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A Review of Existing Scientific Literature and Current Good Agricultural Practices (GAPs) Guidelines for Composting in Vegetable Production.

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Abstract

Current research has yielded new scientific evidence to suggest that Good Agriculture Practices recommendations for composted soil amendments may not be adequate to control foodborne illness microorganisms. A review of composting methods, the science of composting, current scientific information and known composting endpoints have yielded a large amount of information showing that current recommendations are not up to date with information that is known by extension specialists, large scale compost facilities and researchers. Composting recommendations can be greatly improved to help lower the potential number of foodborne illnesses linked to organic produce. Areas which potentially could be improved include; the temperature at which microorganism complete kill occurs, the amount of time that one should wait before harvesting a vegetable that was amended with a compost or manure, incorporation of manure directly into the ground, and the impact that cold temperatures can have on the composting process in relation to pathogen control.

Introduction

The growth and production of organic vegetables and fruits often include the use of soil amendments and nutrient enrichments. One type of amendment commonly used is a natural product known as composted organic matter. Since the components used to make composted organic matter (e.g., raw manure) are known to be associated with pathogenic microorganisms, foodborne, improperly composted materials, may lead to foodborne illness outbreaks in fresh products. Producers have specific food safety guidelines, i.e., Good Agriculture Practices (GAPs) to follow when preparing and using compost. The review of current literature that follows addresses the question of current GAPs recommendations for composting.

A Need for Change

The CDC report from 2011 estimates that each year 48 million people become sick from a foodborne diseases, 128,000 are hospitalized, and 3,000 die. Only 9.4 million cases are from known pathogens and the other 38.4 million are unspecified agents *(12).* This information shows that there is always room for improvement in the area of food safety, agriculture production, and Good Agriculture Practices. Today there is increased concern over the contamination of fresh produce due to surveillance and outbreaks of foodbourne illnesses associated with fresh produce.

The (CDC) Center for Disease Control and Prevention has found that "there has been a significant increase in the percentage of outbreaks from which, the CDC or other food-safety agencies have been unable to determine and report which food source caused the person to fall ill" *(12).* The fact that illnesses have become less identifiable leads one to speculate that the illnesses may be originating from food commodities, which are hard to tell apart and trace such as fresh vegetables and fruits.

A current trend in the United States is locally grown produce, farmers markets and homegrown vegetable production, which all corresponds with the push for a healthier America. As more people embark on the quest for more healthy homegrown foods grown in a small farm environment risks of food bourne illnesses have the potential to increase. When one grower provides all the produce that is consumed in a given region the food is monitored more closely on a large scale operation. More money is often available to help ensure the safety and the education of the workers.

Farming methods used by small producers may be at risk for a foodborne illness contamination because of the risk that is taken when compost is created at home by an individual will little knowledge of the scientific process that occurs when compost is made, the stages it must go through, and the temperatures required to totally kill microorganisms. Traditional farming often uses man-made chemicals and fertilizers that do not contain pathogens, limiting the inherent risk of a contamination. In contrast the nontraditional farmer is often introducing into the environment, in an effort to improve the soil, organisms which may not have original been found in the area of introduction.

According to Lutter "outbreaks hurt not only public health, but also food producers and distributors, by depressing consumption and disrupting markets even after an outbreak is declared over *(12)."* "Research by the U.S Department of Agriculture found that consumers responded to a prominent outbreak of Foodborne Illness linked to spinach by eating less spinach after the outbreak was declared over and by reducing spending on all leafy greens, in the short term" *(12).* In the long run, it is important that all players in the fresh fruit and vegetable industry maintain a high standard of quality or all players will suffer. Small producers, taking more risk with natural soil amendments and nutrient enrichments such as mature compost should be absolutely sure that what they are using and the GAPs that they are following will insure that level of quality. The dissemination of information is also essential so that small producers along with large-scale producers know the potential contaminants they are adding to their soil when they add improperly composted products.

Background Information

What is Compost?

The word 'compost' is derived from the Latin verb *componere,* which means to put together. Composting involves the putting together of a mixture of vegetable residue, manure, soil, and water to form humus *(21).* Composing has always existed in nature and “as vegetation falls to the ground, it slowly decays, providing minerals and nutrients needed for plants, animals, and microorganisms*” (24).* Composting is a natural process that when harnessed can be beneficially used on a large scale for vegetable and fruit farmers, There are two main types of compost; natural compost, which often is created by piling organic matter with very little management and allowing it to slowly deteriorate over time with very little temperature and time management, and mature compost. “Mature compost, includes the production of high temperatures, through a carefully managed composting procedure, with a specifically selected material ratio, formulated to preserve the valuable nutrients found in the original parent material. Mature composting differs from natural compost because it is managed to destroy pathogens and weed seeds that natural decomposition may not kill due to the unmanaged conditions” *(24).*

The most comprehensive definition of mature compost comes from the U.S Composting Council which states that “Compost is the product resulting from the controlled biological decomposition of organic material that has been sanitized through the generation of heat and stabilized to the point that it is beneficial to plant growth, compost bears little physical resemblance to the raw material from which it originated" *(23).* Compost is an organic matter that can improve soils, it helps to change the chemical, physical, and biological characteristics of the soil, it contains nutrients but most scientists do not characterize it as a fertilizer *(23).*

There are many factors that contribute to composting, according to Texas Extension "A diversity of materials is the key to first-rate compost. In addition to the major plant nutrients such as nitrogen, phosphorus, and potassium, plants take up a host of minor elements and trace elements. The more diverse the materials composted, the more likely that these elements are returned to the plants" *(21).* An interesting statistic about compost is that the original carbon content of the material is reduced by about half, when the plant material is changed over to compost.

The nutrients in compost have been found to be in a very stable form when compared to non-composted nutrient holding material *(3)*. There are many factors to monitor when composting that will be discussed later in the paper but it is always important to remember that a total absence of air, such as in a peat bog, will prevent decomposition. In very dry places or in very cold climates, decomposition may be slowed or stopped *(21).*

Composting of natural products by humans has been occurring for thousands of years, According to Texas Extension, historians have traced the first known composter to Roman, Marcus Cato. The most important advance in composting was by Sir Albert Howard 75 years ago in India *(21).* He took information about composting and turned it in to a "Composting Method" "This process involved stacking alternate layers of animal mature, sewage sludge, and garbage, organic matter, such as straw, leaves, and municipal refuse. The material was stacked to a height of about 5 feet or was placed in specially constructed pits 2 to 3 feet deep. The original procedure called for turning the material only twice during the composting period of six months or longer*" (21).*

<u>What scientifically occurs during composting?</u>

There are many processes that occur as compost breaks down, the first component to examine are the two main processes that yield compost. The two processes are anaerobic decomposition meaning without oxygen and the second process is aerobic decomposition meaning with oxygen *(21).*

Anaerobic decomposition takes place in environments which lack oxygen; an example is the decomposition of organic mud at the bottom of marshes and buried organic materials. During this process putrefactive breakdown of organic material also occurs. Putrefactive is the breakdown of organic material by the action of living organisms *(21).* According to Texas Extension "The organisms use nitrogen, phosphorus, and other nutrients to live and to develop cell protoplasm, but they reduce the organic nitrogen to organic acids and ammonia. The carbon from the organic compounds, which is not utilized in the cell protein, is liberated in the reduced form of methane into the air (CH_4)" *(4).* A small portion of carbon may be respired as carbon dioxide as the organic matter is broken down during the compost process (CO_2) *(21).*

Anaerobically produced organic matter, when placed on the soil, goes through aerobic oxidation due to the fact that the organic matter was produced as a result of a reduction process. The organic matter when placed on soil will decompose further after being exposed to air. During anaerobic decomposition less heat is generated than during aerobic decomposition. It is important to note that the lack of generated heat is a huge disadvantage for anaerobic created organic matter. The disadvantage lies in the fact that high temperatures according to Texas

Extension "are needed for the destruction of pathogens and parasites. In anaerobic decomposition, the pathogenic organisms eventually disappear in the organic mass, this occurs as a result of the unfavorable environment and biological antagonisms" *(21).* For anaerobic decomposition to occur time is the important factor, anaerobic compost is not safe if used before a year's time has passed *(21).*

The second process that yields compost is called aerobic decomposition. Aerobic decomposition is when materials decompose in the presence of oxygen. Aerobic decomposition takes place on ground surfaces such as forest floors. Unlike anaerobic decomposition, aerobic decomposition does not normally produce odor. In aerobic decomposition, living organisms that use oxygen feed upon the organic matter *(21).* Along with oxygen, the organisms use nitrogen and phosphorus, carbon and other nutrients. "Much of the carbon serves as a source of energy for the organisms and is burned up and respired as carbon dioxide (CO_2). Since carbon serves both as a source of energy and as an element in the cell protoplasm, much more carbon than nitrogen is needed. Generally about two-thirds of carbon is respired as CO_2, while the other third is combined with nitrogen in the living cells. The more cycles of organisms the better composted the organic matter will become" *(21).* Over time as organisms die their stored nitrogen and carbon becomes available for other organisms to use. "When the ratio of available carbon to available nitrogen is in sufficient balance, nitrogen is released as ammonia. Under favorable conditions, some ammonia may oxidize to nitrate" *(21).* Occasionally if the carbon to nitrogen ration is too large, the biological activity that aids in the breakdown of materials will slow or stop resulting in poor decomposition.

An important factor in the process of composting is heat. During composting, energy is released in the form of heat as oxidation occurs and as carbon is changed to CO_2. According to

Texas Extension if a gram of glucose is dissimilated under aerobic conditions, 484 to 674 kilogram calories (kcal) of heat may be released *(21).* If the organic material is in a pile or is otherwise arranged to provide some insulation, the temperature of the material during decomposition will rise to over 170°F. If the temperature exceeds 162°F to 172°F, however, the bacterial activity is decreased and stabilization is slowed down *(21).*

The temperature of the compost pile will greatly impact the type of microorganisms that reside and break down and consume the available nutrients, the temperature distribution is important because the temperature is not always even in all parts of the compost pile. The first organisms to consume the organic materials are the mesophilic organisms. Mesophilic organisms live in temperatures between 50°F and 115°F *(21).* At temperatures of 120°F thermophilic organisms develop and thrive, preferring temperatures of 115°F to 160°F *(21).* The thermophilic temperatures result in faster oxidation and decomposition. Above 160°F there are only a few select groups of thermophiles that carry on activity. The benefit of the high temperatures according to Texas Extension is that "high temperatures will destroy pathogenic bacteria, protozoa (microscopic one-celled animals), and weed seeds, which are detrimental to health and agriculture when the final compost is used" *(21).*

The temperatures in composing can occur relatively quickly, compost piles under aerobic conditions attain a temperature of 140°F to 160°F in one to five days depending upon the material and the condition of the composting operation *(21, 8).* This temperature can also be maintained for several days before further aeration. The heat necessary to produce and maintain this temperature must come from aerobic decomposition which requires oxygen.

For proper decomposition there are certain requirements that must be met. The requirements include; aeration, moisture, particle size, and a sufficient source of carbon and nitrogen. Oxygen is essential for decomposition to occur; without oxygen the compost will have a foul odor and take much longer to acquire the status of mature compost. Mixing the pile once or twice a month provides the necessary oxygen and significantly hastens the composting process *(21).* A pile that is not mixed may take three to four times longer to decompose. Proper aeration can also involve elevating the pile off the ground so it can be completely surrounded by oxygen. The percent of oxygen in the compost as it is maturing is essential “oxygen levels should be kept at 5% throughout the entire pile for proper decomposition. Typical oxygen percents range from 6% - 16% in the pile (21). A large variety of different products help to move air through the mixture. Pore space should range from 35-50% to maintain adequate aeration” *(8).* It is also important to note that air may be forced through the pile to speed up the process; however, forced aeration adds complexity to the process *(8).*

A factor that most people do not consider when creating compost is moisture. Moisture is important for microbial activity. If water is not available the microbial activity level will drop in the compost pile resulting in slow composting. It is essential to monitor the compost and add water so that it maintains the proper moisture level. “The moisture content of compost should ideally be 60 percent after organic wastes have been mixed. Depending on the components of the mixture, initial moisture content can range from 55 to 70 percent; however, as the moisture content exceeds 60 percent the structural strength of the compost deteriorates” *(8).*

A third factor is particle size; particle size can be changed by grinding and chopping the compost. Small particle size makes it easier for the microorganisms to absorb the nutrients into their cell wall. Grinding of organic materials helps the compost process to occur more quickly *(8)*.

The fourth factor, temperature was described above but it is essential for the cycle of different organisms to thrive and break materials down for further composting. It is also essential for food safety to insure that food borne pathogens and microorganisms are killed before they are used on a human food sources that it could essentially contaminate *(8).*

"Nutrient balance is determined primarily by the ratio of carbon to nitrogen in the compost mix (C/N ratio). It is like balancing carbohydrates and protein in a diet. Bacteria, actinomycetes, and fungi also require carbon and nitrogen for growth" *(8).* Carbon and nitrogen are found in the organic material that is the base of the compost pile the more variety in the pile the more nutrients that will be held in the final compost. Great compost is not formulated by just throwing random organic matter into a pile, it must be carefully formulated to have the correct carbon to nitrogen ratio, based on specific ingredients in order to achieve the best results. As microorganisms work in the pile, live and die they contribute carbon as they decompose. Carbon and nitrogen have an importation role in compost; this relationship is called the C:N ratio. Science has shown that the best ratio in compost is a C:N ratio of 30:1 (8). This means that the material has 30 times as much C as N. "If you are trying to compost leaves with a 60:1 C: N ratio for every 60 pounds of leaves, you will need 2 pounds of N" *(21).* It is important to remember that a small percentage of the carbon and nitrogen may not actually be available for decomposition. As the ratio exceeds 30, the rate of composting decreases. As the ratio decreases below 25, excess nitrogen is converted to ammonia. This is wasted into the atmosphere and results in undesirable odors *(8).* The decomposition of organic matter is brought about by living organisms, which utilize carbon as a source of energy and nitrogen for building cell structure.

“Generally, the dry, coarse materials such as straw, wood chips, etc. are high in C and low in N. The "green" materials such as grass clippings, fresh plant material, kitchen scraps and manures, are high in N and lower in C” *(21).* For more information on C: N Ratios of specific products please refer to Table 1found below.

Table 1: Carbon/Nitrogen Ratios for Composting Organics *(21)*

Material	**Carbon/Nitrogen Ratio**
Sandy loam (fine)	7:1
Humus	10:1
Food scraps	18:1
Alfalfa hay	10:1
Grass clippings	12-25:1
Coffee grounds	20:1
Vegetable trimming	12-20:1
Cow manure	20:1
Horse manure	25:1
Horse manure with litter	60:1
Rotted manure	20:1
Poultry manure (fresh)	10:1
Poultry manure with litter	18:1
Sandy loam (coarse)	25:1
Oak leaves (green)	26:1
Leaves, varies	35-85:1
Peat moss	58:1
Corn stalks	60:1
Straw	80:1
Pine needles	60-110:1
Farm manure	90:1
Newspaper	50-200:1
Douglas fir bark	491:1
Sawdust, weathered 2 months	625:1

Current Composting Methods

Composting methods can be broke down into two main areas; traditional methods and rapid composting methods. Composting has advanced considerably since researchers started looking at the best way to break waste down into a useful soil-amending product. The following section will look at current composting methods from the simplest method to the most complex. In total there are 11 categories of composting methods under the two main areas, and numerous examples under each of the 11 categories *(14).* Traditional methods of composting include; anaerobic decomposition, aerobic decomposition through passive aeration, and large-scale passive aeration. Rapid composting methods consist of; shredding and frequent turning, use of mineral nitrogen activator, use of effective microorganisms (EM), use of cellulolytic cultures, use of forced aeration, controlled systems with forced aerations, accelerated mechanical turnings, and use of worms *(14).*

Traditional Compost Methods

Traditional methods are used all over the world and on average take 4-8 weeks for the organic material to become compost. It is important to remember that just because a material is compost, does not mean that it is free of microorganism; it may still contaminate a food source.

<u>Anaerobic Decomposition Pits</u>

In anaerobic decomposition pits are dug in the ground (used in areas with low rainfall) organic material, residues and night soil are added in alternating layers. The materials remain in the pit with no addition of water or air, the process takes 6-8 months *(14).* A second example of anaerobic composting is stacking manure in piles; the decomposition takes a long period of time due to the fact that no air can enter the mix and because the mix is often very dense and lacking positive pore structure *(14).*

Aerobic Decomposition through Passive Aeration

The second method is aerobic decomposition through passive aeration. The first example of this type of composting is called the Indian Indone Pit Method. In this method, a pit is elevated above water level, it is slowly filled with organic waste, layer after layer. Once the pit is full, it is turned three times during the period of decomposition and water is added to aid in the processes *(14)*. In the Chinese pit method the same process is used, except the mix has bamboo poles inserted into the compost for aeration.

Large Scale Passive Aeration

The last method of traditional composting is large-scale passive aeration. The first example of this type of composting is windrow composting. Windrows are long, narrow piles that are turned when required based on temperature and oxygen requirements. Compost ingredients are mixes and piled outside or under a roof. The Aeration of the compost can be enhanced with fans blowing through plastic tiles or by piling the compost on a wood chip base *(19)*. Windrowing produces a uniform product and the procedure can be remotely located, this process does require a great deal of labor, and requires a large amount of space *(8)*

The size of a windrow that can be effectively aerated is determined by its porosity. The rate of air exchange depends on the porosity of the windrow. A light fluffy windrow of leaves can be much larger than a wet dense windrow containing manure. If the windrow is too large, anaerobic zones occur near its center which release odors when the windrow is turned. On the other hand, small windrows lose heat quickly and may not achieve temperatures high enough to evaporate moisture and kill pathogens and weed seeds *(14)*.

It is very important to maintain a schedule of turning. The frequency of turning depends on the rate of decomposition, the moisture content, porosity of the materials, and the desired composting time. The decomposition rate is greatest at the start of the process, the frequency of turning decreases as the windrow ages *(14).* Easily degradable or high nitrogen mixes may require daily turnings at the start of the process. As the composting process continues, the turning frequency can be reduced to a single turning per week *(14).*

Passively Aerated Windrows

The second method of large-scale passive aeration is passively aerated windrows. In this method air is introduced to the stacked pile by perforated pipes and blowers. This method requires no labor to turn the compost but is weather sensitive, and can have unreliable pathogen reduction due to imperfect mixing *(19).* Passive aeration eliminates the need for turning by supplying air to the composting materials through perforated pipes embedded in each windrow. The pipe ends are open, air flows into the pipes and through the windrow because of the chimney effect created as the hot gases rise upward out of the windrow (14).

Rapid Composting Methods

Shredding and Frequent Turning

The following methods are considered to be rapid composting methods. The shredding and frequent turning category includes the Berkley Rapid Composting Method; this method yields compost in two to three weeks. In the method, materials are chopped between ½ in and 1 ½ in. The moisture content in the pile is 50 % and the pile must be relatively small with diminutions of 36 in x 36 in x 36 in. Such piles must be turned everyday to achieve rapid decomposition and monitored so that the temperature does not exceed 160 degrees F. If an ammonia smell is present it indicates that the ratio of C to N is not correct or at 30:1 this can be fixed by adding sawdust to the pile. When ammonia can be detected the compost is losing essential nitrogen into the air *(14).*

Mineral Nitrogen Activators/ North Dakota State University Hot Composting Method

In the area of mineral nitrogen activators, there is one main type of composting method. That method is called the North Dakota State University Hot Composting Method. The Hot Composting Method involves creating compost piles to a height of 6 feet. The aerobic bacteria population is kept high by adding 0.12 kg of nitrogenous fertilizer per each cubic foot of dry matter. Four or five holes are then punched into the compost pile. The compost is turned every three of four days. With the Hot Method, composting occurs fast in the summer taking three to four weeks. It takes much longer in the spring and fall and it is important to note that it has been found that no measurable composting activity occurs during a typical North Dakota winter *(14).*

Effective Microorganisms (EM)

Use of effective microorganisms (EM) is conducted by use of a method called EM Based Quick Compost Production Process. The process is conducted in a unit plant consisting of nine pits of 6 ft x4 ft (w) x 3 ft (d) which are all enclosed by low walls and covered with a roof. An EM solution also known as a Compost Accelerator must then be prepared. Ingredients in the compost mix include cow dung, rice husk, rice husk/charcoal, rice bran/ milled, and accelerator containing 33 liters of trichoderma solution. The accelerator when mixed with molasses and water will decrease the composting period from three months to one month. In the pit after every half foot of compost is added accelerator is poured on top. This continues until the pit is full. The pit is then covered with a plastic sheet and mixed 2-3 weeks later.

Cellulosic Cultures

Cellulosic cultures are used in the IBS Rapid Composting Technology Method. This method involves inoculating plant substrates with cultures of *Trichoderma harzianum*, a cellulose decomposing fungus. This fungus, when mixed with sawdust and leaves of A Ipil Ipil leguminous tree, is called a CFA or compost fungus activator. Compost time is from 21 to 45 days. In this method of composting, compost heaps are located in a shady area on a platform, which allows air movement. The activator CFA is mixed into the compost and the heap is covered completely. The heap is then turned once every 5-7 days. After the initial composting the mature compost must be dried in the sun for two days. It is then put into sacks and stored in a shaded area so that the fungus can continue to decompose the organic matter, the result of IBS composting is a finely fragmented powdered textured material *(14)*.

Forced Aeration

Use of forced aeration also known as the Aerated Static Pile Method, is more advanced than the piped aeration system because it uses a blower to supply air to the composed materials. This allows the compost to be piled in much larger piles than usual. With aerated static piles complete compost is achieved in 3 to 5 weeks *(14)*.

Controlled Systems with Forced Aeration and Accelerated Mechanical Turning

Controlled systems with forced aeration and accelerated mechanical turning can be demonstrated with In-Vessel Composting. In vessel composting refers to a group of methods, which confine the compost within a building, or container. The first example is bin composting, bin can be done easily in a series of small grain bins, the material can be aerated from the floor, or a mechanical device inside the bin. The best method is to periodical empty one bin to another, to aerate the material as it is moved *(14).*

A second example is Rectangular Agitated Beds. In this method beds are moved by a belt and auger. As the machine moves the compost is aerated, and chopped into small pieces. If the bed moves the compost 10 feet in each turning and the bed is 100 feet the composting period is ten days with daily turning. Rectangular Agitated Beds create compost in a very fast amount of time, but the compost is not complete without a long curing period. The curing period is necessary for the elimination of microorganisms and weed seeds. The last example is a rotating drum. Materials once added to the drum, can be composted in a matter of three days. The compost then requires a second stage in which it is maintained and cured in static pile windrows *(14).*

Vermicomposting

Use of worms is called vermicomposting, vermicomposting is a practical form of composting, earthworms can consume all kinds of organic matter, and they can eat their body weight in food every day. A compost heap of 2.4 m by 1.2 m and 0.6 m high can support more than 50,000 worms. If worms are used for composting, aeration and turning are not necessary. The types of worms that are used in the process are very important. Two main types are used. The Red Worm also known as *Lumbricus rubellus*, and the Thermo-Tolerant Worm, *Eisenia* *fortida*. These two varieties are important to use because normal night crawlers do not survive in the high composting temperatures. Vemicomposting requires many steps, because the health of the worms must be considered during every step *(14).* Typically 1 pound of worms can eat 4 pounds of waste per week. Many schools use this type of composting as an environmental education tool. Worm castings will bring a premium price but the investment in worm stocking may be high depending on the size of the operation. If too much waste is added anaerobic conditions may occur.

Information That the Typical Grower is Provided With to Guide Good Agriculture Practices for Vegetable Farmers.

Current GAPs for Compost Use on Vegetables

The Good Agriculture Practices for producers was created for the purpose of creating a unified set of guidelines to help educate producers on making choices to help ensure that the produce that they grow and sell are as safe as possible, and are based on the most current research results. Good Agriculture Practices are not regulated by an official branch of the government, and there is no official penalty if the practices are not followed. A lack of regulations does not indicate a lack of importance. GAPs help farmers prepare for third party audits of their farming operations helping to provide safe food. A vegetable producer can document that he follows the recommended GAPs guidelines; this documentation can be shown to potential buyers to prove that the farmer has done all in his control to make sure that the food is safe, and to show that the producer actively implements preventive measures against food bourne contaminants.

Growers that do not follow GAPs may experience monetary losses in the form of reduced sales to wholesale buyers who only buy from producers that follow and document GAPs. Not following GAPs can also result in the producer being responsible for causing a sickness that could have been prevented with a few simple changes. If someone becomes sick and the producer does not have documentation, the reputation of the producer could be ruined resulting in a potential loss of sales *(26)*.

Good Agriculture Practices are broke down into many area, but the focus of this paper is on the handling of composted manure and soil amending products. Manure should be stored for six months prior to field application and disposal. The manure should also be composted correctly. When creating compost, piles should be managed actively, in order to achieve uniform composting *(26)*. Managing actively includes maintaining a high temperature; the temperature should be 131-140° F for at least three days at a depth of 18-24 inches *(25)*. Managing actively also includes maintaining good moisture, proper aeration, and mixing. A benefit to proper composting is the kill of microorganisms and weed seeds *(5, 25)*. What the Good Agriculture practices fail to mention is what the proper good moisture, proper aeration and mixing standards should be.

Once the compost has been created the next step is application to the vegetable crops. If applying composted manure in the spring, to fruit and vegetable crops a wait period of 120 days should occur before harvest of the fresh produce (*26, 1, 25)*. This is important to maintain because not all pathogens die at the same rate. It is also important to note that raw manure when applied to vegetable crops should be incorporated into the ground, and raw manure should not be side-dressed with fresh vegetable production *(26, 25, 1)*. Non-composted manure should also be applied in the fall to cover crops and in the spring incorporated into the soil two weeks prior to spring planting *(25,1)*.

Good Agriculture Practices also include; keeping records of manure or compost use, knowing the source of the manure or compost that is used on the vegetable crops, knowing the methods that are used to produce the compost or manure, maintaining records of application rates, timing, and fields receiving the manure or compost *(25)*.

Compost supplies shall have written standard operating procedures to prevent cross-contamination of finished compost with raw materials through equipped, run off or wind *(7, 25)*. An important step in the safety of the compost that is applied to the vegetable crop is periodic microbiological testing of soil amendments prior to application. GAPs also include verifying that the time and temperature process during the composting process reduces, controls, or eliminates the potential for residual microorganisms in the composted material *(7, 25)*. One problem with current GAPs information is that no guidelines on time are given for creating mature compost.

Current Information That is Distributed by Universities and Researchers but Which is not Provided in Typical GAP Information Sheets.

Current Composting Endpoints That Producers Should Target to Eliminate Food Borne Pathogens From Compost.

A composting endpoint is the point at which the compost can be assumed to be free of pathogens that have the potential to cause food borne illnesses. It is also the point where it can be assured that the fertility of plant and weed seeds has been eliminated, along with the DNA (4).

Endpoints help to establish when compost can be classified as mature, and ready for application to plants. Not all states have regulations for composting operations, one state that does have regulations, which could be used by other states to help establish compost endpoints, is California. The endpoints for compost are found in California Code of Regulations *(4).*

According to the California Code of Regulations, the following time and temperatures must be met in order for a compost to be mature. For enclosed or within-vessel composting systems, the compost must maintain a minimum temperature of 131°F for three days *(4).* For Windrow Composting, the compost must maintain aerobic conditions at a temperature of at least 131°F for 15 days, with a minimum of five turnings (4). For Aerated Static Pile Composting, Compost must be covered with at least 12 in of insulated materials and maintain a minimum of 131°Ffor three days *(4).*

The temperatures and times above were established to kill target organisms. The target organisms include fecal coliforms, *Salmonella serovars* and *E. coli* O157:H7 *(4).* It is important to note that the target organisms are major culprits in foodborne illness but that there are a number of other organisms that should also be targeted *(4).*

In California each lot of 5,000 cubic yards must be tested for the survival of microorganisms before the compost can be applied to fields *(4).* Each lot of compost is certified as pathogen free if the following is met: Fecal coliforms < 1000 MPN/gram, *Salmonella*: Negative or <1/30 grams), and *E.coli* O157:H7: Negative <1/30 grams *(4).*

Moisture is another factor that can be taken into account when evaluating the maturity and endpoints for compost, optimum moisture content for biodegradation ranges from 50-70% on a wet basis *(18).* In the study by Tom Richard from Iowa State University, it was found that the optimum moisture content increased during the course of his study from 56 % to 74 % after

40 days *(18).* The moisture changed due to changes in pore sizes, oxygen diffusion and solubility and microorganism activity. It is also important to note that the optimum moisture levels in the final stages will decrease to 45% indicating maturity *(20).*

The carbon loss can also be evaluated to test the maturity of the compost; the total amount of carbon loss during composting can be an indicator of maturity. According to Daniel Said-Pullicino carbon loss during composting was found to be approximately 36% of that present in the initial compost pile *(20).*

The last indicator that one could use is the visual indictor. Physical evidence of mature compost indicating that it is well cured includes; continued decomposition, no odors, and no potential toxicity. Indicators of immature compost include; fatty acids or other water soluble compounds that may inhibit seed germination and root and seedling development. Compost material may become anaerobic, odorous, and develop toxic compounds indicating that maturity has not yet been reached *(5).*

Current Research Which May Contradict Current GAP Information and Improve Food Safety

In CFASN guidance for industry on vegetable production it was stated that "Research on pathogen survival in untreated manure, treatments to reduce pathogen levels in manure, and assessing the risk of cross-contamination of food crops from manure under varying conditions is largely just beginning" *(6).* The statement by CFASN was made in 1998 and as research was conducted for this paper on compost, manure, and foodborne pathogens, it was found that there were many gaps in research, that still today in 2011 need to be addressed and research which needs to be replicated. The statement by CFASN and my findings show that the GAPs we have currently may need to be updated based on recent research. It is known that “some pathogens tolerate higher temperatures than others. In addition, management practices required to achieve the time and temperature necessary to eliminate or reduce microbial hazards in manure or other organic materials may vary depending on seasonal and regional climatic factors” (6). This statement by the CFASN is important because it shows that as new information is discovered, it should be quickly placed into the hands of those who need it the most, the producers, both large and small.

Temperature/ Composting Climate Temperature

It was found that with windrow composting, the temperature within the pile is affected by ambient temperatures outside the pile *(22).* The research also found that the rate of composting in the winter pile was slower than in the summer pile and that it did not reach maturity even by the end of the composting, which was 91 days. The highest temperature reached in the winter windrow compost was 132°F, the problem is that the temperature was not maintained, over a long enough time frame to create stable compost. Outside temperatures were between 41 and 77°F which are typically much warmer than the normal winter temperature for the midwest United States *(22).*

This indicates that windrow composted over the winter in the midwest United States has a large chance of never having the composting temperature reach the optimal levels to kill foodborne illness microorganisms. A study by Rosa Margesin found that when composting in the winter, the more often the compost is turned, the more heat that is lost, resulting in slow composting *(13).*

This information is not found in any GAP documentation, it is important that growers creating their own compost or disposing of their own manure, known that climate does have an impact on the decomposition of the compost and that the typical turning routine will result in slow decomposition in the piles. This current information does dispute the GAP recommendations that manure be stored for 6 months prior to field application *(26)*. Evidence shows that if the manure is stored during the winter that microorganism may not truly be impacted by the storage time because of the cold environmental conditions. GAPs also states that composted manure in the fall should be spread on fall cover crops *(25, 1)*. One problem that may be encountered if the weather turns cold early and stays cold late in the spring is that the manure/compost may not have time to decompose, and reach the needed temperatures during the winter to kill the microorganisms.

Time

In a recent study by Ogefere, *E. coli* microorganisms were isolated throughout a 40-week time frame. During the 40 weeks a total of 13 strains of *E. coli* were isolated from compost, this was thought to be due to the low temperature that was reached which was 80°F to 98°F. The compost was created with the open air/heap method. The study's findings suggest, that compost used for vegetables be created in a closed vessel composting system that could better manage the temperature *(15).* This study shows that compost does not always reach the temperature needed for complete microbe kill which by GAP standards is 131-140°F *(25)*. It also shows evidence that a microorganism could survive the composting process, be transferred to vegetable material and cause a foodborne illness.

In a study by H. Bohnel, samples of marketed bio-compost were tested and results showed that about 50% of the tested samples contained *C. botulinum.* This study shows that the use of bio-compost represents a health hazard to humans and animals, especially in the future when spores will have accumulated in the environment *(2)*. During the study 14 different compost sources were tested, all of the original composting methods involved windrow composting. This study proves that composting does not always kill all organisms, even at facilities that are selling on a large scale; it also found that compost might easily become re-contaminated before being sold to the buyer *(2).*

Manure and Soil Incorporation

Research shows that not incorporating contaminated livestock wastes into soil is a potential intervention measure that may help to limit the spread of zoonotic agents further up the food chain. GAPs recommend that all manure be directly incorporated into the soil (26, 25, 1). This study shows that the amount of time-contaminated waste remains on the soil surface influences the rate at which pathogens decline. This means that incorporating animal waste and compost into the soil at the initial application time will increase the total time that manure-borne pathogens remain viable in the soil after waste spreading. It was found that by leaving manure and compost on the soil surface, UV irradiation from sunlight and the drying effect of the atmosphere will help lower the number of microorganisms *(9).* This study shows that the GAPs recommendation of incorporating manure into the soil two weeks before spring planting may need to be adjusted so that the manure lays on the surface for a certain amount of time before being incorporated.

Temperature of compost

In 2008 and 2009 three people from Scotland were infected by legionnaires disease caused by *Legionella longbeachae* sg 1. All infected individuals were working with compost as an amendment for gardening. The compost was found to be made from shredded potting compost, which was heat treated at above 149°F for five to ten days and composed of 30-50% peat which is not heat treated, there was also a 2nd type of compost that was composed of composted bark green material and not heat treated 75-80% peat. All compost used conformed to the PAS 100 standards *(17).*

In a study on the prolonged survival of *Campylobactoer* species in bovine manure compost created with the windrow method of composting, temperatures did not reach 131°F until after the 49th day of composting. During no time of the 325 day did composting on the outside of the compost reach 131°F. According to the study *Campylobactor* was recovered throughout the active period of composting (up to 126 days) *(10).* At later times in the study it was hard to detect the *Campylobactor* because of the fast growing and spreading colonies of various ubiquitous bacteria (*Bacillus, Paenibacillus* and *Brevibacillus*) thus obscuring detection of *Campylobactor*. The study did find DNA at all stages of composting proving that *Campylobacter* persisted in manure and subsequently in compost for a prolonged period (longer than 10 months) *(10).* The case of legionella and the study on campylobacter are evidence that the GAPs recommended temperature for microorganism kill at 131-140°F is not high enough for total microorganism kill.

Can Compost Really Contaminate?

In a study by Mahbub Islam *(11),* the fate of *Salmonella* was tested using three different compost types and irrigation waters, each sample was inoculated with *Salmonella enterica* and added to soil. It was found that *Salmonella* survived for an extended period of time, with the bacteria surviving in soil samples for 203 to 231 days. *Salmonella* was detected on radish seeds planted in the inoculated compost for 84 and 203 days on radish and carrots. This proves that compost can play an important role in contaminating soil and root vegetables for several months *(11).* The study also shows evidence that waiting 120 days after the incorporation of compost and manure may not be long enough to prevent microorganisms from contamination of vegetable produce.

Conclusion

Composting is a very in-depth procedure with many steps and numerous methods available for the purpose of creating the naturally made product. The purpose of all methods is to create the most microorganism-free nutrient rich, soil amending product. The number of composting methods makes it hard to have one set of Good Agriculture Practice guidelines that works for every type of composting method. Each type can be very diverse on the specification needed to create a microorganism free-composted product.

One way to overcome the large number of composting methods, and the vast amount of specific GAPs that would be needed if safety documents were created for each type of composting available, would be to create a specific composting method that could be recommended for use by all compost-producing growers. The recommended composting method would allow a more specific set of GAPs to be created specifically for compost, being applied to vegetable crops. Currently GAPs does not recommend a certain method of composting it just states that “producers should compost manure properly to kill pathogens.” In searching for documents that tell how to compost manure properly information was hard to find and even harder to understand. Based on information obtained during the literature review, a recommended method of composting for small farm produces would be to compost with the windrow composting method. To ensure the most consistent results during the composting processes, producers should also regularly monitor temperatures to ensure that microorganism kill is possible. Producers should also maintain records of the temperatures, to use as references when evaluating the finished compost.

GAPs should be created so that producers have more access to information, especially small producers such as those who sell at roadside stands, and the large populations of Amish and Mennonites that do not have access to computers and whom often sell at farmers markets.

Currently when searching the internet for scientific documents about Good Agriculture Practices for vegetable production, information was hard to find. There was very little information that directly explained what the producer needed to do to create their own compost, to use on their own vegetable crops, to ensure that large populations of food borne illness producing organisms were killed.

The literature review of Good Agriculture Practices (GAPs) and the comparison of the new information available from recent research prove that the current GAP guidelines in the area of compost and manure incorporation are not sufficient to eliminate without a doubt foodborne illness microorganisms. Current research shows that a moderate amount of the recommended practices have the potential to be changed based on new research results.. Areas of the GAPs that should be reviewed based on current research include; the temperature at which microorganism complete kill occurs, the amount of time that one should wait before harvesting a vegetable that was amended with a compost or manure, incorporation of manure directly into the ground, and the impact that cold temperatures can have on the composting process for the purpose of microorganism kill.

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