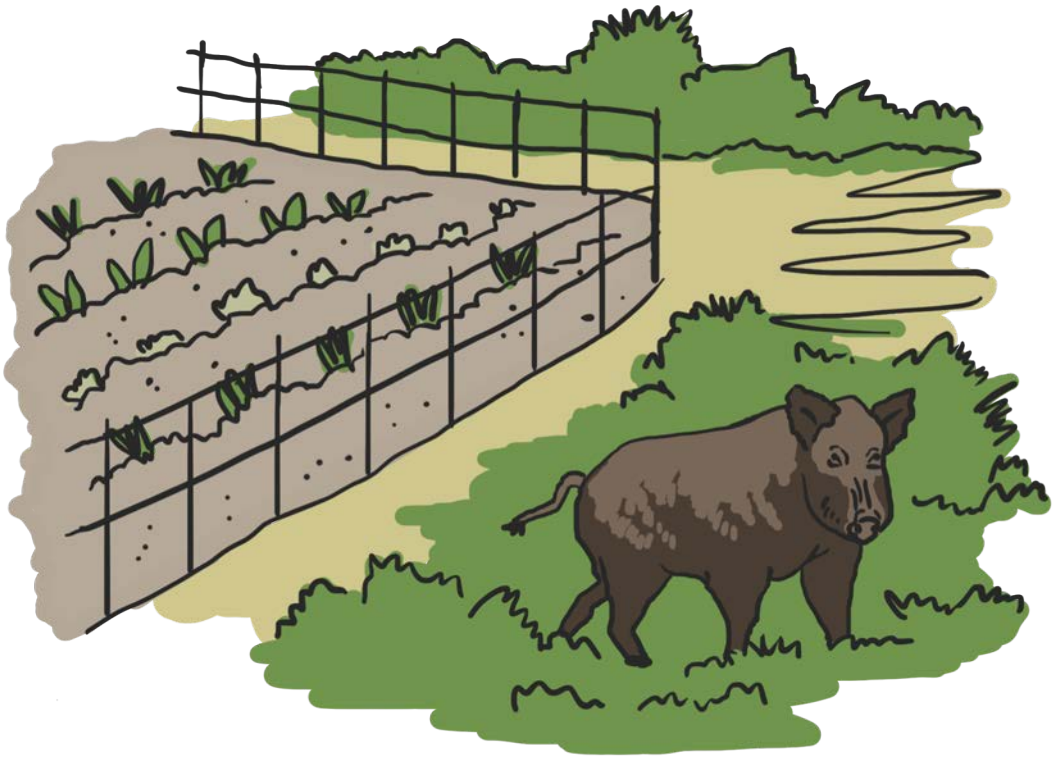
O'AHU RESOURCE CONSERVATION & DEVELOPMENT COUNCIL

COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES
UNIVERSITY OF HAWAI'I AT MĀNOA

Food Safety and Conservation Co-Management

A Guide for Hawai'i Growers



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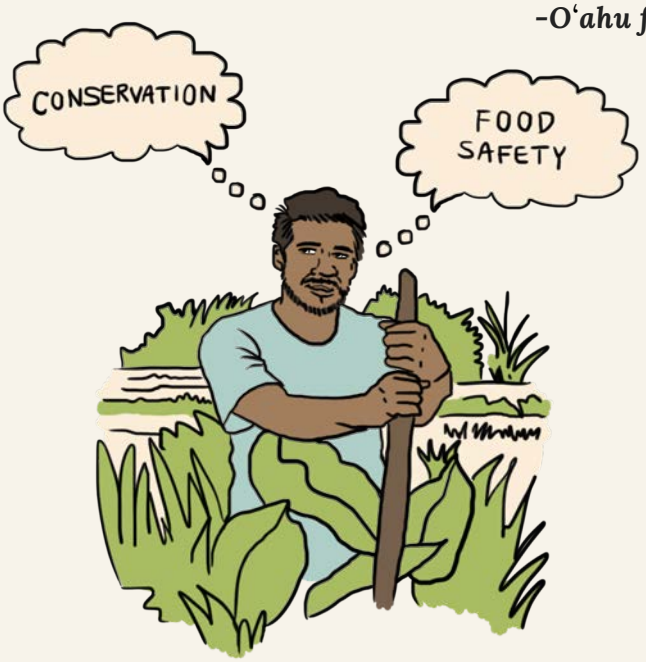
What is Co-Management?

"We're growing healthy food, and preserving the land we grow it in"

-Oʻahu farmer

Co-management
refers to managing farms and their surrounding environments, such that multiple goals are achieved: natural resource conservation *and* food safety.

Co-management practices
refers to those *best management practices* (BMPs) which meet objectives in both goal areas.



Goal:
Reduce risks to food safety

Goal:
Protect and conserve soil and water resources

Co-Management:
Streamline labor and efforts into field practices that satisfy both goals

In a 2020 survey, Hawaiʻi agricultural professionals and farmers shared their thoughts on what co-management could mean for them. In summary, they responded:

- Saving money by focusing on and prioritizing practices that will offer multiple benefits
- Creating more incentives to install conservation practices, which previously may not have been considered as efforts towards food safety
- Optimized use of farmer time - especially at workshops, events, and field days

Importance and Role of Co-Management

Co-management encourages a balance between nature and agriculture, where positive results for both goals are achieved with one practice. Farmers can balance food safety goals with natural resource conservation, using this management technique.

Sustainable food production relies on long-term soil and ecosystem health, consumer safety and wellbeing, and economic viability.

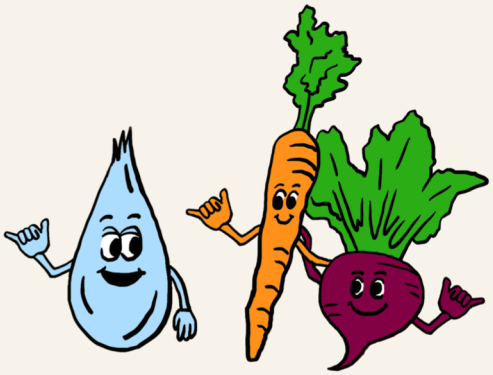
- ➔ Farms that experience continual loss of soil health, beneficial microorganisms, and native ecology can become expensive to manage and lead to reduced agricultural yields.
- ➔ Contamination from animals and microbiological pathogens can pose serious food safety risks to consumers if good agricultural practices are not implemented.

Farmers are busy people, with limited time and resources. Co-management can assist farmers with identifying practices that promote both natural resource conservation and food safety.

- ➔ This guidance document seeks to assist farmers interested in co-management by providing a list of suggested practices and information for farms in Hawai‘i to streamline the decision-making process.
- ➔ This resource can be utilized as farmers meet with conservation planners and food safety planners, to facilitate co-management integration into each planning process.

Potential Challenges

- Some farm features and practices that benefit the environment (e.g., animal habitat, etc.) may present food safety risks.
- Certain practices that promote farm food safety (e.g., utilizing bare ground to minimize animal habitat and allow for animal monitoring) may lead to soil-water degradation and loss via erosion or runoff from heavy rainfall events.

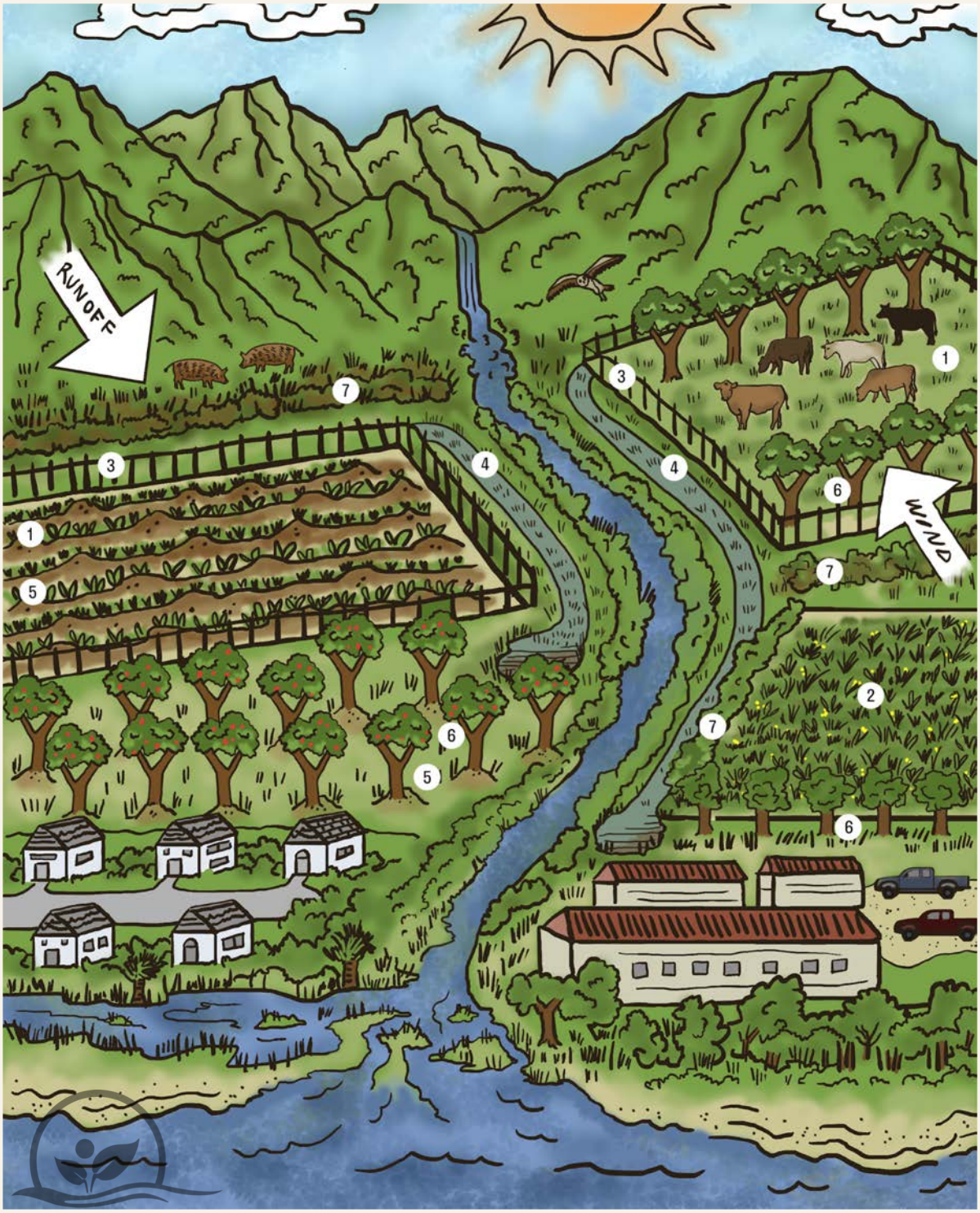


What this means: We have two issues, and solutions to each can be harmonious with proper design, but are challenging to align without consideration and understanding for the farm as a whole.

In *modern agriculture*, conservation and food safety efforts must align to achieve sustainable outcomes. Here, we try to identify common ground.

What Does Success Look Like?

An ahupua'a with co-management agricultural practices



A *co-management ahupua'a:* Compost amendment (1), Cover crop (2), Fencing (3), Grassed waterway (4), Mulching (5), Vegetative barrier (6), Windbreak (7)

Farm Food Safety

the basics

Preventive action through co-management is recommended to reduce potential future food-related illness outbreaks.

Farm food safety prioritizes the prevention of physical, chemical, and biological contamination of fresh produce by utilizing a set of risk-reduction guidelines that are grounded in scientific knowledge called Good Agricultural Practices (GAPs). GAPs are the foundation for farm food safety, as well as federal regulations and third-party audits.

Farm food safety requirements can fall under two different entities:

1. The Food Safety Modernization Act- Produce Safety Rule (FSMA-PSR) is a mandatory federal regulation under the Food and Drug Administration (FDA) that requires certain criteria be met regarding farm food safety practices for certain crop and farm types.
2. Third-Party Audits are voluntary certification processes that involve an auditor inspecting a farm for food safety on behalf of a buyer. Although audits are voluntary, some buyers may require a farmer to pass an audit before purchasing produce.

Hawai‘i Recall and Outbreak Highlights

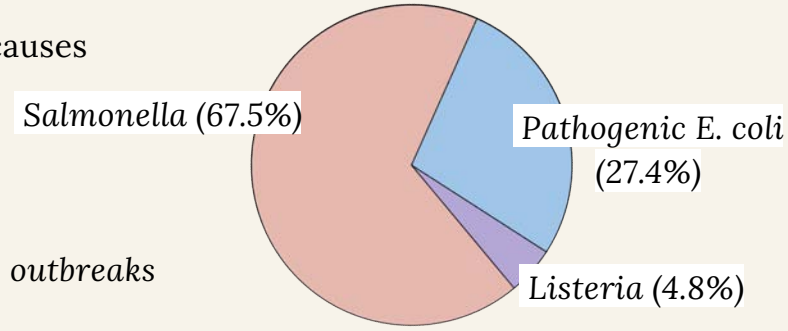
- Macadamia nut recall for possible *E. coli* contamination (2018)
- Macadamia nut recalls for *Salmonella* contamination (2016)
- *Salmonella* outbreak from ogo (seaweed) grown on O‘ahu (2016)
- *E. coli* outbreak from lettuce grown on Kaua‘i (2007)

Multi-State Outbreaks Associated with Fresh Produce Caused by Bacteria (2010-2017)

83 outbreaks in the US with confirmed causes

- 4,4501 illnesses
- 1,117 hospitalizations
- 55 deaths

**Salmonella was linked to majority of the outbreaks*

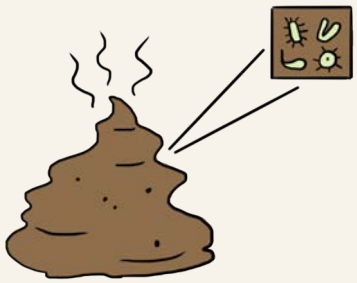


Bacterial causes of outbreaks

Farm Food Safety

the basics

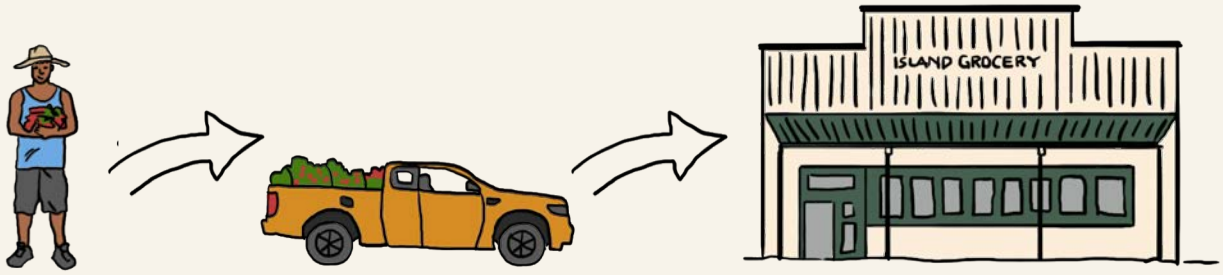
Feces (human and animal), cross-contamination, and improper hygiene are major sources of contamination on produce. Sources of contamination and potential solutions are included in the following table.



Contamination Source	Potential Solutions
Wildlife intrusion and animal feces in production zones (e.g. fields and packing sheds) and water sources	• Co-management practices (e.g. fencing) • Animal deterrents • Pre-harvest inspection • Do not harvest produce contaminated with feces
Contaminated water or runoff that contacts edible portions of crops	• Co-management practices (e.g. vegetative barrier) • Treat agricultural water with appropriate sanitizer • Do not harvest crops adulterated by runoff/flooding
Improper cleaning and sanitizing practices that fail to eliminate contaminants	• Implement regular cleaning and sanitizing schedules • Monitor concentration of sanitizer solutions, if applicable
Poor worker hygiene practices (e.g. improper hand washing and toilet practices, ill workers handling produce)	• Provide adequate toilet and handwashing facilities • Train workers on proper handwashing technique • Send home workers who are ill

<u>Other useful practices to strengthen farm food safety</u>:

1. A *food safety plan* that lists farm policies, practices, procedures used to address food safety concerns, and stores any records and documentation for regulatory purposes and future reference.
2. A *traceability system* that can track your products back to the field from which it was harvested and to whom it was sold, in case of a recall event or outbreak.



Natural Resources and Conservation

the basics

What are goals for healthy ecosystem conditions?

Before landscapes were industrialized, they were part of a natural ecosystem that kept interactions of resources and organisms in balance. Examples of natural resources are soil, water, air, and wildlife.

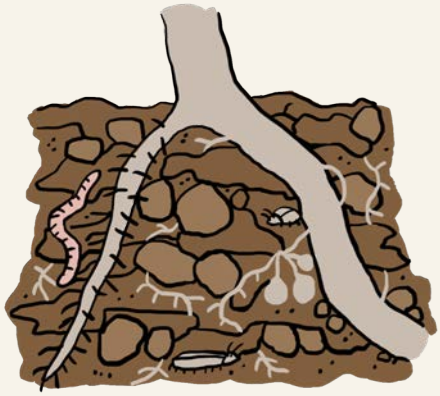
As we progressively manage resources to meet our needs for food and fiber (specifically soil and water in agricultural operations), we must remain mindful of what made them healthy to begin with and aim to maintain fertile environments and soils, imitating natural processes as much as possible.

Water

- ➔ Precipitation/irrigation water is able to **rapidly infiltrate the soil**, replenish groundwater, and minimal amounts reach the ocean as runoff
- ➔ Water in or near streams is met by **buffers of vegetation** which help to remove contaminants, soil, and to slow the speed of flowing water
- ➔ Water is **free of man-made contaminants** or pollution

Soil

- ➔ Healthy soil has **plentiful organic matter and microbial life** - typically, soils rich in organic matter and life are dark and have a sweet earthy smell
- ➔ Healthy soil can **effectively cycle nutrients** with the help of microorganisms, requiring minimal synthetic inputs
- ➔ Soil has a **continuous presence of living roots**, and should never be left bare
- ➔ Soil should have **visible structure**, created by organic matter, roots, and organisms, which creates pore spaces and allows it to hold both water and air



Healthy soil is *ALIVE!*

Natural Resources and Conservation

the basics

Organisms

- ➔ Life in a **healthy ecosystem is biodiverse**, meaning a wide variety of species, with a focus on maintaining native populations where possible.
- ➔ **Sufficient habitat variety** to support a biodiversity of wildlife, plants, and various other organisms is necessary for a functioning ecosystem.
- ➔ **Lack of a dominating invasive or pest species** - organisms (including plants, animals, and microbes) will naturally compete for resources and keep populations in balance in a healthy system. Diverse soil microbial populations generally also promote predation and antagonism of pathogenic microbes, positively influencing food safety and plant health.

Biodiversity refers to the variety of life in the world or in a particular habitat or ecosystem.

In an agricultural ecosystem, maintaining biodiversity of plants, animals, and microbes, can help keep pest and pathogen populations in check.

Potential Tradeoffs Between Food Safety and Conservation Goals

How do environmental features influence Hawai'i agriculture and co-management?

Identifying and understanding potential tradeoffs between an ecosystem and an agricultural operation can improve management decision-making, even when there is no simple "win-win" to attain both conservation and food safety goals. Examples of some tradeoffs that impact food safety and conservation efforts are detailed below:

Environmental Feature	Presence/ Absence	Impact on Food Safety	Impact on Conservation
Wildlife	Presence	Fecal contamination Transmission of pathogens	Increased biodiversity Potential invasive species issues (e.g. invasive plant seeds, vegetative disturbance)
	Absence	Less fecal contamination	Lack of biodiversity and native species
Vegetative Cover	Presence	Habitat for pests Protects against runoff, dust contamination	Increased biodiversity and wildlife habitat Plant roots and ground cover protect soil against erosion
	Absence	Less habitat for pests Potential runoff, dust contamination	Soil erosion due to lack of plant roots and vegetative cover

*Red=relative negative impact ; green=relative positive impact

What Co-Management Practices are Suitable for Hawai‘i Agriculture?

benefits and practicalities

Effective co-management practices must not only balance conservation and food safety needs, but also be practical for the farmer.

While there is no one-size-fits-all approach to farming with co-management, some practices can be considered on an individual basis to suit the needs of the farmer.

Of the many co-management practices available, presented below are the most popular practices determined by Hawai‘i agricultural professionals well-versed in both conservation and food safety, and refined by local farmers from across the state for perspectives on beneficial and feasible practices for Hawai‘i agriculture.

**Note: Co-management practices listed may suppress microbial pathogens and associated risks, but do not solve food safety risks completely. A comprehensive food safety program grounded in Good Agricultural Practices should be implemented to minimize farm food safety risks.*

Farmers have a difficult task of managing food safety with land stewardship, and remaining profitable. While each farm is unique, the functions of these seven co-management practices provide a suite of benefits to both food safety and conservation.

Compost Amendment

Priority concern addressed: Soil Health

[Application of decayed organic carbon-rich material with many microbiological, structural, and fertility benefits for soil]

Improves soil health and soil biodiversity, helping to encourage microbial diversity and competition that suppress pathogens. Compost can improve soil structure, leading to increased infiltration of water and reduced risk of potentially contaminated runoff or irrigated water to come in contact with produce.

Functions

- ➔ Increased microbial biodiversity
- ➔ Improved soil structure
- ➔ Increased water holding capacity
- ➔ Increased available nutrients

Best use: *Good for farms that need to improve soil health and function.*

Benefits

...to food safety

- ❖ Balancing/suppressing populations of human pathogens

....to conservation

- ❖ Building soil carbon and health
- ❖ Improved drought resistance
- ❖ Improved nutrient availability

Practicality

the cons

- ❖ May be too expensive/labor intensive for large scale operations
- ❖ Using an unfinished compost or improper application can pose food safety risk

the pros

- ❖ Reduced need for fertilizer
- ❖ Compost tea is convenient to add into drip irrigation
- ❖ Long term benefits, requiring infrequent application in subsequent years

Cover Crops

Priority concern addressed: Soil Health

[Grasses, legumes, and forbs planted for seasonal vegetative cover and encouraging beneficial insects]

Improves soil health and soil biodiversity, helping to encourage microbial competition that suppress pathogens. Cover crops can also improve soil structure, leading to increased infiltration of water and reduce the risk of potentially contaminated runoff or irrigated water to come in contact with produce. Some cover crops are also effective at increasing nutrients in the soil.

Functions

- ➔ Increased plant and microbial biodiversity
- ➔ Improved soil structure
- ➔ Increased water infiltration
- ➔ Increased available nutrients

Best use: *Good for farms that need to improve soil health, reduce fertilizer input, and attract beneficial insects.*

Benefits

...to food safety

- ❖ Balancing/suppressing populations of human pathogens
- ❖ Reducing potentially contaminated runoff or standing water

....to conservation

- ❖ Building soil carbon and health
- ❖ Reducing runoff and soil erosion
- ❖ Improved drought tolerance
- ❖ Improved nutrient availability

Practicality

the cons

- ❖ Uncertainty regarding which cover crops will best compliment the farmer's goals
- ❖ Using a cover crop incorrectly can be detrimental to the cash crop
- ❖ Lack of equipment for seeding and/or removal
- ❖ Cost and availability of seed

the pros

- ❖ Reduced need for fertilizer
- ❖ Suppression of crop pests
- ❖ Reduced erosion and increased infiltration

Fencing

Priority concern addressed: Pests/pathogens

[A constructed barrier to animals or people]

Excludes wildlife which reduces the risk of feces and other contaminants from coming in contact with produce. Fencing reduces the ability of wildlife or livestock to transfer pathogens into a production zone.

Functions

- ➔ Wildlife exclusion
- ➔ Livestock enclosure

Best use: *Good for farms near forested areas or zones frequented by ungulates*

Benefits

...to food safety

- ❖ Reduced potential for animal fecal contamination in production zones

....to conservation

- ❖ Reduced soil disturbance from larger wildlife

Practicality

the cons

- ❖ Expensive materials and installation
- ❖ State or federal restrictions regarding endangered species habitat may prevent installation

the pros

- ❖ Effective to eliminate damage from ungulates

Grassed Waterways

Priority concern addressed: Runoff

[A vegetated channel that conveys surface water at a non-erosive velocity to a stable outlet]

Encourages infiltration of potentially contaminated runoff into the soil and diverting away from production areas. This practice reduces the amount of potentially contaminated runoff that flows over production fields and reduces exposure of harmful pathogens on produce and/or to farm employees.

Functions

- ➔ Increased surface water infiltration
- ➔ Improved soil structure
- ➔ Increased plant cover

Best use: *Good for farms with steep topography and high rainfall*

Benefits

...to food safety

- ❖ Reduced risk of contamination from runoff and floodings to farm production areas

....to conservation

- ❖ Reduced soil erosion
- ❖ Building carbon and soil health
- ❖ Groundwater recharge

Practicality

the cons

- ❖ Labor, equipment, and cost required to dig channel and establish seed.
- ❖ Requires regular manual maintenance of grass

the pros

- ❖ Helps to reduce problematic puddling
- ❖ Effective to guide water into more desirable areas, such as to a sediment basin/catchment pond

Mulching

Priority concern addressed: Soil Health

[Applying plant residues or other suitable materials to cover soil]

Covers and protects the soil, which improves erosion control and soil health. Improves water infiltration into the soil, reduces the risk of potentially contaminated runoff or irrigated water coming in contact with produce. Additionally, mulch may create habitat for biodiverse organisms which may suppress pathogen populations.

Functions

- ➔ Increased microbial biodiversity
- ➔ Increased water holding capacity
- ➔ Increased soil cover
- ➔ Increased organic matter/ microbial substrate

Best use: *Good for farms that need to reduce irrigation costs and improve soil health*

Benefits

...to food safety

- ❖ Balancing/suppressing populations of human pathogens
- ❖ Reduced need for irrigation resulting in reduced risk of potentially contaminated runoff

....to conservation

- ❖ Building soil carbon and health
- ❖ Improved drought resistance
- ❖ Reduced erosion

Practicality

the cons

- ❖ High cost and labor to implement
- ❖ Concern of creating habitat for undesired pests such as slugs and snails

the pros

- ❖ Helps reduce soil movement and tracking around the farm
- ❖ Helps to reduce need for irrigation water, reduces water cost

Vegetative Barriers

Priority concern addressed: Runoff

[Permanent strips of stiff, dense vegetation established across runoff areas]

Traps sediment and minimizes runoff containing potentially contaminated soil or water from entering active production areas, reducing exposure of harmful pathogens.

Functions

- ➔ Increased surface water filtration
- ➔ Increased living roots/plant cover
- ➔ Increased water infiltration

Best use: *Good for farms with steep topography and high rainfall*

Benefits

...to food safety

- ❖ Reduced transfer of potentially harmful pathogens via runoff and flooding into farm production areas

....to conservation

- ❖ Reduced soil erosion
- ❖ Building carbon and soil health
- ❖ Groundwater recharge

Practicality

the cons

- ❖ Can create habitat for undesirable insects, birds, and rodents

the pros

- ❖ Effective to slow runoff and trap sediment in runoff

Windbreaks

Priority concern addressed: Pests/pathogens

[Single or multiple rows of trees or shrubs, positioned to reduce wind speed

Blocks wind and reduces airborne contamination risks. A windbreak installed perpendicular to the direction of prevailing winds can block undesired sediment and pathogens from landing on production fields and introducing risk from neighboring areas. Windbreaks may also decrease the rate of evaporation from production zones, resulting in a reduced need for irrigation and risk of irrigated water runoff.

Functions

- ➔ Increased plant biodiversity
- ➔ Interception of airborne pathogens
- ➔ Increased pollination
- ➔ Reduced evaporation of irrigated water

Best use: *Good for farms seeking visual or airborne contamination protection, or wind-sensitive crops*

Benefits

...to food safety

- ❖ Reduced transmission of airborne contaminants

....to conservation

- ❖ Build soil health and carbon, habitat creation
- ❖ Water conservation
- ❖ Reduce wind erosion

Practicality

the cons

- ❖ Length of land lease may impact farmer desire to invest in permanent vegetation
- ❖ Can encourage undesired bird populations near fields

the pros

- ❖ Reduces wind stress on crop
- ❖ Reduces pesticides/herbicide drift and sediment transport from neighbor operations
- ❖ May be multi-purpose, such as food/timber

Co-Management Practices in Food Safety Planning

How can you put co-management ideas to work when writing a food safety plan?

Communicating conservation solutions to improve food safety can assist a farmer, if and when they are asked about their farm food safety practices, especially during inspections or audits.

Co-management practices can be conveyed both verbally, or in writing, such as in documents like farm food safety plans, policies, and procedures. To do this, interested farmers should:

1) Assess and evaluate food safety risks on the farm, including sources of the risk
2) Determine which co-management practices may be suitable to address those risks
3) Understand and be able to describe how the selected practices support farm food safety goals to minimize risks. It is important to communicate how the practice supports the farm's specific needs and goals - every farm is unique!

If needed, local agricultural professionals can assist farmers in Steps 1 & 2. After Step 2, a farmer may decide to utilize the suggested language in Appendix A to aid in communication of Step 3:

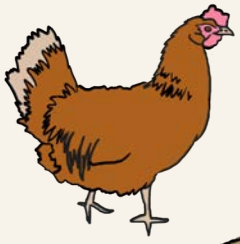
Using _____ (insert co-management practice) helps to support my farm food safety goal by_____ (insert template language from Appendix A).

Co-Management

an example for food safety planning

Farmer Kalani follows all recommended food safety precautions during the post-harvest phase, but would also like to do more to reduce risk during pre-harvest to best protect his consumers.

Farmer Kalani identifies two risks to food safety at the pre-harvest stage:



1) His mauka neighbors have a poultry farm, and during heavy rain events, potential runoff containing feces could enter his cabbage fields and pose a food safety risk.

2) He also has concerns that the E. coli and Salmonella risk is high in his fields after occasionally noticing signs of pigs and deer at the farm (e.g. tracks, feces, crop damage).

Kalani asks for help from conservation specialists in his local network and identifies that a ***vegetative barrier*** could help to reduce runoff that enters his property from his neighbor's farm. They also identify that ***fencing*** the field borders may minimize wildlife intrusion into his cabbage fields. Additionally, the conservation specialist encourages ***compost*** or ***cover crops*** as a means to promote a diverse microbial community in the soil, which can enhance microbial competition and lower survival of pathogens in the soil.

In his *food safety plan*, Farmer Kalani explains how these four co-management practices are supporting his goals to improve the quality and safety of the food he produces, by using the example language provided in Appendix A for each practice.

Farmer Feedback

barriers to co-management

With so many potential benefits, why aren't some farmers doing more of it?

Feedback from interviewed farmers made evident the occasional conflicting goals of co-management. Generally, practices that would improve the ecosystem health had the potential to conflict with farmer objectives in one or more of the following ways:

- High cost of labor
- High cost of materials
- Lack of appropriate equipment for installation or maintenance
- Conflict with plant productivity
- Uncertainty of impact/benefit
- Amount of time it takes to benefit exceeding the length of the lease on the land for the current farmer
- Negative impact of the conservation issue is not a critical concern for the current farmer

By considering these potential conflicts on a *case-by-case basis*, we can better support and identify our continued efforts to provide useful co-management resources to farmers in Hawai'i.

Help Beyond the Farm

assistance required from outside resources

Farmers and professionals across the state express that we have a complex issue at hand, one which requires the continued collaboration of private, non-profit, public, and government entities to improve. The following items are identified as concerns that extend beyond the responsibility of individual farmers and will require the attention of additional resources in order to see improvement in food safety and natural resource conservation in Hawai‘i.

- Upgrading mauka ungulate management and fencing
- Encouraging native plants, wildlife, and wetlands in the surrounding residential development areas and public spaces
- Improving farmer access to affordable cover crop seed and composts/organic amendments
- Increasing farmer access to reduced/no-till equipment and cover cropping equipment
- Improving the quality of water available to farmers for irrigation use, where contamination may occur due to poor resource management (e.g. ungulate disturbance and waste)
- Building greater scientific understanding of where contamination originates in Hawaiian landscapes and the risks/benefits of natural ecosystem features

KEY MESSAGE

Harmful pathogens on produce - mostly originating from untreated livestock, wildlife, and human waste - can make people sick. Some of the recommendations to eliminate these risks can conflict with recommendations for conserving wildlife, soil, and water quality. It's important to find ways that farmers can utilize co-management practices to produce safe food, be good land stewards, and remain economically viable. Farmers who are making high-stakes decisions with limited available information, will ultimately require greater support in governmental farm policy and rule-making to achieve a balance of objectives.

Who can help

Oʻahu Resource Conservation and Development Council (Oʻahu RC&D): Grant opportunities for BMP installation, providing informative workshops, on-site technical support, and providing fee for service or grant-funded conservation planning.

College of Tropical Agriculture and Human Resources Extension (CTAHR extension): Food safety technical assistance, Produce Safety Rule Grower Trainings, On-Farm Readiness Reviews.

North Shore Economic Vitality Partnership (NSEVP): Trainings and resources regarding Food Safety Modernization Act and GroupGAP opportunities.

Natural Resource Conservation Service (NRCS): Federally funded conservation planning and BMP technical and financial support.

Department of Fish and Wildlife (DOFAW): Review and assistance with identifying where potential wildlife habitats exist.

Where to learn more

Wild Farm Alliance: Food safety and Conservation Resources

Roots FSMA Guide

Produce Safety Alliance

Oahu RC&D

Contributors

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COOPERATIVE EXTENSION
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NORTH SHORE ECONOMIC VITALITY PARTNERSHIP

Mahalo to all of our participating farmers and agricultural professionals!

USDA
United States Department of Agriculture
National Institute of Food and Agriculture

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WESTERN SARE
Sustainable Agriculture Research & Education

Appendix A:

food safety plan template language

Compost amendments: Improving soil health, carbon, biodiversity, helping to encourage microbial diversity and competition that suppress pathogens. Compost can improve soil structure, leading to increased infiltration of water and reduce the risk of potentially contaminated runoff or irrigated water to come in contact with produce.

Cover crops: Improving soil health and soil biodiversity, helping to encourage microbial competition that suppress pathogens. Cover crops can also improve soil structure, leading to increased infiltration of water and reduce the risk of potentially contaminated runoff or irrigated water to come in contact with produce.

Fencing: Excluding wildlife which reduces the risk of feces and other contaminants from coming in contact with produce. Fencing reduces the ability of wildlife or livestock to transfer pathogens into a production zone.

Grassed waterways: Encouraging infiltration of potentially contaminated runoff into the soil and diverting away from production areas. This practice reduces the amount of potentially contaminated runoff that flows over production fields and reduces exposure of harmful pathogens on produce and/or to farm employees.

Mulching: Covering and protecting the soil, which improves erosion control and soil health, and also serves as a barrier between potentially contaminated soil and crops. Mulching improves water infiltration into the soil, and reduces the risk of potentially contaminated runoff or irrigated water from coming in contact with produce. Additionally, mulch may create habitat for biodiverse organisms which may suppress pathogen populations.

Vegetative barriers: Trapping sediment and minimizing runoff containing potentially contaminated soil or water from entering active production areas, reducing exposure of harmful pathogens.

Windbreaks: Blocking wind and reducing airborne contamination risks. A windbreak installed perpendicular to the direction of prevailing winds can block undesired sediment and pathogens from landing on production fields and introducing risk from neighboring areas. Windbreaks may also decrease the rate of evaporation from production zones, resulting in a reduced need for irrigation and risk of irrigated water runoff.

Appendix B:
resource summary

Practice	Mechanism	Reference	Summary
Compost amendment	Pathogens, Runoff	Kim et al. 2011 Paniel et al. 2010 Williams et al. 2015 Xing et al. 2019	*E. coli* O157:H7 growth in compost was negatively correlated with higher indigenous microorganism populations (Kim et al. 2011). Pathogens did not survive in stabilized compost with high indigenous microorganism populations,compared with sterilized compost (Paniel et al. 2010). Higher soil organic matter and moisture content, soil microbial diversity, and lower soil pH suppress *E. coli* abundance in the soil (Williams et al. 2015; Xing et al. 2019).
Cover crops	Pathogens, Runoff	Patel 2013 Williams et al. 2015 Xing et al. 2019	Glucosinolate compounds from Brassica cover crops and residues have an antibacterial effect on Salmonella and E. coli O157:H7 (Patel 2013). Higher soil organic matter and moisture content, soil microbial diversity, and lower soil pH suppress *E. coli* abundance in the soil (Williams et al. 2015; Xing et al. 2019).
Fencing	Wildlife Intrusion	Lavelle et al. 2011 Reidy et al. 2008	Electric fences reduced feral pig intrusions by 65% compared to non-electrical fences, with 2- and 3-strand fences having 40-50% fewer crossings than a single strand fence (Reidy et al. 2008). Hog wire panels were the most effective fencing option at containing feral swine, followed woven-wire mesh and electric fences. Regular maintenance of hog panels and lethal removal by helicopter shooting further increased success to 97-100% (Lavelle et al. 2011).

Appendix B:
resource summary

Practice	Mechanism	Reference	Summary
Grassed waterways	Runoff	Fiener & Auerswald 2003	Grassed waterways can significantly reduce runoff volume and velocity (up to 90% for unmanaged vs 10% for cut), including sediments and agrochemicals.
Mulching	Runoff	Honjoh et al. 2014 Micallef et al. 2016 Qu et al. 2018 Xu et al. 2016	Plastic mulch reduced *Salmonella* contamination on lettuce leaves in contaminated soils, likely due to reduced contact between lettuce and soil (Honjoh 2014). Green waste and organic mat mulches reduced windborne dust erosion by 60-80% compared to bare-ground at wind speeds less than 16 mph (Qu 2018). Bacteria and E.coli can survive under mulch, with higher populations found under plastic and straw mulch than bare ground (Micallef et al. 2016; Xu et al. 2016).
Vegetative barriers	Runoff	Roodsari et al. 2005 Sellers et al. 2018 Sullivan et al. 2007 Tate et al. 2006	Vegetated filter strips of fescue grass reduced runoff by 59-81% and fecal coliform discharge by 23-67% compared to bare-ground, primarily through increased water infiltration into the soil (Roodsari et al. 2005). Vegetated buffers from 1 to 25 meters wide reduced the fecal coliform levels in runoff water by more than 99% (Sullivan et al. 2007). Vegetative buffers reduced *E. coli* discharge by 0.3 to 3.1 $\log_{10}$ with each additional meter of buffer, but loss efficiency with higher runoff volumes (Tate et al. 2006). Hedgerows surrounding walnut orchards and tomato fields promoted wildlife diversity, but did not lead to increases in wildlife intrusion into crop production areas or prevalence of foodborne pathogens (Sellers et al. 2018).

Appendix B:
resource summary

Practice	Mechanism	Reference	Summary
Windbreaks	Aerosols	Burley et al. 2012 Hernandez et al. 2012 Malone 2004 Sames et al. 2020	Vegetative tree buffers of cypress, willow, pine, or cedar reduced dust in the air downwind of the buffer strip by 30%-60% of dust (Malone 2004; Hernandez 2012). Vegetative tree buffers of maple, oak, poplar, adler, willow, and grasses reduced viral infections of chicken coops compared to the control in only the last year of a 3-year study. It was thought that once the buffers had grown to a fuller and greater height, they would have functioned better to reduce the spread of pathogens (Burley et al. 2011; Sames et al. 2020).

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References

Baumgartner, Jo Ann, and Runsten, Dave. 2013. Farming with food safety and conservation in mind. Wild Farm Alliance and Community Alliance with Family Farmers.

Baumgartner, Jo Ann, Lowell, Karen, and Donavan, Meaghan. 2016. Co-Managing Farm Stewardship with Food Safety GAPs and Conservation Practices: A Grower's and Conservationist's Handbook. Wild Farm Alliance.

Burley, H. K., Adrizal, A., Patterson, P. H., Hulet, R. M., Lu, H., Bates, R. M., Martin, G. P., Myers, C. A. B. and Atkins, H. M. 2011. The potential of vegetative buffers to reduce dust and respiratory virus transmission from commercial poultry farms. Journal of Applied Poultry Research, 20(2), 210-222.

Fiener, P. and Auerswald, K. 2003. Effectiveness of grassed waterways in reducing runoff and sediment delivery from agricultural watersheds. Journal of Environmental Quality, 32(3), 927-936.

Hernandez, G., Trabue, S., Sauer, T., Pfeiffer, R., and Tyndall, J. 2012. Odor mitigation with tree buffers: Swine production case study. Agriculture, ecosystems & environment, 149, 154-163.

Honjoh, K. I., Mishima, T., Kido, N., Shimamoto, M., and Miyamoto, T. 2014. Investigation of routes of *Salmonella* contamination via soils and the use of mulch for contamination control during lettuce cultivation. Food Science and Technology Research, 20(5), 961-969.

Kim, J., C. Miller, M. Shephard, X. Liu, and X. Jiang. 2011. Impact of indigenous microorganisms on *Escherichia coli* O157:H7 growth in cured compost. Bioresource Technology 102: 9619–25.

Lavelle, M. J, Vercauteren, K. C., Hefley, Phillips, G. E., Hygnstrom, S., Long, D. B., Fischer, J. W., Swafford, S. R., and Campbell, T. A. 2011. Evaluation of Fences for Containing Feral Swine under Simulated Depopulation Conditions. USDA National Wildlife Research Center - Staff Publications. 1326.

Malone, B. 2004. Using trees to reduce dust and odour emissions from poultry farms. Proc. Poult. Information Exchange, 33-38.

Micallef, S. A., Callahan, M. T., and Pagadala, S. 2016. Occurrence and dispersal of indicator bacteria on cucumbers grown horizontally or vertically on various mulch types. Journal of food protection, 79(10), 1663-1672.

Paniel, N., Rousseaux, S., Gourland, P., Poitrenaud, M., and J. Guzzo. 2010. Assessment of survival of *Listeria monocytogenes*, *Salmonella Infantis* and *Enterococcus faecalis* artificially inoculated into experimental waste or compost. Journal of applied microbiology, 108(5), 1797-1809.

Patel, J. 2013. Glucosinolate-derived compounds as a green manure for controlling *E. coli* O157:H7 and *Salmonella* in soil. Center for Produce Safety Interim Report.

Qu, B., Li, S., Sun, X., Yun, B., Zhang, H., Wang, X., and Xiong, K. 2019. Effects of Different Mulching Materials on Reducing Soil Dust from Bare Soil. Polish Journal of Environmental Studies, 28(1).

Reidy, M. M., Campbell, T. A., and Hewitt, D. G. 2008. Evaluation of electric fencing to inhibit feral pig movements. The Journal of Wildlife Management, 72(4), 1012-1018.

Roodsari, R. M., Shelton, D. R., Shirmohammadi, A., Pachepsky, Y. A., Sadeghi, A. M., and Starr, J. L. 2005. Fecal coliform transport as affected by surface condition. Transactions of the ASAE, 48(3), 1055-1061.

Sames, A., Noll, S., Wyatt, G. J., Zamora, D., Current, D., & Janni, K. 2020. Effects of Vegetative Windbreaks on Dispersal of Highly Pathogenic Avian Influenza-A Review of Literature. Journal of the NACAA, 13(1).

Sellers, L. A., Long, R. F., Jay-Russell, M. T., Li, X., Atwill, E. R., Engeman, R. M., and Baldwin, R. A. 2018. Impact of field-edge habitat on mammalian wildlife abundance, distribution, and vectored foodborne pathogens in adjacent crops. Crop Protection, 108, 1-11.

Sullivan, T. J., Moore, J. A., Thomas, D. R., Mallery, E., Snyder, K. U., Wustenberg, M., Mackey, S.M. & Moore, D. L. 2007. Efficacy of vegetated buffers in preventing transport of fecal coliform bacteria from pasturelands. Environmental Management, 40(6), 958-965.

Tate, K. W., Atwill, E. R., Bartolome, J. W., and Nader, G. 2006. Significant *Escherichia coli* attenuation by vegetative buffers on annual grasslands. Journal of environmental quality, 35(3), 795-805.

Williams, M., LeJeune, J. T., and B.M. Gardener. 2015. Soil conditions that can alter natural suppression of *Escherichia coli* O157:H7 in Ohio Specialty Crop Soils. Applied and environmental microbiology, 81(14), 4634-4641.

Xing, J., Wang, H., Brookes, P. C., Salles, J. F., and J. Xu. 2019. Soil pH and microbial diversity constrain the survival of *E. coli* in soil. Soil Biology and Biochemistry, 128, 139-149.

Xu, A., Buchanan, R. L., and Micallef, S. A. 2016. Impact of mulches and growing season on indicator bacteria survival during lettuce cultivation. International Journal of Food Microbiology, 224, 28-39.