The Effect of Soil Remediation Treatments on Microbial Populations Following an Extreme Flooding Event

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Abstract:

Flooding may pose a risk of contamination of soils and crops by human pathogens. Crops growing in previously flooded areas may be at risk for contamination by foodborne pathogens. In June and July of 2015 the Wabash River flooded a portion of the Southwest Purdue Agricultural Center near Vincennes, IN. When floodwaters receded, an experiment, consisting of a randomized complete block design with 4 replications of 6 treatments, was established in a previously flooded field. Soil samples were periodically collected from experimental plots. Samples were then tested for levels of coliforms, aerobic microbes, and yeast and molds. Data analysis performed at the conclusion of the experiment suggested that best practice in the case of extreme flooding is to leave soils undisturbed for a period of time following the recession of floodwaters.

Background:

The potential for contamination of fresh produce by foodborne pathogens has been well documented (2). Flooding increases the probability of soil and crop contamination by human pathogens. The U.S. Food and Drug Administration (FDA) considers any edible part of a produce crop that has been contacted by floodwater to be adulterated and unfit for sale or introduction into the public food supply (5). After flooding, produce growers must observe a window of time prior to planting (or re-planting). Consequently, growers are interested in techniques that may reduce the required window of time prior to planting.

The Wabash River is the largest river in Indiana. The river travels across Northern Indiana, turns south and forms the western boundary with Illinois, with several municipalities along its course. The Southwest Purdue Agricultural Center (SWPAC), a regional research farm operated by Purdue University, is situated along the Wabash River. The 2015 growing season saw record rainfall throughout much of Indiana. Consequently, the river was out of its banks for an extended period of time. Records indicate that the river rose above flood stage in June 2015 and subsequently flooded SWPAC Field #1, a 25 acre (10.1 ha) field that lies along the riverbank, on June 17. The river was not below flood level again until August 2015. River levels dropped sufficiently to expose the higher portions of Field #1 on August 27. The field was submerged for 40 days. During that time, water covered the field to a depth of up to 6.5 ft. (2.0 m). Prior to floodwaters receding, it was determined that agricultural land exposed to extreme flooding offered an excellent opportunity to study changes in the levels of indicator organisms as flood

waters receded and soils dried and to investigate the effect of possible remediation techniques on levels of indicator organisms.

Research Methods:

Initial water sample collection
Prior to project initiation, water samples were taken from flooded areas at SWPAC. Ten samples were collected on July 7, placed on ice, and transported to the Purdue University main campus in West Lafayette, IN, where testing was done in the lab of Dr. Amanda Deering in the Department of Food Science. Samples were plated onto Petrifilm Coliform Count Plates and Petrifilm Aerobic Count Plates (3M Corp., Saint Paul, MN) at various concentrations in order to estimate the level of coliforms and overall biological activity in the flood water.

Plot establishment
Flood waters receded from Field #1 on July 27. The field was accessed on July 30, three days post-recession. At that time, plots were established. Each of the 24 established plots measured 25 ft. x 50 ft. (7.6 m x 15.2 m). Plots were arranged in 4 rows, with each row containing 6 plots. Additionally, plots were separated from each other by 20 ft. (6.1 m) on all sides. This allowed for movement of equipment within the study.

Collection of soil samples
Immediately following plot establishment, initial soil samples were taken from each individual plot on July 27 (3 days post-recession). Samples were collected with a soil probe. Within each plot, 5 cores were taken to a depth of 8 inches. Cores were taken randomly within plots and were mixed thoroughly to create a composite sample that was used for analysis. Soil samples were taken at 3, 14, 24, 36, 52, 67, 78, and 107 days post-recession.

Experiment establishment
The study as established as a randomized complete block design (7) with 4 replications of 6 treatments. Treatments were as follows:

1. Control – Plots used for this treatment were undisturbed, except for collection of soil samples.
2. Cover crop – Plots were subjected to tillage and a cover crop was established. Initial tillage was performed on August 12 using a disc cultivator (Allis Chalmers Model 2300). Plots were again tilled on August 14. Following tillage, oats were sown into the plots using a grain drill (John Deere Model B). Agricultural production in the Midwest consists primarily of agronomic crops. Current agronomic recommendations call for cover crops to be sown into fields laid bare by flooding (1). The use of cover crops is a valid technique for soil conservation and may be advisable in those situations where crops are not intended for human consumption. However, in those situations where crops intended for human consumption may be planted following a flood, the effect of this practice on indicator organisms is unknown. This treatment was used to estimate the effect of cover crops on indicator organisms.
3. Collards + incorporation – Plots receiving this treatment were tilled with a disc cultivator on August 12 and again on August 14. Immediately following the second tillage, collards

were sown into plots with a grain drill at recommended rates (4). Brassicas have been shown to have anti-microbial properties (6). Collards were chosen because it is a short-season crop and could be produced with what remained of the growing season at the time of plot establishment. Following establishment, collards were allowed to grow and were incorporated into the soil with a disc cultivator at on October 21 (68 days after planting).

4. Black plastic mulch – Black plastic mulch is frequently used in vegetable production in the Midwestern and Southeastern U.S. Plastic mulch retains heat from sunlight and consequently results in elevated soil temperatures. It was hypothesized that increased soil temperatures under the mulch due to soil solarization would accelerate the decline of indicator organisms in the root zone. Following tillage on August 12 and 14, black plastic mulch (90-day photodegradable, Ginegar Corp.) was placed into plots on August 14. Five rows were laid with a plastic layer (Model 90, Mechanical Transplanter Co., Holland, MI). Rows were 50 ft. (15.2 m) long, extending the entire length of the plots. Once plastic was applied, soil samples were taken from under the plastic with a soil probe. Five cores were taken from under the plastic within each plot and were mixed to form a composite sample.
5. Clear plastic mulch – Clear plastic mulch functions as black plastic mulch and increases soil temperature. While not as commonly used, clear plastic mulch tends to result in higher soil temperatures than black plastic mulch and is used by growers to accelerate crop development and maturity of early (first-planted) crops. Clear plastic mulch was laid into plots on August 14, following tillage with a disc cultivator on August 12 and 14, in the same manner as the previously described treatment. Again, following establishment of plastic rows, soil samples were taken from the center of the plastic rows.
6. Tillage – Tillage breaks up compacted soil and crusted soil surfaces. This results in more rapid drying, as well as increased soil aeration, and may affect the rate of decrease of indicator organisms. Plots receiving this treatment were tilled with a disc cultivator on August 12 and 14, as well as September 23. With the exception of three tillage operations, plots receiving this treatment remained undisturbed.

Other treatments

With the exception of the previously described treatments, all plots were treated in a uniform fashion. On August 18, the entire study received an application of paraquat (Gramoxone Herbicide, Syngenta) at the rate of 3 pts/acre (3.6 L/ha) in an effort to manage pigweeds (*Amaranthus* spp.) that started to grow following the recession of floodwaters. Prior to application, a non-ionic surfactanct was added to the spray solution at the rate of 1 pt./100 gal. (0.12 L/100 L) of finished spray solution.

Monitoring of soil temperature

Soil thermometers were placed in plots in an effort to monitor soil temperatures. Thermometers were placed in at least one replication of each treatment at a depth of 6-8 inches (15.2-20.3 cm). Additional thermometers were placed in those treatments which contained plastic mulch. Thermometers placed in plastic mulch treatments were located in the center of mulch rows.

Processing of soil samples

Following collection, soil samples were initially transported to the main campus of Purdue University and were tested in the lab of Dr. Amanda Deering in the Department of Food Science.

Samples were processed by diluting 25g of soil in 225 ml of phosphate buffer (pH=7). The resulting mixture was either plated onto Petrifilm Coliform Count Plates and Petrifilm Aerobic Count Plates (3M Corp., Saint Paul, MN) or used to prepare dilutions that were subsequently plated. Samples were tested for both total coliforms and total biological activity (total aerobic plate count). After the project was initiated, testing facilities were established at SWPAC. Soil samples collected following the establishment of facilities at SWPAC were stored on-site in a walk-in cooler at 40F and tested using identical procedures. Additionally, samples processed at SWPAC were plated onto Petrifilm Yeast & Mold Count Plates (3M Corp., Saint Paul, MN). For each soil sample, at least three petrifilms were plated for each individual test (coliform count, aerobic count, and yeast & mold count). This gave adequate subsamples for estimating and averaging the overall microbe level for any individual soil sample. Coliform Count, Aerobic Count, and Yeast & Mold Plates were enumerated at 24 ± 2h, 48 ± 2h, and 5 days respectively. Plate counts were recorded and were used to estimate the number of colony forming units per gram (CFU/g) of soil. These values were used in statistical analysis.

Collection of final water samples

In late December 2015 the Wabash River once again rose above flood level and flooded Field #1 at SWPAC. Samples of the flood water were again taken. Five samples were collected using the same technique as previously employed. Samples were processed in the same manner as previous water samples in order to estimate coliforms and biological activity.

Research Results:

Results of initial water sample testing

Initial water samples taken during the flooding event confirmed the presence of coliforms in the floodwater. The results of initial flood water sampling are given in Table 1.

Table 1. Results of floodwater samples taken prior to the establishment of the experiment.

Sample	**Mean total coliforms** (CFU/ml) (n=3)	**Mean total coliforms** Log (CFU/ml) (n=3)	**Mean total aerobic count** (CFU/ml) (n=3)	**Mean total aerobic count** Log (CFU/ml) (n=3)
1	$3.00x10^1$	1.42	$4.63x10^4$	4.67
2	$3.60x10^1$	1.52	$5.23x10^4$	4.72
3	$2.13x10^1$	1.31	$3.17x10^4$	4.5
4	$1.40x10^1$	1.13	$1.21x10^4$	4.04
5	$2.33x10^1$	1.30	$8.33x10^3$	3.92
6	$1.33x10^1$	1.10	$6.37x10^3$	3.77
7	$1.87x10^1$	1.23	$1.16x10^4$	4.06
8	$3.67x10^1$	1.52	$2.73Ex10^3$	3.44
9	$2.17x10^1$	1.29	$8.77x10^3$	3.94
10	$2.20x10^1$	1.27	$8.17x10^3$	3.90

Initial soil sample results

In general, initial soil sample results taken prior to establishment of treatments showed a large degree of variation. Coliform counts in the initial soil samples ranged from 267-156,333 CFU/g soil. Data were transformed to Log(CFU/g soil) and subjected to an analysis of variance (ANOVA) using SAS ANOVA (SAS Institute, Inc., Cary, NC). The ANOVA confirmed differences among replications at the α=.05 significance level.

Aerobic counts of the initial soil samples were considerably more uniform than coliform counts, ranging from $3.8x10^6 – 1.05x10^7$ CFU/g soil. An ANOVA of log-transformed values indicated no significant differences among plots at the α=.05 significance level.

Analysis of soil coliform counts over time

Plots of coliform counts (CFU/g soil) vs. time (days post-recession) for all individual plots in the experiment failed to indicate a clear relationship between the two variables. Plots of log-transformed data were more linear in appearance. Consequently, least-squares regression was used to identify the "best-fit" line for coliform counts (Log CFU/g soil) vs. time for each replication within each treatment. The slope of the regression line for each replication of each treatment was considered to be the overall rate of decrease or increase for each plot over the duration of the experiment. An ANOVA of the slope of the regression lines for each treatment failed to detect differences in treatments or replications within treatments at the α=.05 significance level. Table 2 gives the mean rate of decrease of coliform levels for each treatment.

Table 2. Treatment means and for rate of decrease of coliforms and Y-intercepts (n=4).

Treatment	Mean rate of decrease	Y-intercept
Collards + incorporation	$-2.52x10^{-3}$	3.72558
Cover Crop	$-3.95x10^{-3}$	3.81404
Tillage	$-4.33x10^{-3}$	3.817115
Black Plastic	$-5.99x10^{-3}$	3.220379
Clear Plastic	$-9.02x10^{-3}$	3.274498
Control	$-1.40x10^{-2}$	1.854486

Due to irregularities in plots of coliform counts (Log CFU/g soil) vs. time and the lack of detectable differences in rates of population change, trapezoidal integration (2) was used to estimate the overall levels of coliforms for each replication within each treatment by calculating areas under the population curves from 3-107 days post-recession. Areas under the curves were subjected to an ANOVA and mean separation procedure (Fisher's LSD). No differences were detected within or among treatments at the α=.05 significance level. However, the mean separation procedure did detect differences in treatment means. Results of the mean separation procedure, given in Table 3, indicated that the mean area under the population curve was significantly different for the control treatment.

Table 3. Results of Fisher's LSD for the mean areas under the coliform population curve.

t Grouping	Treatment	Mean area under the curve
A	Cover Crop	381.30
A	Tillage	376.77
A	Collards + incorporation	376.35
A	Black Plastic	299.88
A	Clear Plastic	291.84
B	Control	94.95

Analysis of aerobic counts over time

Following the conclusion of soil testing, aerobic plate counts were transformed into CFU/g soil. Plots of CFU/g soil vs. time were analyzed. In general, aerobic counts increased with time. However, no clear relationship appeared to exist. As a result, trapezoidal integration was used to estimate areas under the population curves from 3-107 days post-recession. Areas were then subjected to an ANOVA and mean separation procedure (Fisher's LSD). The results indicated highly significant differences in the overall levels of aerobic organisms within replications, but failed to detect differences among treatments. The mean separation procedure indicated significant differences among treatment means at the α=.05 significance level. These differences are summarized in Table 4.

Table 4. Results of Fishers LSD for mean areas under the aerobic count population curve.

t Grouping	Treatment	Mean area under the curve
A	Cover Crop	2.18×10^9
B	Black Plastic	1.37×10^9
BC	Tillage	1.27×10^9
BC	Collards + incorporation	1.21×10^9
BC	Clear Plastic	1.20×10^9
C	Control	1.01×10^9

Aerobic counts from the last soil sampling at 107 days post-recession were tabulated and subjected to an ANOVA and mean separation procedure. The ANOVA indicated highly significant treatment differences. The mean separation procedure (Fisher's LSD) indicated significant differences in treatment means at the α=.05 significance level. Treatment means are given in Table 5.

Table 5. Results of Fishers LSD and treatment means for aerobic counts at 107 days post-recession.

t Grouping	Treatment	Mean aerobic count (CFU/g soil)
A	Cover Crop	$1.99x10^7$
AB	Collards + incorporation	$1.88x10^7$
ABC	Clear Plastic	$1.58x10^7$
BC	Black Plastic	$1.53x10^7$
BC	Tillage	$1.53x10^7$
C	Control	$1.43x10^7$

Analysis of yeast & mold counts over time

At the onset of this project, soil samples were transported to the main campus of Purdue University for testing. Soil samples taken to the main campus were not analyzed for yeast & mold. As facilities were established at SWPAC for processing soil samples, yeast & mold (YM) counts were added to the testing protocol. Consequently, data for these counts are not as numerous as for coliform and aerobic plate counts. However, in general, the quantity of yeasts and molds appeared to increase over time. Initial YM counts ranged from 7,974-209,840 CFU/g soil. An ANOVA of initial YM counts did not indicate any detectable treatment differences. Highly significant differences among replications were indicated by the ANOVA. This process was repeated with YM counts at the end of the experiment. YM counts at the end of the experiment ranged from 90,931-314,760 CFU/g soil. ANOVA results indicated no differences in treatments or replications.

Results of final water sampling

As stated previously, the Wabash River once again flooded Field #1 at SWPAC in late December 2015. Water samples were collected and processed in the same manner as were initial samples. The results of the sample tests are given in Table 6. While the December 2015 flood reached a level greater than the flooding in June/July 2015, the flood was much shorter in duration and floodwaters receded by early January 2016.

Table 6. Results of final floodwater samples.

Test	Mean sample results (CFU/ml), n
Coliform Count	$1.76x10^1$, 5
Aerobic Count	$7.25x10^6$, 2
Yeast & Mold Count	$2.05x10^1$, 4

Results of soil temperature monitoring

Soil thermometers were placed in plots shortly after the experiment was established. Thermometers were placed at a depth of 6-8 inches and were located 10 individual plots. Soil temperatures were not recorded as a part of this project, but were monitored. Our original hypothesis was that soil temperatures in those treatments which contained plastic mulch would increase to the point that microbe levels were diminished. In the Midwest, July and August are

generally the hottest months. During this time, it was observed that the soil temperature under the plastic mulch did not exceed 35C at a depth of 6-8 inches (15.2-20.3 cm).

Outcomes and Accomplishments:

Several outcomes and accomplishments may be attributed to this project. That the project came into existence is in itself an accomplishment. This project was designed and implementation began over a period of approximately two weeks and would not have been possible without rapid response support from the Center for Produce Safety.

This project has met the outcomes anticipated in our original proposal. It was anticipated that the experiment would give insight into the dynamics of soil microbial populations following an extreme flooding event. It was further anticipated that the experiment would identify those soil remediation techniques that were best suited to Midwestern production. The project has definitely given insight into the dynamics of soil microbial populations. Testing has indicated that undisturbed soil experiences lowest overall post-recession levels of indicator organisms (based on areas under the population curve). Testing also indicated that yeast and mold, as well as aerobic plate counts, increased most dramatically in those treatments where a tillage operation was involved. This intuitively makes sense in that any tillage or disturbance of the soil surface would break up compacted surface layers and increase soil aeration, allowing for an increase in aerobic microbes.

Our interpretation of the experimental results is that following an extreme flooding event, soils are compacted by the pressure exerted by floodwater, which limits entry into the soil by waterborne microbes. During extended flooding, it appears that indicator organisms may settle on soil surfaces. Our results suggest that any tillage operation following a flood will incorporate indicator organisms. Once incorporated, it would appear that they survive relatively well in soils, just as other aerobic microbes. Consequently, in the case of extreme flooding, our data would suggest that the best soil remediation technique would be to leave soil undisturbed and allow for a natural reduction of organisms on the soil surface by dehydration and sunlight.

Summary of Findings and Recommendations:

Our study suggests that during an extreme flooding event, waterborne microbes are deposited on soil surfaces. Leaving the soil undisturbed results in the most rapid rate of decline of indicator organisms, presumably due to sunlight and dehydration as soils dry. Tillage operations for any purpose aid in drying and aeration of soils. However, any operation that involves tillage will incorporate flood-deposited organisms, reduce their rate of decline in the soil, and increase the level of aerobic microbes.

Based on our data, we offer the following recommendations –

1. Following an extreme flooding event, soils should be left undisturbed and bare in order to maximize the amount of sunlight reaching the soil surface, to encourage drying on the soil surface, and to avoid incorporation of microbes deposited by floodwaters.

2. In the period following an extreme flood, weeds should be controlled by use of herbicides to avoid disturbing soil surfaces.
3. Produce growers who wish to utilize plastic mulch following an extreme flooding event should do so with caution. Soil temperature monitoring indicated that root-zone temperatures in plastic treatments did not exceed 35C. Plastic mulch is known to trap soil moisture. Based on our observations, plastic mulch does not build a high enough temperature in the root zone to effectively decrease levels of flood-deposited organisms.

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Food Safety Considerations for Flooded Fields

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Recent heavy rains across much of the state have resulted in widespread ponding and flooding in fields. This creates multiple considerations for those growing produce for fresh consumption. Flooding and pooling create food safety challenges because of their potential to introduce contaminants (i.e. risk) into the production system. However, with proper management, many of these risks can be mitigated.

Following heavy rains, growers should first determine if water in their fields is the result of pooling or flooding. Pooling is more common than flooding. Pooled water generally accumulates in lower areas of the field or between rows, especially if raised beds are used. The **key distinction** between flood water and pooled water is that flood water originates from an uncontrollable source such as a river or creek. Standing water that originated from a river or creek would still be considered flood water. Pooled water can cause damage to crops, but is generally not considered to carry as much risk for microbial contamination as flood water. In the case of pooled water, growers should consider whether or not the water is contacting the edible portion of the crop, how long the water was pooled, previous soil amendments, and whether or not the pooled water has resulted in increased wildlife activity in or near the affected area.

Fields that have experienced flooding present growers with difficult management choices. Flooding is defined (per FDA) as the "Flowing or overflowing of a field with water outside a

grower's control". Flooding is associated with streams, creeks, or ponds that overflow their banks and cannot be controlled. The FDA considers food contacted by flood water to be "adulterated" and not fit for human consumption. Due to microbial and other concerns, produce cannot be harvested and sold into the public food supply once it contacts flood water.

Fortunately, most crops are nowhere near harvest and many crops have yet to be planted. In those cases where flooding does occur in or near the crop but does not contact the edible portion of the crop, FDA guidance states that growers should, "Evaluate on a case-by-case basis for the likelihood of contamination".

The following are considerations for managing flooded fields:

1. Document the extent of any flooding in fields with photos and flags or other markers. This will insure that the flooded area remains defined once flood waters have receded. In the case of planted fields, photos will help other involved parties (ex. Insurance adjusters, third-party auditors) to understand the extent of the issue.
2. Remember that flood water introduces more than microbial risks. Flood water may contain mycotoxins, PCB's, heavy metals, pesticides, or other contaminants. While growers can test for any of these contaminants, tests are not definitive and there is always the chance for a "false negative". Seek technical advice before investing in tests for non-microbial contaminants.
3. Growers should consider planting previously flooded fields to agronomic crops for this season. If this is not possible, another strategy would be to plant previously flooded fields to crops defined by FDA as "seldom consumed raw". These crops include pumpkins, winter squash, and sweet corn. These crops are generally cooked prior to consumption, which mitigates many microbial risks.
4. Once flood water has receded, leave the flooded area undisturbed for as long as possible. Research done at the Southwest Purdue Ag Center in 2015 indicated that the population of microbes introduced into a field through flooding decreased most quickly when the soil was left undisturbed. Allowing undisturbed soil to thoroughly dry on the surface and maximizing exposure to sunlight appears to encourage a decrease in microbes deposited by flood water near the soil surface. Tillage, cover crop establishment, or any other operation that disturbs the soil incorporates oxygen and drives flood-deposited microbes into the soil where they may exist for an extended period of time.
5. Check your well. Any wells affected by flooding that are used to supply agricultural or postharvest water should be tested for generic *E. coli* (CFU/100 ml water) prior to use.

If only part of a field is affected by flooding, growers should manage the flooded portion so that it does not affect the unflooded part. In addition to the above recommendations, growers should do the following to protect unflooded parts of a field:

1. Define a buffer zone beyond the flooded area where produce is not planted. It is recommended that the area be at least 30 ft. wide. This will help to reduce the risk of cross contamination of splashing from overhead irrigation or additional rainfall.

2. If at all possible, avoid traveling through the flooded areas to access the unflooded portion of the field. This helps to insure that microbes don't hitch a ride on boots, shoes, or tires.
3. Wear boots and gloves while working in flooded areas. Be sure to clean them thoroughly before entering the unaffected areas.
4. Any equipment that is used in flooded areas should be thoroughly cleaned prior to entering unaffected areas. Ideally, equipment should be used in unaffected areas first, and flooded areas last.

Remember that these are general recommendations. Growers who undergo third party audits for GAPs certification should consult their particular audit scheme for specific guidance and requirements.

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Figure 1. Flooding in a field.

Flooding, defined as the “Flowing or overflowing of a field with water outside a grower’s control” is illustrated in Figure 1. Note that the Wabash River is visible through the break in the trees.

Figure 2. Pooling of water.

Pooling is the collection of water in a low area of the field as is shown in a low corner of this asparagus planting.

For Immediate Release

Produce Growers Should Consider Food Safety Risks Before Planting into Previously Flooded Fields

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Recent heavy rains across much of the state have resulted in widespread ponding and flooding in fields. This creates challenges for farmers growing produce for fresh consumption because of the potential for the introduction of contaminants into growing areas. However, with proper management, many of the risks introduced by flooding can be mitigated.

"Growers who have water-covered fields should first determine if it is the result of pooling or flooding", said Scott Monroe, Food Safety Educator with Purdue Extension. "Pooled water, generally more common than flooding, accumulates in lower areas of the field or between rows, especially if raised beds are used. Flooding originates from an uncontrollable source such as a river or creek." Pooled water can cause damage to crops, but generally carries less risk for microbial contamination than flood water. When dealing with pooled water, growers should consider whether or not the water is contacting the edible portion of the crop, how long the water was pooled, previous soil amendments, and whether or not the pooled water has resulted in increased wildlife activity in or near the affected area.

According to Amanda Deering, Clinical Assistant Professor with Purdue Extension, fields that have experienced flooding present growers with difficult management choices. "FDA considers food contacted by flood water to be "adulterated" and not fit for human consumption", said Deering, "Due to microbial and other concerns, produce cannot be harvested and sold into the public food supply once it contacts flood water." In those cases where flooding does occur in or near the crop but does not contact the edible portion of the crop, FDA guidance states that growers should, "Evaluate on a case-by-case basis for the likelihood of contamination".

Produce growers who experience flooding in their fields should first document the extent of the flooding with photos, flags, or other markers. This will insure that the flooded area remains defined after flood waters have receded. Growers should also remember that flood water may contain chemical contaminants, in addition to human pathogens. "If at all possible, flooded fields should be planted with agronomic crops this season", said Monroe, "However, on smaller and non-diversified farms that may not be a viable option".

If it becomes necessary to plant produce in flooded fields, growers should leave fields undisturbed as long as possible. Research performed at the Southwest Purdue Agricultural Center in 2015 indicated that leaving fields undisturbed may be the best way to encourage die-off of flood-deposited bacteria on soil surfaces. "At a minimum, fields should be allowed to dry thoroughly and should receive several days of intense sunlight before any tillage operations take place", said Deering. "This may mean changing planting plans so that previously flooded fields are reserved for late crops." Growers should also consider using flooded fields for produce that is seldom consumed raw, such as pumpkins or sweet corn. These commodities are generally cooked prior to consumption, which introduces a kill step and significantly reduces microbe populations.

Growers should also pay close attention to water sources, as they can become contaminated by flood water. Wells used to supply water for production or postharvest should be tested for generic *E. coli* prior to use. While microbial risks are often the focus when dealing with flooded fields, growers should remember that flood water may contain other contaminants. Always seek technical advice before investing in tests for non-microbial contaminants.

In those cases where only part of a field is flooded, growers should take steps to minimize cross-contamination into the rest of the field. "Growers should leave a buffer zone of at least 30 ft. between the flooded and non-flooded parts of the field", advised Monroe. Other tactics to avoid cross contamination include avoiding travel through flooded field sections to access non-flooded sections, using equipment in non-flooded areas prior to flooded areas, thoroughly cleaning equipment after use in flooded areas, and using boots and gloves while working in flooded areas.

Produce growers who have additional questions concerning management of fields following a flood should contact Scott Monroe at the Southwest Purdue Agricultural Center at (812)886-0198 or Amanda Deering in the Department of Food Science at (765)494-0512.

References:

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