THE HIGH-CARBON STRATEGY

On-Farm Trials of a Method for Pre-Composting Cranberry Residuals

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On-Farm Trials of a Method for Pre-Composting Cranberry Residuals

I. Project Background

Cranberry farming is the second largest agricultural sector in Massachusetts, accounting for just over $100 Million in revenue a year according to the Commonwealth's 2015-2016 annual report on agriculture.[1] The processing of cranberries into marketable products generates a variety of residuals, including thousands of tons of culled berries, during the harvest season. The primary method for returning discarded berries to beneficial reuse in Massachusetts is composting. To date, however, publicly available information about effective methods for incorporating cranberries into composting operations is scarce. The lack of technical resources in this area is problematic since cranberries are a high- moisture and high-acidity material, factors that are distinct and potentially challenging from a composting perspective. State agencies have reported issues with smell when composters have added cranberries into typical compost mixes.

In response to escalating concerns, a veteran composter and organic cranberry grower, Philip DeMoranville of Kingfisher Corporation in North Dartmouth, Massachusetts, began experimenting with a method we've come to call the high-carbon strategy (HCS). The HCS involves blending cranberries with wood chips and allowing the composting process to buffer the pH of the mix. Once the acids are degraded, the mix can be used as a bulking agent in typical composting recipes, without the risk of initiating or exacerbating undesirable pH conditions in other putrescent feedstocks.

Initial HCS trials in 2017 showed strong promise, and with support from Ocean Spray Cooperative and Compost Technical Services LLC, and in consultation with Massachusetts Department of Agricultural Resources, Kingfisher Corporation conducted scaled-up on-farm trials of the HCS during the 2018 harvest season. The project tested different cranberry-wood chip compost recipes. We analyzed over 70 compost samples over 6 months, and documented pH buffering of the cranberry mixes over time. Overall, our experimentation showed an incredibly effective and forgiving process, as long as woody materials are the only feedstock used. In most instances, the acid neutralization was rapid. The methods and results are discussed in this report, along with some lessons learned about method optimization, and risks of which compost practitioners should be aware.

II. Commercial Scalability

There is a risk when piloting a new composting methodology that the results will not be commercially scalable or viable. The HCS requires access to a lot of wood chips, and space, and it takes extra time before it yields a salable end product. One of the advantages that we had going into the 2018 trial was that, along with years of experience on the farm working with cranberries, we had results from the previous year. We were confident enough in the process that, in parallel to the much smaller controlled experiment, Kingfisher was simultaneously processing thousands of tons of cranberries using the HCS. While we did not do extensive testing of the commercially processed material, the testing that we did do, as well as our anecdotal observations, showed that the process worked faster at a large scale, which we think was due to larger pile size and higher temperatures. Smells from the HCS piles were virtually non-existent.

We showed that with enough space, time, and wood chips, this process works. It is commercially viable assuming the composter negotiates an adequate tipping fee, and assuming the cranberry processors are willing to pay that tipping fee as a means of avoiding potential issues.

By no means are we suggesting this as the only method for composting cranberries, this is just the only method that we are aware of that's been documented to create reliably trouble-free results on a large scale. Traditionally, challenging materials are managed using the "dilution is the solution" philosophy. When it comes to remediation of potentially odorous feedstock, dispersal of the problem compounds into a biologically active and aerobic mix is highly effective in most cases. When it comes to cranberries, however, dilution is both a challenging and nuanced proposition. First, the volumes generated would simply overwhelm any regional composter attempting to incorporate berries at, say, a 5% dilution rate. Second, we understand very little about how the extreme acidity of cranberries (<3 pH) interacts with other materials. It is possible that a 5% dilution rate could work in one recipe, while in another it could create an issue. These factors make simply incorporating cranberries into existing compost mixes a risky endeavor. But what those who work with cranberries report, and what this project indicates, is that cranberries in of themselves are not an odorous material when composted.

Anecdotal evidence suggests that when cranberries are added to potentially odorous feedstocks such as food scraps and yard debris, the odors generated can be stronger than if the two materials were composted separately. Holding true to both the science and experience of composting, low pH conditions can exacerbate odor generation and slow odor degradation. What the HCS allows the composter to do is to process the cranberries quickly, and at a relatively low dilution rate, essentially storing and pretreating them for later use. That said, the strategy requires space and access to wood chips, and therefore may not be adoptable in many composting scenarios.

III. Cranberries as a Compost Feedstock

As with any organic material, cranberries have distinct characteristics that need to be understood before attempting to compost them in large volumes. Through lab testing, discussion with those working in the industry, and hands-on experience, several key factors have helped us to better understand cranberries from a composting management perspective:

- **Seasonal** - Cranberries are primarily a seasonal material, with generation of culls starting in late September, peaking in October, and tapering off by December. Following the season, there may be additional volumes of 'set aside' requiring an outlet (this was true of the 2018 harvest due to overproduction, but is less likely in subsequent years). As Massachusetts's regulations are currently written and interpreted, cranberries cannot be stored by the composter like other carbon feedstocks, for processing over time. As a result, composters working with cranberries need to have extra capacity available during the brief window of the harvest season.

- **Stable** – Cranberries are contained in an impervious waxy husk. The cranberries are stable compared to other fruits and will not readily decompose until the husk is either physically or biologically broken. We have observed that the majority of cranberries break 2-3 months after being incorporated into an active compost mix. Under optimal and active composting conditions they degrade much sooner.

- **High Moisture** - Whole cranberries are high moisture, with moisture contents (MC) tested at between 87% and 93%. Target MC for composting is typically 50%-65%. Although the composting process can tolerate a wider range, balancing high pile moisture with dry matter is key to effective decomposition and nuisance prevention. Because of their waxy husk, the moisture in cranberries is "tied up" until the husks break. This means that the practical MC of the compost mix is a moving target, even more so than with other materials. We can generally assume that the moisture in cranberries will take much longer to “free up” than in other high moisture materials, and that release will be staggered over time, although in a really active mix it’s likely to happen sooner. Higher MC with the HCS is less of an issue than with a more typical recipe because woodchips are very porous and the mix is unlikely to become anaerobic. We believe that the mix’s high aerobicity and staggered moisture release allows us to compost with moistures in the 65%-75% range, while maintaining active pile conditions and mitigating loss of free moisture from the piles.

- **Acidic** - Cranberries are low pH (<3). The preferred pH for composting is between 6.5 and 8 (although composting can tolerate a wider range of pH).[2] Low pH conditions often correlate with odor generation in certain materials.[3] While cranberries appear to be a low odor risk material on their own, in combination with high nitrogen and high protein feedstocks such as food scraps (which are often also low pH), the possibility of nuisance odors is undoubtedly elevated. Both low and high pH compost mixes tend toward neutral over time.[4] The HCS uses composting’s natural buffering capability to neutralize the cranberry mix prior to combining it with nitrogenous or other challenging feedstocks.

- **High Carbon** - Cranberries are high carbon, with carbon to nitrogen ratios as analyzed in the trials ranging from 50:1 to 80:1. They are a non-typical feedstock in that they are high in both moisture and carbon. Typical C:N ratio targets for composting are between 25:1 and 30:1, although in this case, we believe that keeping the C:N ratio high is beneficial in preventing odors. Composting can tolerate a wide range of C:N ratios and high carbon composting is very common.

- **Unknowns** – As a compost feedstock, there is little previous published research and documentation on how to manage cranberries. Recent trials conducted by the farm of the high-carbon strategy have provided better insight into the early stages of the breakdown process in terms of the timeline of pH neutralization. However, the test piles created during the trials took 2-3 times longer to become neutral than did many of the other piles on the site. There appear to be variables that may lead to better performance; these were not replicated in the controlled 2018 trials.

Cranberry compost trial piles.

IV. On-Farm Trials

The overarching goal for using the high-carbon strategy (HCS) on the farm is to buffer cranberries’ low pH, thereby mitigating the risk of nuisances and rendering the cranberry feedstock usable in a wide variety of composting applications. We believed that this was possible on a replicable basis going into the experiment because of earlier trials initiated by the farm. In December of 2017, the farm created two cranberry test piles, each of approximately 360 cubic yards. The piles were blended using a ratio of 1 part whole cranberries (~60 Tons or 120 yards) to 2 parts wood chips (240 yards). One pile was mixed using a total mix ration mixer (tractor PTO driven Lucknow 2260). The second pile was bucket blended with a front-end loader. The piles were turned 5 times over the course of nine months, with the first turning happening 2 months after blending. While no analysis was done of the raw compost blend, lab analysis of the compost mixes sampled after 9 months indicated that the piles had decomposed significantly, buffering the pH to around 7.

While the results of the 2017 cranberry composting trials were extremely promising, they did not provide insight into what unfolds early in the HCS composting process, nor did we know what the precise characteristics of the original blends were. Especially important to future operations were the recipe characteristics in terms of initial pH, moisture content (MC), and bulk density (BD) that lead to efficient pH buffering.

To answer some of these questions, in 2018 the farm conducted additional trials in partnership with Ocean Spray Cooperative, and with the support of Compost Technical Services LLC and Massachusetts Department of Agricultural Resources. The trials were designed to advise future management decisions and amendments to the farm's Facility Management Plan. The test piles were formed on October 08, 2018 and final sampling occurred 24 weeks later, in March of 2019. The trial methods and findings are outlined here.

Cranberry bog at Kingfisher Corporation

A. Test Pile Design

The test piles were designed to better our understanding of the potential benefits and drawbacks associated with several key management variables in terms of pH buffering. These variables include:

- How do different ratios of wood chips to cranberries influence the rate of pH buffering?
- Does the pre-processing of cranberries to remove moisture using a screw press influence the rate of pH buffering? Is the added cost necessary or justified?
- Does the blending of cranberries and wood chips with a total mix ration (TMR) mixer influence the rate of pH buffering compared to blending with a front-end loader? Is the added cost of the TMR mixer necessary or justified?
- Can the "buffered mix" (pre-treated material) created using the HCS be reused as a feedstock in place of wood chips for further processing new cranberries?

Each of these questions has associated costs or savings and may increase or decrease the risk for the composter when managing cranberries. The goal of the trials was to optimize future management of cranberries as a feedstock using lab testing, pile monitoring, and pile observation as feedback mechanisms for how the compost process is responding to different pre-processing, recipe, and mixing conditions. We looked at changes in pH over time in relation to these management variables, with the goal of keeping processing costs low and mitigating any nuisance odors from the composting process.

In preparation for the trials, several samples were taken of the raw feedstocks (raw materials to be composted), including of whole and pressed cranberries, wood chips, and a four-week- old buffered mix (pre-treated cranberry/wood chip blend) following a Feedstock Sampling Protocol.[5]

The analyses of these samples, as well as some analysis done by Ocean Spray were used in determining the original trial recipes. Analysis of these feedstocks are provided in Table 1 below:

Table 1. Trial Feedstock Analysis

Feedstock Type	pH	Bulk Density, (Pounds/ Cubic Yard)	Moisture Content (%)	Organic matter (% dry weight)	Carbon : Nitrogen Ratio
Cranberry Whole Berry	2.5	959	89.8	97.8	79
Cranberry Pressed (25 PSI)	2.6	1022	87.1	98.5	69
Cranberry Pressed (40 PSI)	2.6	1033	88.9	97.9	54
Buffered Mix (4 Weeks Old)	7.3	942	60.8	71.4	36
Wood Chips*	5.9	599	61.2	97.8	91
* Note: The wood chips sampled were used on the operation, but were not available for use in the trial piles. There is no analysis of those chips, but based on observation and testing of the trial piles, they appeared to be dryer, have a higher C:N ratio, and have less available carbon than did the wood chips represented above.					

i. Test Pile Recipes, Blending, and Sampling

The HCS compost recipes as they were constructed for the trials are provided in Table 2 below, as well as the sampling schedule for the piles as they progressed. The protocol for blending and sampling the test piles was as follows:

1. Each test pile consisted of 15-40 cubic yards of feedstocks.

2. Mixer-blended test piles were mixed for 10 Minutes/Batch.

3. Loader-blended test piles were mixed for 5 Minutes/Batch with an 8-yard bucket loader.

4. The piles were formed and labeled with wooden stakes numbered 1-9.

5. Two samples were taken per pile of both freshly-blended (Day 1) and 2-week-old piles. One sample was taken per pile at 4 weeks, 8 weeks, 12 weeks, and 24 weeks. Sampling was conducted following the Feedstock Sampling Protocol.[6]

6. All samples were tested at Penn State Agricultural Analytical Services Laboratory (using TMECC testing procedures) for the following characteristics:
    a. pH
    b. Total Carbon
    c. Total Nitrogen
    d. Carbon : Nitrogen Ratio
    e. Moisture Content
    f. Bulk Density (not tested after 4 weeks)
    g. Soluble Salts (Conductivity)
    h. Organic Matter

7. All piles were monitored visually and for temperature once per week. Weekly monitoring continued for 6 weeks, at which point monitoring was conducted every other week until week 12.

   Pile monitoring consisted of the following:

   - Temperature was taken in the front and back of the pile at 1 foot and 3 feet for a total of at least 4 temperatures per pile.
   - Moisture content was tested for in lab analysis.
   - Observations were taken including notes on smell, visible berries, pile consistency/density, and free moisture at the base of the piles.
   - Photos were taken to document visual changes.

8. The piles were turned two times. Turnings were documented. The timing of the turnings was based on observation of the pile, smell, and pH testing, as well as to facilitate representative sampling of piles as much as possible.

Table 2. Trial Recipes and Day 1 Pile Characteristics

Recipe and Blending Method				Day 1 Analysis			
Pile ID	**Cranberry**	**Wood Chip**	**Blending Method**	**pH**	**Moisture Content (%)**	**Bulk Density (Pounds/ Cubic Yard)**	**Carbon : Nitrogen Ratio**
Pile 1	1 Part Whole Cranberry	2 Parts Wood Chip	Mixer Blended	3.3	69.7	820	215
Pile 2		3 Parts Wood Chip	Loader Blended	4.3	57.0	661	116
Pile 3		3 Parts Wood Chip	Mixer Blended	3.5	62.4	832	208
Pile 4		4 Parts Wood Chip	Mixer Blended	3.5	62.7	820	176
Pile 5	1 Part Pressed Cranberry (25 PSI)	3 Parts Wood Chip	Mixer Blended	4.0	64.6	709	99
Pile 6	1 Part Pressed Cranberry (40 PSI)	2 Parts Wood Chip	Mixer Blended	3.3	67.7	811	105
Pile 7		2 Parts Wood Chip	Loader Blended	3.8	63.2	729	83
Pile 8		3 Parts Wood Chip	Mixer Blended	4.0	63.3	686	79
Pile 9	1 Part Whole Cranberry	3 Parts Buffered Mix (4 Weeks Old)	Loader Blended	6.1	70.0	1012	60

B. Flaws in Trial Design

The results of the trials were overwhelmingly successful and show that the HCS worked in every scenario we tried. There were several flaws in the experiment that make definitive comparisons between different trial piles challenging in some instances, although they in no way affect the overall conclusions of the project. As an on-farm trial, the project lacked the sort of replication and statistical analysis that larger academic research projects entail. In our experiment, we did strive to control for as many variables as possible to ensure useful results. To help others interpret the results, we want to be fully transparent about factors such as variable pile size, which may have affected some piles' performance differently, as well as considerations that affect how we interpret the results, such as sampling and lab methodologies.

A variable that under ideal circumstances would have been better controlled was pile size. Due to time and material constraints during trial set up, the mixer-blended piles were 15-20 yards, whereas the loader-blended piles were 20-40 yards. We are seeing more heating and faster degradation of acids in larger piles across the facility. This is especially true given the cold time of year and amount of rainfall. That said, average temperatures in the first 2 months were only 4 degrees F different in pile 2 (loader blended) compared to pile 3 (mixer blended) and the high temperature in pile 2 was only 10 degrees F higher than in pile 3. Likewise, average temperatures in the first 2 months were 3 degrees F different in pile 7 (loader blended) compared to pile 6 (mixer blended) and the high temperatures in both piles were recorded at 110 degrees F. These temperature monitoring results indicate that pile size had only a minimal effect on pile activity, which is directly associated with pH buffering, early on, although as temperatures dropped these differences would likely become greater.

Another factor that may be helpful in interpreting our results is to understand that pH is measured at the lab by creating a liquid extract from the compost mix. The acids in the whole unbroken berries would not be as extractable as in broken berries, making the mixer-blended compost appear more acidic in lab analysis. The fact that day 1 pH of the mixer-blended compost was 0.5-0.8 less would confirm this was true initially. However, the berries in the loader-blended mix were visibly broken by the 8-week sampling, and acids would show up in the analysis if present. The fact that the initial pH of pile 2, which was whole-berry and loader-blended, was 4.3, shows that the acids were represented at least in part in the initial analysis.

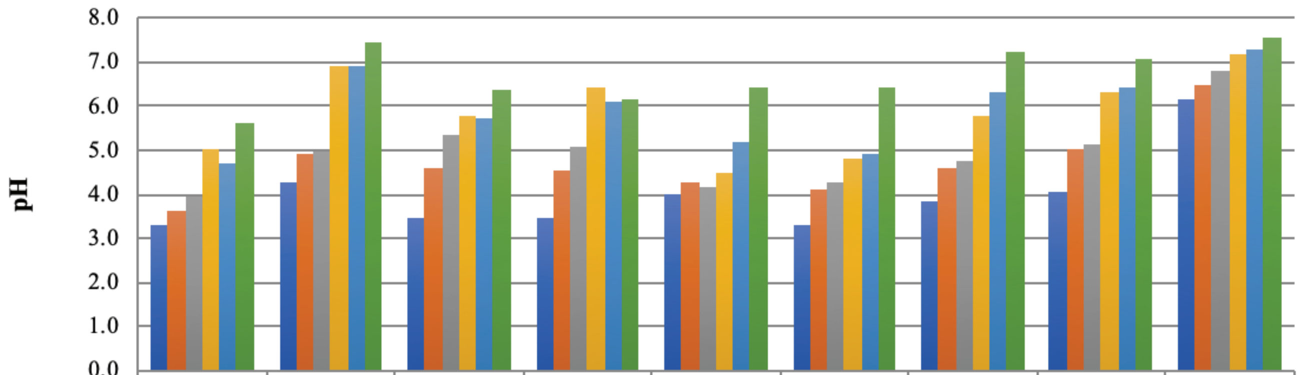
A third factor that almost certainly influenced the results was that the samples at 8 weeks and 24 weeks were taken immediately after the piles were turned, while at 2, 4, and 12 weeks, samples were taken by digging 1- to 2-foot deep holes in the piles, which were 8 to 10 feet wide. This means that at 2, 4, and 12 weeks, we were not sampling at the very core of the piles where more acid degradation was likely occurring. Therefore, these are less representative samples and the results may show a slightly more acidic pH because of it. Notably, there was little pH rise between weeks 8 and 12 in most of the piles, and we actually saw a slight drop in pH in 3 of the 9 piles. While this might in part represent a latent effect of cranberries breaking and releasing acids, or natural variation in sampling, the minimal rise in pH across the board between 8 and 12 weeks, then the big jump between 12 and 24 weeks (when the piles were very cold) shows that there was clearly some difference between sampling methods. We can't rule out some natural stagnation and regression in acidity, but that is unlikely to be the only factor.

There are some factors in the trial's design that in hindsight could have been better controlled. It should be noted, however, that two of the three issues discussed in this section would suppress pH buffering (or show lower pH buffering than was actually occurring in the case of variation in the sampling methodologies). Rather than discrediting the results, these factors support our conclusion that the HCS is effective. In other words, had we better controlled for these factors by building all of the piles larger, and sampling all of the piles after turning, the resulting pH would almost certainly have come out higher rather than lower, e.g. less acidic.

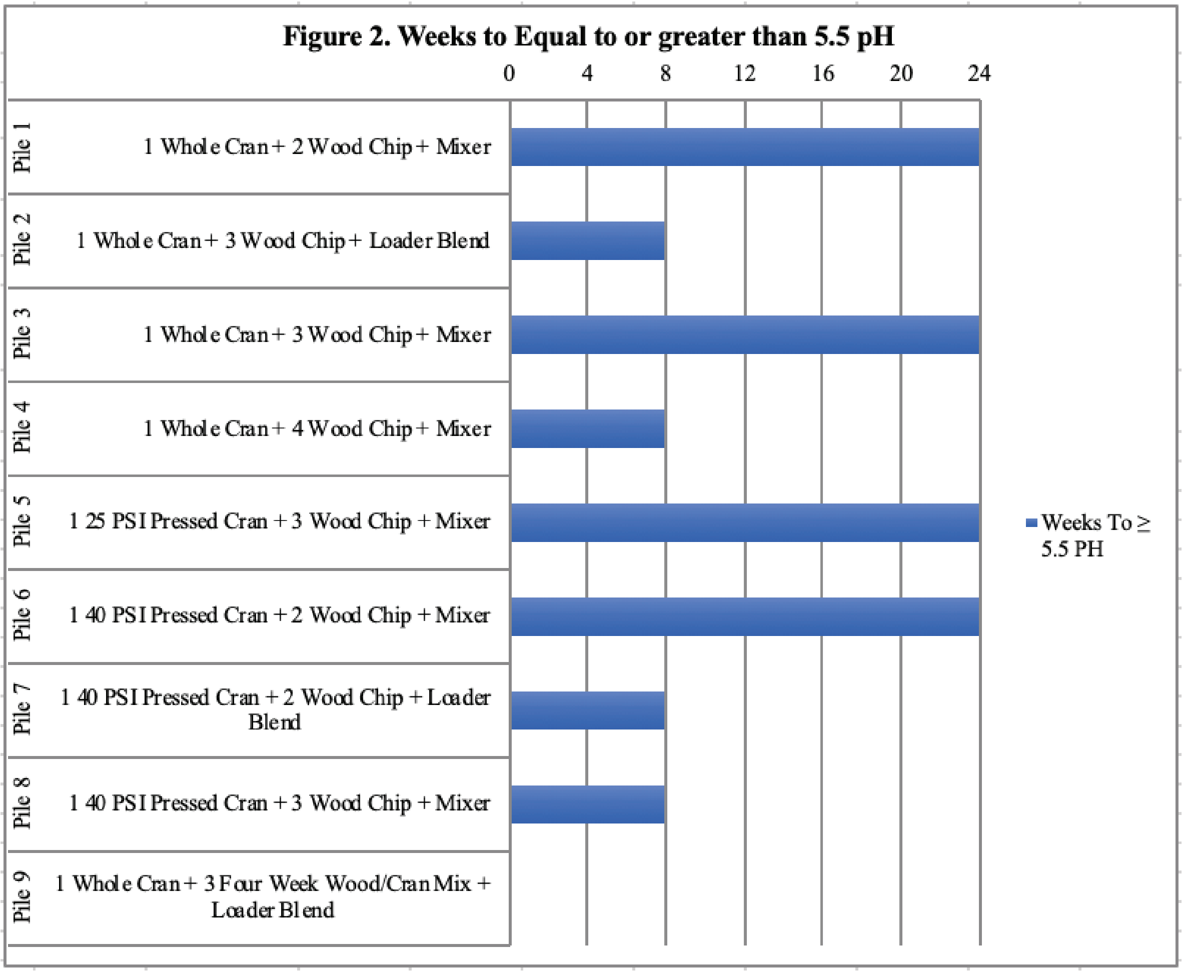
C. Trial Results

The target set forth in the farm's Facility Management Plan for pH buffering using the HCS was to achieve a pH of 5.5 or greater prior to reuse of the buffered mix (the biodegraded cranberry-woodchip compost). Ideally the farm wants to reach a pH in the range of 6-7 prior to reuse. In meeting these targets, the trials were overwhelmingly successful. Of the 9 piles, 5 had reached a pH of 5.5 or greater by 8 weeks, and all of the piles reached a pH of 5.5 or greater by 24 weeks (~6 months), which is when the final samples were taken. By 24 weeks, 8 of the 9 piles had reached a pH above 6, with 4 of those reaching a pH above 7. The pH analysis of the piles over time is presented in Figure 1 below.

Figure 1. pH Changes in Time



	Pile 1 1 Whole Cran + 2 Wood Chip + Mixer	Pile 2 1 Whole Cran + 3 Wood Chip + Loader Blend	Pile 3 1 Whole Cran + 3 Wood Chip + Mixer	Pile 4 1 Whole Cran + 4 Wood Chip + Mixer	Pile 5 1 25 PSI Pressed Cran + 3 Wood Chip + Mixer	Pile 6 1 40 PSI Pressed Cran + 2 Wood Chip + Mixer	Pile 7 1 40 PSI Pressed Cran + 2 Wood Chip + Loader Blend	Pile 8 1 40 PSI Pressed Cran + 3 Wood Chip + Mixer	Pile 9 1 Whole Cran + 3 Four Week Wood/Cran Mix + Loader Blend
Day 1	3.3	4.3	3.5	3.5	4.0	3.3	3.8	4.0	6.1
2 Weeks	3.6	4.9	4.6	4.6	4.3	4.1	4.6	5.1	6.5
4 Weeks	4.0	5.0	5.3	5.1	4.2	4.3	4.7	5.1	6.8
8 Weeks	5.0	6.9	5.8	6.4	4.5	4.8	5.8	6.3	7.2
12 Weeks	4.7	6.9	5.7	6.1	5.2	4.9	6.3	6.4	7.3
24 Weeks	5.6	7.5	6.4	6.2	6.4	6.4	7.3	7.1	7.6



i. Recipe and the Rate of Acid Degradation

The trials included blending woodchips with whole and pressed cranberries at different dilutions using the TMR mixer in order to test recipe variables. Three different TMR mixer blended piles were created using whole cranberries, at 2:1, 3:1, and 4:1 ratios of wood chips to cranberries. Pressed berries (40 psi) were blended with the TMR mixer at 2:1 and 3:1 ratios of wood chips to cranberries. There were faster pH buffering times in the higher wood chips to cranberries ratio piles. The 3:1 and 4:1 dilutions met the 5.5 pH or greater target at 8 weeks, while the 2:1 dilutions (mixer blended) did not reach 5.5 or above until somewhere between the 12 and 24 week samplings. While we can safely assume that a higher dilution would speed up the process, these results need to be viewed within the context of the overall experiment and operation. As discussed in Flaws in Trial Design (p. 7), the mixer-blended piles were smaller than ideal, and their performance suffered compared to the larger loader-blended piles. Pile 7, which was loader blended at a 2:1 ratio of wood chips to 40 PSI pressed cranberries, had a pH of 5.8 at 8 weeks, outperforming its mixer blended counterpart by a full pH point, and meeting the ≥5.5 or greater pH target within the same timeframe as the piles with more wood chips. Windrows made in the site's non-trial piles performed similarly, although we do not have detailed documentation of these results. The mixer-blended piles created at a 2:1 ratio should therefore be viewed as a worst-case scenario in terms of buffering times, a finding which is reassuring to the farm because it shows the HCS effectiveness even under poor composting conditions.

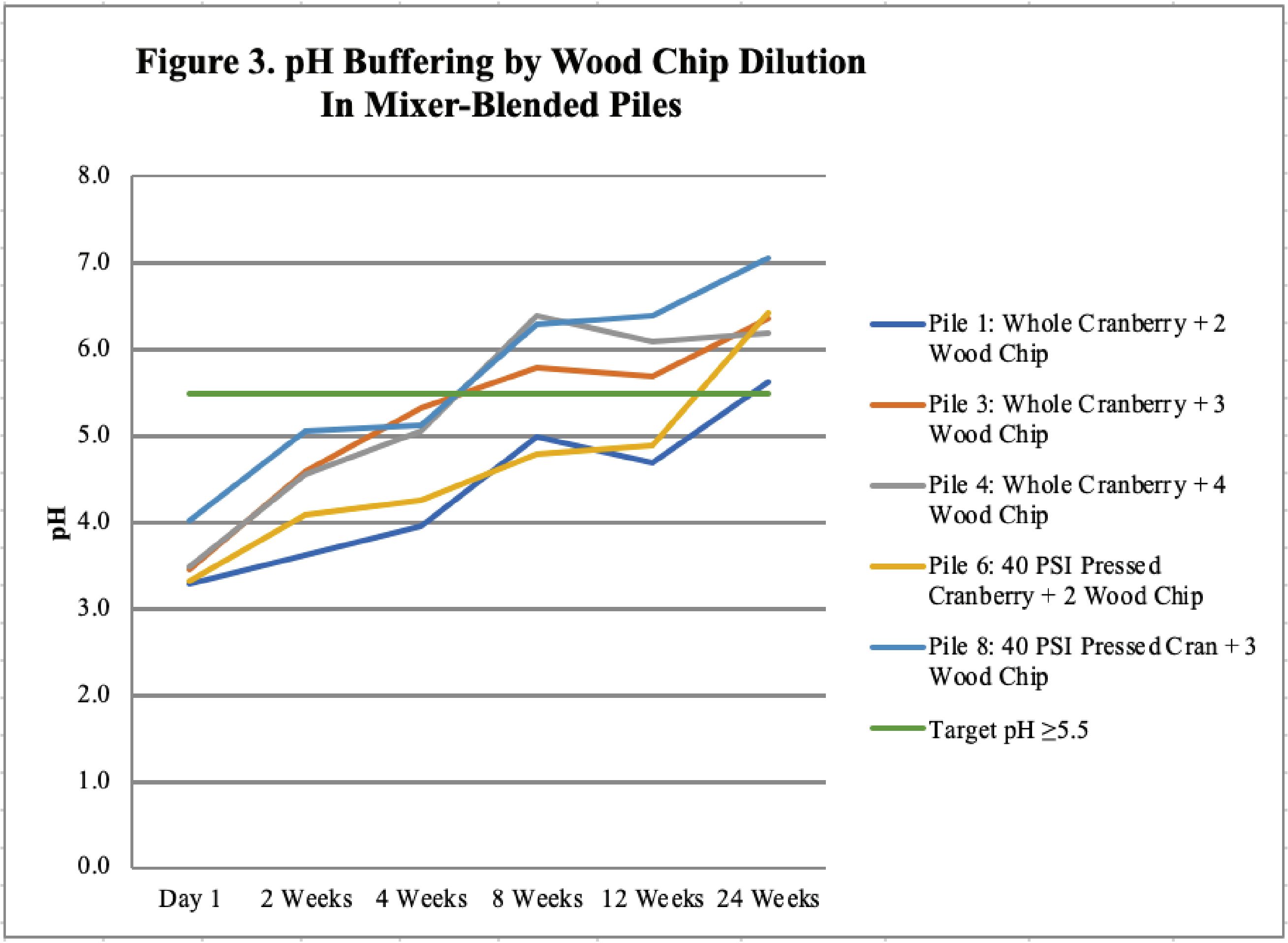


Table 3. pH Buffering by Wood Chip Dilution In Mixer Blended Piles

Treatment	Day 1	2 Weeks	4 Weeks	8 Weeks	12 Weeks	24 Weeks
Pile 1: Whole Cranberry + 2 Wood Chip	3.3	3.6	4.0	5.0	4.7	5.6
Pile 3: Whole Cranberry + 3 Wood Chip	3.5	4.6	5.3	5.8	5.7	6.4
Pile 4: Whole Cranberry + 4 Wood Chip	3.5	4.6	5.1	6.4	6.1	6.2
Pile 6: 40 PSI Pressed Cranberry + 2 Wood Chip	3.3	4.1	4.3	4.8	4.9	6.4
Pile 8: 40 PSI Pressed Cranberry + 3 Wood Chip	4.0	5.1	5.1	6.3	6.4	7.1

ii. Pre-Processing Using a Screw Press

In another component of the trials, we looked at how the practice of pre-processing cranberries with a screw press separator impacted the rate of pH buffering, as compared with composting whole unprocessed berries. At the point of generation, cranberries were fed into a Vincent KP-16 Screw Press running at 40 psi. The pressed berries were then transported to the farm for the trials. The berries were sampled at the farm and analysis showed that the moisture content of the pressed berries was only 0.9 less than the whole cranberries, which tested at 89.8%. This was a minimal reduction compared with the performance one would expect with other materials, such as manures, in which moisture can be reduced by 20% or more. While there has been variation reported in the screw press's effectiveness depending on variables such as berry size and quality, overall its performance throughout the season was poor, at best reducing moisture by 5%-10%.

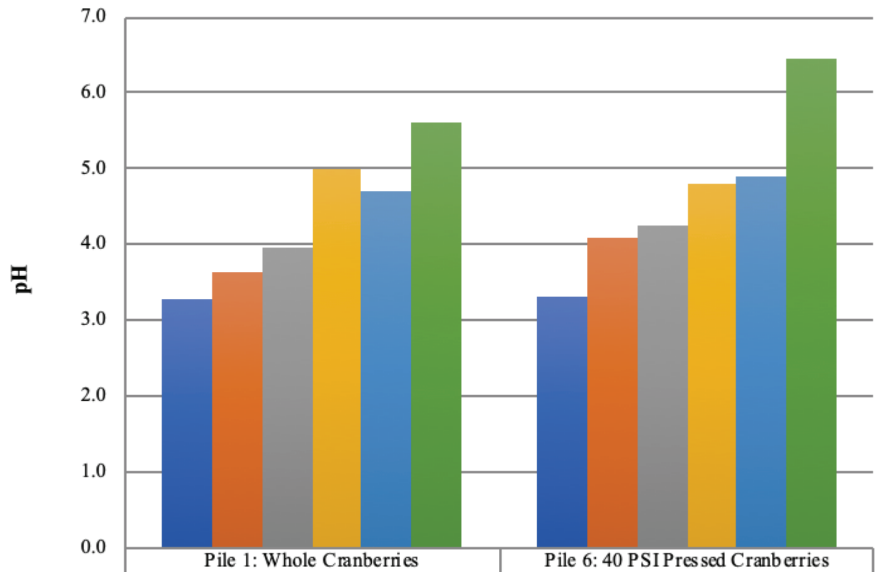
On the day of the trials, our analysis would indicate that the screw press was producing particularly poor outcomes in terms of moisture reduction; however, it did function to break the berries, and we could see a difference visually between the whole and pressed cranberries. For the trials, 4 piles were designed to directly compare the pressed and whole cranberries. We created mixer-blended piles using 2 and 3 parts wood chips. These two dilution rates were blended with both whole and pressed berries.

As illustrated in Image 1 and Image 2 below, the pressed cranberry piles had higher pH, except in two instances where the pH was the same or very similar. The end pH was higher in the pressed berry treatments by 0.8 and 0.7 in the 2-wood-chip and 3-wood-chip piles respectively. While we can assume that the pressed berries reached a pH of 5.5 or greater in a shorter time than the whole berries based on their higher overall pH, it is noteworthy that the two cranberry types reached 5.5 or greater at the same sampling interval, in both woodchip dilutions. The results indicate relatively similar timeframes for neutralization both in pressed and whole cranberries.

Image 1. Whole Cranberries

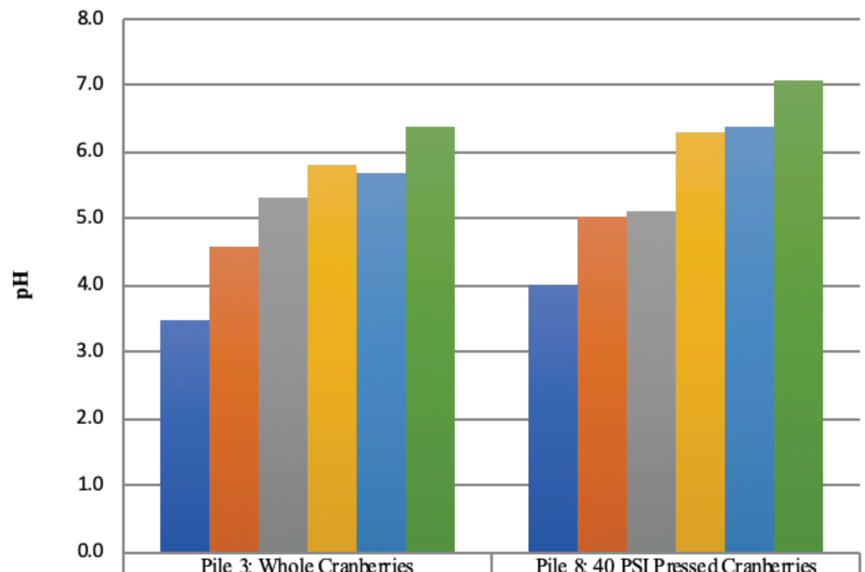
Image 2. Pressed Cranberries

Figure 4. pH in Whole and Pressed Cranberries (2 Wood Chip)



	Pile 1: Whole Cranberries	Pile 6: 40 PSI Pressed Cranberries
Day 1	3.3	3.3
2 Weeks	3.6	4.1
4 Weeks	4.0	4.3
8 Weeks	5.0	4.8
12 Weeks	4.7	4.9
24 Weeks	5.6	6.4

Figure 5. pH in Whole and Pressed Cranberries (3 Wood Chip)



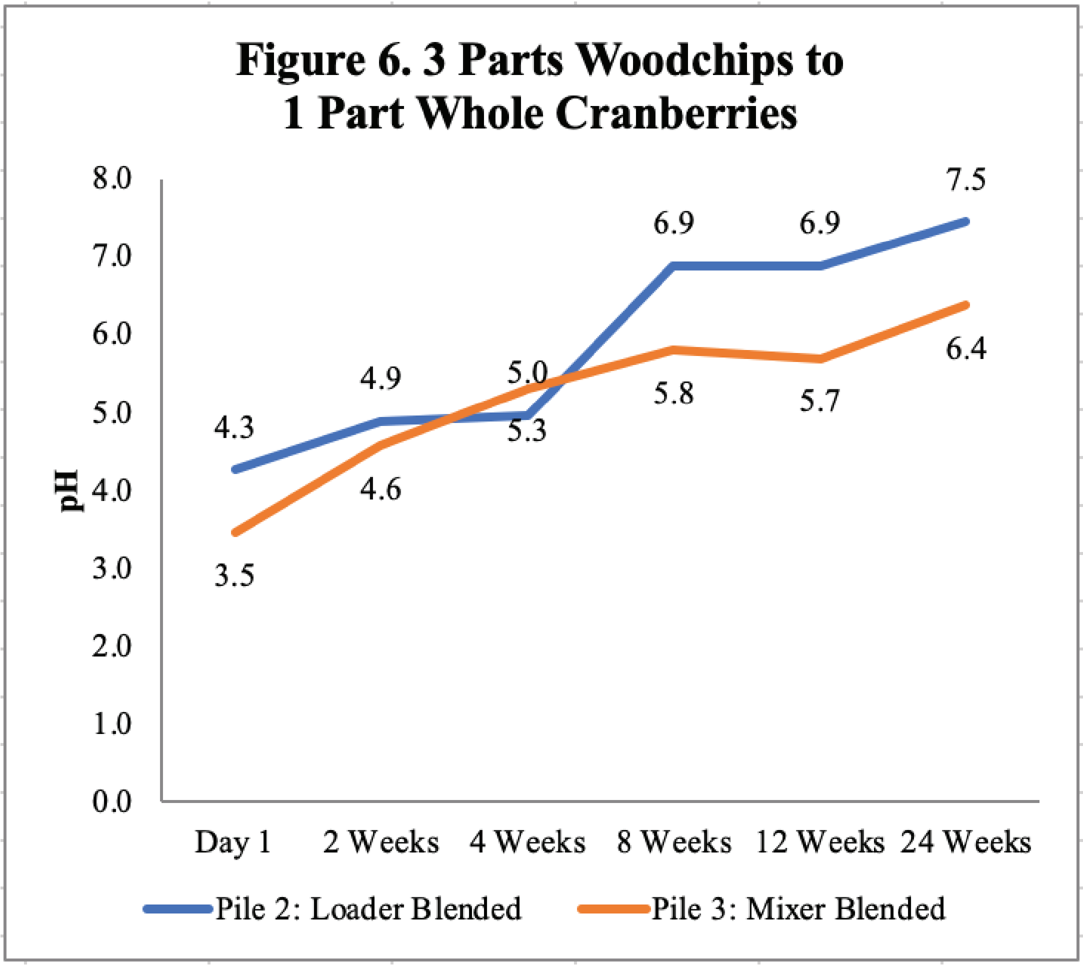
	Pile 3: Whole Cranberries	Pile 8: 40 PSI Pressed Cranberries
Day 1	3.5	4.0
2 Weeks	4.6	5.1
4 Weeks	5.3	5.1
8 Weeks	5.8	6.3
12 Weeks	5.7	6.4
24 Weeks	6.4	7.1

iii. Mixing Methodology

In order to compare the effectiveness of cranberry-woodchip blending methods, 4 piles were created following 2 recipes. Each recipe was mixed using both of the blending methods, one pile blended with the front-end loader and the other with the Total Mix Ration (TMR) mixer, to create piles 2, 3, 6, and 7. As shown in Figures 6 and 7, the piles blended with the front-end loader had higher pH levels overall.

In the two pressed-cranberry piles the differences between mixer- and loader-blended piles were less pronounced early in the process, while in the whole cranberry piles, the mixer-blended pile had a faster rate of pH rise than its loader-blended counterpart, surpassing that pile temporarily at the 4 week sampling. At 8, 12, and 24 weeks, the pH of the two loader-blended piles was 0.9-1.4 points higher than the mixer-blended piles. The 8-week sampling took place in early December, so it is possible that as external temperatures dropped, the larger sizes of the loader-blended piles held more heat, continuing with a higher rate of pH buffering than in the smaller, mixer-blended piles (as discussed in Flaws in Trial Design, p.7).

The two mixer-blended piles had surprisingly similar pH at 24 weeks, as did the two loader-blended piles. We can safely assume, given these results, that loader blending is an effective option, although we cannot rule out that mixer blending would perform equally or even better with larger pile sizes.



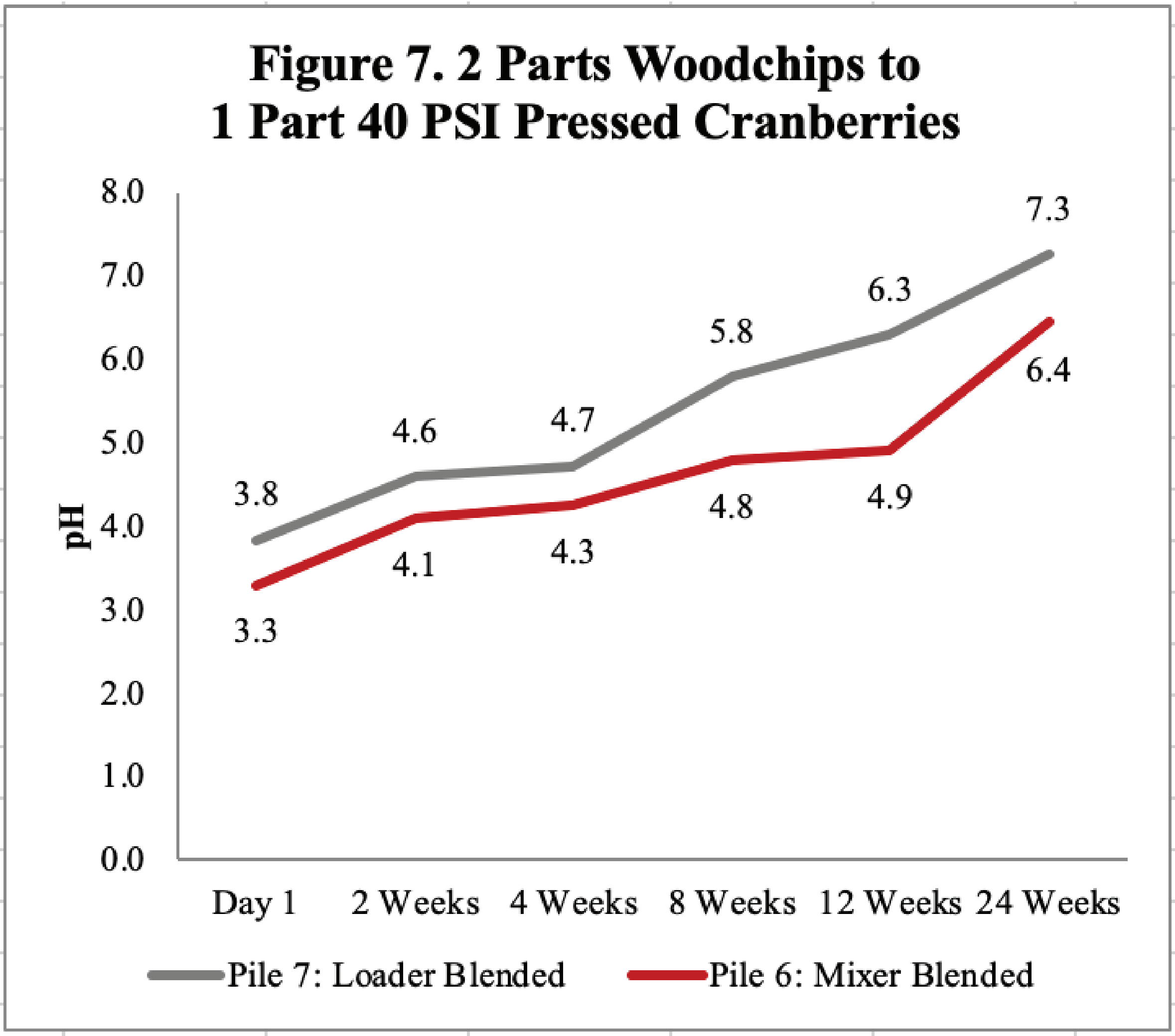


Image 3. Mixer-blended

Image 4. Loader-blended

iv. Reuse of the Buffered Mix

The final component of this trial involved re-using a pH-neutralized cranberry wood chip compost, which the farm calls its buffered mix, to process fresh cranberries. The buffered mix was created separately from the trials as part of the farm's ongoing composting activities, and was an example of how fast the process could work in a compost pile with optimal activity. It was a 2-parts chip, one-part cranberry mix that was sampled at 2 weeks and showed a pH of 6.2. At approximately four weeks the buffered mix had a pH of 7.3, which is when we re-blended at a rate of 3 parts buffered mix to 1 part whole cranberries with a bucket loader to create pile 9. On day 1, pile 9 had a pH of 6.1 and a pH of 7.6 by 24 weeks.

V. Discussion and Recommendations

While the on-farm trials described in this report took a controlled and scientific approach, the intentions of the trial were primarily practical. The partners who developed the project wanted to document a composting methodology that was capable of remediating the high-moisture, high-acid qualities of cranberries, while preventing the negative issues that can arise when those qualities are combined with odor-prone feedstocks. The pre-composting methodology, which we're calling the high-carbon strategy (HCS), was highly successful in the trials, and was also shown to work well at scale across the operation. In the farm's composting operations at large, thousands of tons of cranberries were processed, and we observed that the buffering process for high volumes worked better in most cases than in the smaller trial piles.

While there are areas where further investigation could be useful, we believe that the results of the trials have given the farm a reliable set of practices for managing cranberries and that these strategies have potential for wider adoption. The next section discusses takeaways from the trial results, as well as lessons learned beyond the trials, and how these have informed the farm in terms of practical implementation going forward.

A. High-Carbon Strategy Recipe

Prior to the trials, Kingfisher Compost had created two cranberry piles using a recipe of 2 parts wood chips to 1 part whole cranberries. These were sampled after 9 months and both came back with a pH around 7. We strongly suspected going into our experiment that given enough time, this recipe would reliably meet the target pH of 5.5 or greater. The main question was how long it would take for this recipe to perform the desired buffering function compared with other recipes. Piles 1, 6, and 7 used the same recipe ratios as the original piles (2:1 woodchip to cranberry). Piles 1 and 6, the two smaller mixer blended piles reached the target pH of 5.5 or greater by 24 weeks (Figure 4, p.12), while pile 7, which was a larger, loader-blended pile, had reached 5.8 by 8 weeks. As discussed elsewhere in this report, pile size appears to have been a major factor in pH buffering, and one that we did not adequately control for in our experiment. That said, pile 7's performance gives us confidence that the 2:1 ratio will work to reach our targets within a 1-2 month window under good conditions and within 3-4 months in suboptimal conditions. Indeed 3 larger piles created by the operation at large with the same recipe and sampled at 4 weeks had pH readings of 6.3, 6.6, and 7.3.

A 3:1 ratio of wood chips to cranberries might be a good option if an operation needed to move material through faster and with more certainty. Pile 2, which was a larger, loader-blended pile created using a 3:1 ratio of wood chips to cranberries, had a pH of 5 at 4 weeks and 6.9 at 8 weeks, so it likely hit 5.5 in under 6 weeks. Assuming that the buffered mix can either be used or consolidated to make more space, an operation would need to weigh the pros and cons of adding 33% more volume to the recipe upfront, in order to finish the process 50-75% faster. There is the up-front cost of the chip, a cost to moving the material into storage (versus storing it in place until it can be used directly), and the value of that space in moving other, potentially more valuable material through the site. Sourcing 50% more chip might also be a challenge. In some cases, using a 3:1 recipe might be justified. At Kingfisher, clearing out additional space and processing in less time did not justify the added costs incurred in increasing the ratio of chip, although it is certainly an option if needed in the future.

***Note:* Some might be concerned with moisture loss or odors from a pile at a 2:1 dilution. Even in a very wet fall with moistures above 70% at times, we saw little-to-no loss of moisture from the piles. This appears to be less of a concern than originally anticipated using the HCS.**
Overall it was hard to distinguish the smell of cranberries from the smell of woodchips, with both being negligible across the board.

It should be noted that while Kingfisher's HCS trials went very smoothly, there were odors reported from at least two other sites that composted cranberries without using the HCS. In one case, the other feedstock was primarily aged leaves, which on their own are generally thought of as a low odor risk. In unofficial test piles at Kingfisher, leaf-cranberry mixes also had a stronger smell. Although these were not terribly offensive, a sour tannin aroma was noticeable, and seemed out of proportion to the pile's relatively small volume (maybe 150-200 yards total). We did not experience issues from a site composting food scraps and cranberries, but anecdotal reports are that this can result in very problematic odors.

Table 4. illustrates our current understanding of the risk levels associated with materials likely to be combined with cranberries. The farm has made the decision to only use the low-risk HCS going forward.

B. Pre-Processing

Several factors weigh in to the choice of whether to press cranberries before composting them. The method was originally used with the belief that it would speed up the process. Our results show only slightly faster acid degradation with pressed cranberries. Visual observations indicated that most of the whole cranberries were broken non-mechanically after about 2 months. This low-tech approach works within a reasonable timeframe, with all but one of the whole cranberry piles reaching a pH of 5.5 or above by 8 weeks.

It is important to note again that the screw press utilized by Ocean Spray (which was a rented Vincent KP-16 operating primarily at 40 PSI) did not appear to work well with cranberries, especially with small and partially rotted cranberry culls, which are most common in the early season. There was also a cost to Ocean Spray in renting and running the equipment and in processing the liquid that was pressed out of the berries, which went to their wastewater treatment plant. While there is almost certainly other equipment better suited to pre-processing the berries in order to speed up degradation, there also may be a risk in doing so in terms of exposing the acids in the berries. If the goal were to speed up the HCS, the risk of odors would be fairly low, but if the goal were to incorporate the cranberries with other materials, the risk might actually increase because of the higher volume of exposed acids and water.

Table 4. Odor Risk Factors In Processing Raw Cranberries

Raw Cranberry (Combined with)	Mixed Food Scraps, High Nitrogen Feedstocks, High Odor Potential Feedstocks	High Risk
	Leaves	Medium Risk
	Wood Chips, Woody Feedstocks	Low Risk

C. Mixing Methodology

While the results of the trials found faster pH rise in the loader-blended piles, this was most certainly in part due to their larger pile size. While we could not determine which method works faster due to this error in trial design, it is clear that both methods work adequately. Phil DeMoranville, the farm's owner, believes that there is probably a benefit to using a TMR mixer in terms of the thoroughness of the mix and breaking of some berries, but during high throughput volume periods, he views the use of the mixer as impractical due to it's high labor requirements compared with loader blending.

D. Reuse of the Buffered Mix

As a new practice for the farm, the high-carbon strategy (HCS) trials leave a number of unanswered questions. The biggest is in regards to reuse and/or end use of the buffered mix. Inherent to the concept of the HCS is that the buffered mix can be added to traditional compost recipes, in a manner similar to how a composter would use wood chips. The buffered mix could also be reused to process a second round of fresh cranberries or it might be used as a high-carbon compost for mulch or green infrastructure applications.

Our study of the reuse phase of the process was limited to one buffered-mix/fresh-cranberry pile in our trial and that pile worked exceptionally well. The farm has been using the buffered mix for processing additional cranberries on a large scale since February 2019, following the trials, and it has also been blending it into its crabshell compost recipes at a rate of about 15% by volume. Anecdotally, we've seen these strategies working well so far, although more time is needed to thoroughly understand the ins-and-outs of cycling this material through the compost process.

While the buffered mix is a carbon feedstock, due to the level of degradation that has already occurred, it can be safely assumed that little of the remaining carbon is biologically available. As the process progresses, an operator can assume that the remaining carbon will become less and less biologically available, decreasing the feedstocks value as a compost activator. The older the material, the more it should be treated a bulking agent or porous filler. One benefit of the pre-composting step is that the chip will be aged and have lower carbon going into the new compost mix, increasing the percentage that is likely to fully degrade within the next round of composting. The buffered mix will also work well as a capping agent or biofiltration media to cover more nitrogenous mixes. The buffered mix also appears to retain relatively high moisture content and should therefore not be considered a dry-matter source in the way that many other high-carbon materials would.

VI. High Carbon Strategy Best Management Practices

One of the primary goals of these trials was to document the farm's methodologies, which is critical to ensuring the process works consistently. While the high-carbon strategy is fairly non-traditional as a composting methodology, probably its biggest advantage is its simplicity. It is low-tech, low labor, and our experience indicates that it is a low-risk process if executed within the parameters we trialed. These practices are outlined here:

Cranberry Recipes – Use low-risk woody materials for the high-carbon cranberry composting strategy, including woodchips, wood grindings, and pH-stabilized cranberry/wood chip mix, also referred to as buffered mix.

1. Target a calculated recipe for cranberries/woody materials at:
    - ≤ 70% Moisture content
    - ≤ 1,100 Pounds/Cubic Yard

2. The following recipes should function well under typical conditions, although higher dilutions will work faster:

	Feedstock Volume		
	Whole Cranberries	Wood Chips	Buffered Mix
Recipe 1	1	2	0
Recipe 2	1	0	2
Recipe 3	1	1	1

3. Document the recipe and track every batch on an ongoing basis.

Receiving & Blending – Receive Cranberries in a designated receiving area. Blend thoroughly using either a bucket loader or a total mix ration (TMR) Mixer.

Pile Formation – Form blended recipe into windrows according to the following steps:

1. Form windrow to a height of 7 feet 6 inches or less and a width of approximately 15 feet in a peaked formation, to encourage shedding of precipitation.
2. Label with a number/name on a wooden stake.
3. Windrows may be formed close together since they will be turned infrequently.

Pile Monitoring – Monitor weekly following the protocols outlined in Compost Pile Monitoring: Why and How.[7] The goal of the monitoring is not to show that typical heat treatment standards have been met (all material ≥131° F for ≥3 days), as is one of the goals with traditional compost piles. In the high carbon strategy, the primary monitoring goals are to:

1. Observe and immediately resolve any offensive odors present.

2. Assess recipe characteristics for excessively wet and dense pile conditions.

This will inform future recipe adjustments if they are needed.

3. Make sure that the piles aren't overheating. The goal is typically to keep the piles below 160 F. Optimal temperatures for pH buffering are thought to occur below 105 F.[8]

4. Gauge when the pre-composting treatment is complete.

Maintaining average temperatures of at least 80 F for at least 2 months is believed to adequately buffer pH under aerobic conditions; however, visual observation and periodic lab analysis should be used to verify that low pH conditions have been remediated.

Turning – Unlike in traditional composting, as a precaution in this method, piles containing cranberries are not turned early in the process. As acids degrade, the piles may be turned if it is deemed advantageous (somewhere in the 1-4 month range). If a pile is overheating (>165 F), it should be turned to dissipate the heat. Prior to turning the pile, the operator should open up a small portion of the pile to check wheather turning it will release a nuisance odor.

Pile Leachate Management* – Free moisture that accumulates at the base of piles or around piles can be a source of odor, attract animals and insects, and will degrade the compost working surface over time. Prevent loss of moisture from the pile by:

1. Creating recipes with a pile moisture of ≤70%.

2. As needed, create a berm of wood chips or other dry carbon materials around and down the slope of the windrow.

3. Adjust the recipe if free moisture becomes a consistent issue.

* This assumes that the site has adequate conservation controls in place to manage precipitation and prevent runoff from the site.

Odor Prevention – The primary means of odor management is prevention. With the woody, porous high-carbon strategy, there is a low risk of odors, as previously discussed. However, low pH and potentially high moisture conditions always pose a risk of sour or offensive smells, particularly when large volumes of material are agitated prematurely. In addition to maintaining a highly porous and carbonaceous pre-treatment recipe, odor prevention measures include the following:

1. Pile size should be kept at or below 7.5 feet, until pH is above 5.5 (using visual assessment described in Use of Buffered Mix, p.17

2. If smells accumulate from the cranberries, the piles should be immediately capped with at least 3 inches of mature compost, buffered mix, or wood chips, to trap and filter odors.

3. Maintain static (unturned) piles until cranberries/acids degrade.

Odor Remediation – If a pervasive and potentially nuisance-causing odor is detected, the operation should proceed with extreme diligence and caution, following these steps:

1. The location or locations of the odor should be identified. This might include:
   a. Compost piles
   b. The compost pad
   c. Receiving areas
   d. Raw materials

2. The operator should assess how the odor originated, through a combination of monitoring and reviewing pile records. Likely sources include:
   a. Dense pile conditions lacking oxygen (anaerobic).
   b. Materials that are not well blended.
   c. Reuse of inadequately stabilized buffered mix.

3. The operator should document the odor in the pile's monitoring log.

4. If the odor is confined to a relatively small volume of material, and the cause of the odor can be easily identified and remediated (through a recipe adjustment, capping with compost, and/or aeration), the operator should proceed immediately to resolve the issue.

5. If the cause of the odor cannot be easily identified or if it is present in a large volume of material, the operator should:
   a. Contact a technical consultant.
   b. Contact relevant state agencies to make them aware that there might be a problem.
   c. Cover the affected material with a thick layer of mature compost.
   d. Work with the consultant and state to create and enact a remediation strategy.

6. The operator should document the remediation strategy and make all necessary adjustments to ensure that the issue is prevented in the future.

Reuse & Management of Pre-Treated Compost – Once the pH is neutralized through compost pre-treatment, the buffered mix may be used as a compost feedstock in more traditional compost recipes or in further cranberry processing. PH can be considered neutralized when the compost reaches above 5.5 and has no acidic smell. Testing of trial piles as described in this report, has shown that pH buffering to 5.5 and above happens under ideal conditions in as little as 2-4 weeks and in less than ideal conditions in 8-24 weeks. A high proportion of visible woody particles will remain, indicating that it would act as a good bulking or capping agent. The operation may re-introduce this material into new compost recipes at that point (including use with more fresh cranberries using the high-carbon strategy) or consolidate windrows by combining them for further breakdown or storage.

Visual cues and temperature monitoring will be the main tools for assessing completed pre-treatment of the buffered mix. Maintaining average temperatures of at least 80° F for at least 2 months is believed to adequately buffer pH under aerobic conditions, with higher temperatures decreasing the required buffering time; however, visual observation must always be used to confirm treatment has occurred, and lab analysis should be used periodically and under any non-typical or questionable applications.

Figures 8 to 10 show piles that have reached a pH of 5.5 or above and are considered a pre-treated buffered mix:

Figure 9.

pH = 5.8

Figure 8.

pH = 6.9

Figure 10.

pH = 6.4

Figures 11 to 13 show piles that have NOT reached a pH of 5.5 and are NOT ready for reuse:

Figure 11.

pH = 5

Figure 12.

pH = 4.5

Figure 13.

pH = 4.8

Care should be taken when combining the buffered mix with potentially odorous feedstocks. Materials with a pH above 6 can likely be used in higher proportions than those in the 5.5-5.9 range, although it will be up to the individual operator to assess the risk. Try new recipes on a pilot-scale first and correct as needed.

Notes

1. Massachusetts Department of Agricultural Resources 2015/2016 Annual Report (Boston, MA: Massachusetts Department of Agricultural Resources, Executive Office of Energy and Environmetal Affairs, 2016), p. https://www.mass.gov/files/documents/2018/02/12/2015%202016%20Annual%20Report%20 JW%20JL%20edits%201%2024.pdf

2. Robert Rynk, ed., On-Farm Composting Handbook (Ithaca, NY: Natural Resources, Agriculture, and Engineering Service, 1992), 7.

3. Cecilia Sundberg et al., “Effects of pH and Microbial Composition on Odour in Food Waste Composting,” Waste Management 33, no. 1 (2012): 210.

4. Chiu-Chung Young et al., “What Happens During Composting?,” Food and Fertilizer Technology Center for the Asian and Pacific Region, December 1, 2005. http://www.fftc.agnet.org/library.php?func=view&id=20110913155219.

5. Feedstock Sampling Protocol (Montpelier, VT: Vermont Agency of Natural Resources, Department of Environmental Conservation). https://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/Documents/ANR%20Feedstock%20Sampling.pdf

6. Feedstock Protocol, VT ANR.

7. Compost Pile Monitoring: Why and How (Montpelier, VT: Vermont Agency of Natural Resources, Department of Environmental Conservation). https://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/Documents/ANR%20Compost%20Pile%20Monitoring%20Why%20and%20How.pdf

8. Cecelia Sundberg, “Improving Compost Process Efficiency By Controlling Aeration, Temperature, and pH” (PhD diss., Swedish University of Agricultural Sciences, 2005), 29.

Compost Technical Services

Ocean Spray

The concept for the high-carbon strategy was developed by Phillip DeMoranville of Kingfisher Corporation, a veteran composter and organic cranberry farmer in Dartmouth, Massachusetts. Early trials were initiated in partnership with James McSweeney of Compost Technical Services LLC (author of *Community-Scale Composting Systems*), with the support of Massachusetts RecyclingWorks. Ocean Spray Cooperative funded the full 2018-2019 on-farm trials and report, under Environmental, Health, and Safety Manager, Patricia Gallagher. Sean Bowen, Agricultural Compost Coordinator for the Massachusetts Department of Agricultural Resources consulted with the team throughout the project and reviewed this report. Report edited by Mary Margaret Breed. Graphic layout by Sarah Atkinson.