus increased from root and plant biomass
Elevated humus supports larger MICROBIAL biomass
Large, active, diverse live soil biomass has 7 functions

SOM and humus
Suppressive factors in soil
Calcium flocculating clay
Calcium reducing Al-Mn toxicity

Pathogen/pests
Parasitism-Hyperparasitism
(Predator nematode)
Antibiosis & Competition x AM
Chitin decomposition
Spore decomposed
Weed seed decomposed

Soil
Disease conductive soil
Low humus and soil organic matter
pH and mineral imbalance
Compaction and increased bulk density
Poor water infiltration

Host
Resistence & tolerance
Genes regulate Mulch induced
Lignin synthesis K, Mn and Cu resistant
Root health improved
High calcium requirement rhizosphere microbe health
BORON, Ca. and P and VAM
BORON, polyphenols insect resistance
Lignin synthesis K, Mn and Cu
Potassium elevates tolerance

Growth of plant improved
Mineral balance Stable nitrogen
Mineral availability

Soil minerals and disease triangle
TILLGE
MANAGEMENT
**Lumbricus rubellus**
(Hoffmeister, 1843) (*Lumbricidea*)
Red wiggler or Marsh worm

- **Peregrine earthworm** (transported world wide by farmers)
  - Origin in northern temperate regions of Europe and Southern Asia
  - Assumed to be found in Hawaii
  - Dorsum red brown or **red violet iridescent**, ventrum is pale
  - 2 ½ to 6 inch length with 4-6 mm width

- **Epigeic or possible Endogeic species**
  - Foraging, mating and casting is below ground and explores mineral soil
  - Has a diapause phase spent in a “ball” in shallow soil
  - Lifespan is 2 or 2 ½ years

- **Obligate sexual reproduction**
  - 80-100 cocoons per year per adult worm
  - Produces cocoons that hatch live worms
**Amynthas corticis**,  
* A. diffringens, A. gracilis  
(Kinberg, 1867) *(Megascolecidae)*  
Black wriggler, Snake worm, Crazy worm, Alabama jumper or Georgia jumper  

- **Peregrine earthworm** *(transported world wide by farmers)*  
  first described in Oahu, Kinberg, 1867  
  misidentified as *A. hawayanus or Pheretima hawayana*  
  Mr. Domingo Cravalho, Jr. Invertebrate, Aquatic Biota specialist, U/H (1/14/04)  
  origin in Southern Asia, described as common Darjeeling in the Himalayas  
  common in Oceania including Polynesia, Micronesia, Japan, Australia, China  
  dark chocolate brown with green iridescence  
  4 ½ to 6 ½ length with 3-6 mm width  
  behavior when perturbed is vigorous lashing and rapid snaking escape  

- **Epigeic species earthworm** *(soil surface litter dwellers)*  
  *Amynthas* has capacity to exist on high C:N ratio organic matter  
  *Amynthas* tolerates heat, drought, sandy soil or clay soil  
  *Amynthas* highly mobile, wanders at night, transportation exceeds Lumbricids  

- **Parthogentic earthworm** *(virgin birth)*  
  reproduces without a mate  
  produces cocoons containing one (1) or two (2) eggs  
  multiplies rapidly throughout year producing up 360 juvenile worm per year
FOOD QUALITY
Soil Biology, Soil Health and Food Quality
developing sustainable farms

• Food quality
  • Flavor, aroma and mouth feel
  • Mineral density
  • Nutrient density...oils, protein
  • Secondary metabolites antioxidants
Coffee antioxidants

- Coffee has remarkable antioxidants Daglia, Papetti, 2004
  - Green beans and roasted coffee both have antioxidants
  - *C. Robusta* has more antioxidant value vs. *C. Arabica* as green
  - Roasted *C. Robusta* and *C. Arabica* were equal in antioxidants
    Castillo, Ames, Gordon, 2002

- Heterocyclic compounds Yanagimoto, Ochi, Lee, Shibamoto, 2004
  - Furans-
  - Pyrroles-
  - Maltol-

- 5-0-caffeoilquinic acid Dr. T. Hofmann, 2004

- Chlorogenic and Caffeic acids Daglia, Papetti, 2004

- Methylpyridinium Dr. T. Hofmann, 2004 EXPRESSO had highest level
  - Formed by roasting from Trigonellin in green coffee bean
  - Melanoidins (medium roasted has highest levels) (dark was least)
  - Roasting induced high MW Maillard reaction products Daglia, Papetti, 2004
Organic farming is viable

- Rodale Institute farming systems trial
  Study replicated 22 years growing corn and soybeans
  Dr. Paul Hepperly, agronomist, Rodale Institute
  Dr. Rita Seidel, agronomist, Rodale Institute
  Dr. David Douds Jr., microbiologist, USDA, ARS, University of MD.
  Dr. James Hanson, agricultural economist, University of Maryland

“Organic farming produces the best food quality, equivalent or higher yields, less soil erosion, more carbon retention in soils, better soil quality and conserves more biological resources when compared with conventional farming”

Dr. David Pinentel,
Cornell University, professor of agriculture
Bioscience, vol. 55:7, July 2005
Organic food is nutritious

Nutritional quality of organic versus conventional fruits, vegetables and grains
Virginia Worthington, M.S., Sc. D., C.N.S.
The Journal of Alternative and Complementary Medicine
Volume 7, number 2, 2001, pp.161-173
mal/10755535/v7n2/s7/p161

Organically produced foods: Nutritive content
A bibliography with 216 papers + research reports
Mary V. Gold, reference librarian/information specialist
Alternative farming systems (AFSIC)
National Agricultural Library, ARS, USDA
E-mail: afsic@nal.usda.gov
Phone 301-504-6559
Antioxidants in organic compared to conventional crops

7 studies compare antioxidants in organic vs. conventional crops

15 cases showed statistically significant differences in antioxidant levels in organic vs. conventional crops

In 13 of the 15 cases, organic showed higher antioxidant levels

Organic crops averaged 33% higher antioxidant content crops
Research comparing farming methods and secondary metabolites

- Asami et al. (2003) USA J. of Ag. Food Ch. blackberry, strawberry, corn
- Ren et al. (2001) Japan, J. of Sci. Food & Ag. onions, peppers, spinach, cabbage
- Carbono et al. (2002) Italy pears, peaches
- Hakkinen-Torronen (2000) Finland strawberries
- Lombardi-Boccia et al. (2004) Italy plums
- Zafrilla et al. (2003) Europe, JAFC 51:4694 wine
- Lavite et al. (2003) France, wine
Where do you find secondary metabolites in living plants?

- Highest concentration at point of attack
  - Fungi, bacteria, virus, physical wound
- Highest concentration in skins
- Highest on sun exposed outer leaves
- Smaller fruit have more (skin to pulp ratio)
- Concentration changes quickly
Cercospora coffeicola Berk. & Cke

Caffea arabica L. Guatemalan typica
Taro leaf blight, *Phytophthora colocasiae*