Severe Flooding of Blueberry Fields

IN SOUTHWESTERN BRITISH COLUMBIA AND NORTHWESTERN WASHINGTON

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Characterizing Severity of Flooding in Blueberry Fields

In response to the recent flooding events in southwestern British Columbia and northwestern Washington State, a report was drafted on the effects of flooding on berry crops (DeVetter et al., 2021). This report was based on a combination of previous experience and scientifically grounded inferences, providing some general information and recommendations for growers to consider. Following the first rainfall events in mid-November, several regions (e.g., Matsqui Flats, Sumas Flats, and Glen Valley) received extraordinary levels of flooding due to the inability of normal drainage mechanisms to clear the large volume of precipitation received over a short time. For many of the blueberry fields in these regions, the waters receded within seven to ten days and damage may be manageable in many cases. Growers began remediation efforts as soon as the weather permitted. For example, we have observed efforts by growers to repair damage sustained in new plants by replacing eroded soil on newly planted fields to prevent drying out of media as well as healing in uprooted plants until such time as raised beds can be repaired for replanting (**Figure 1**).

The background information provided in the initial report will hopefully be of some assistance to growers whose fields were impacted by relatively low or moderate severity of flooding of <10 days. However, since this first report was drafted, the duration and severity of flooding has surpassed the scope of a general discussion into relatively uncharted territory because more than a thousand acres of blueberries were submerged in very deep waters for long periods of time. In the Sumas Flats in particular, several hundred acres of blueberries had a high severity of flooding, being under water between 10-14 days, while flooding in another several hundred acres was extremely severe, lasting more than 2 weeks, and more than 3 weeks in some cases. Compounding the fact that flooding lasted for a long time is that some of the flooded areas were under very deep waters, and the blueberry plantings that were under water for the longest were also under the greatest depth of water, up to ten feet in the worst areas. At the time that the current report was drafted (2021-12-12), most of the blueberry acreage in the Sumas Flats was free of standing water in all but the lowest spots of some fields, but the severity of this flooding event was truly unprecedented for BC blueberry growers.

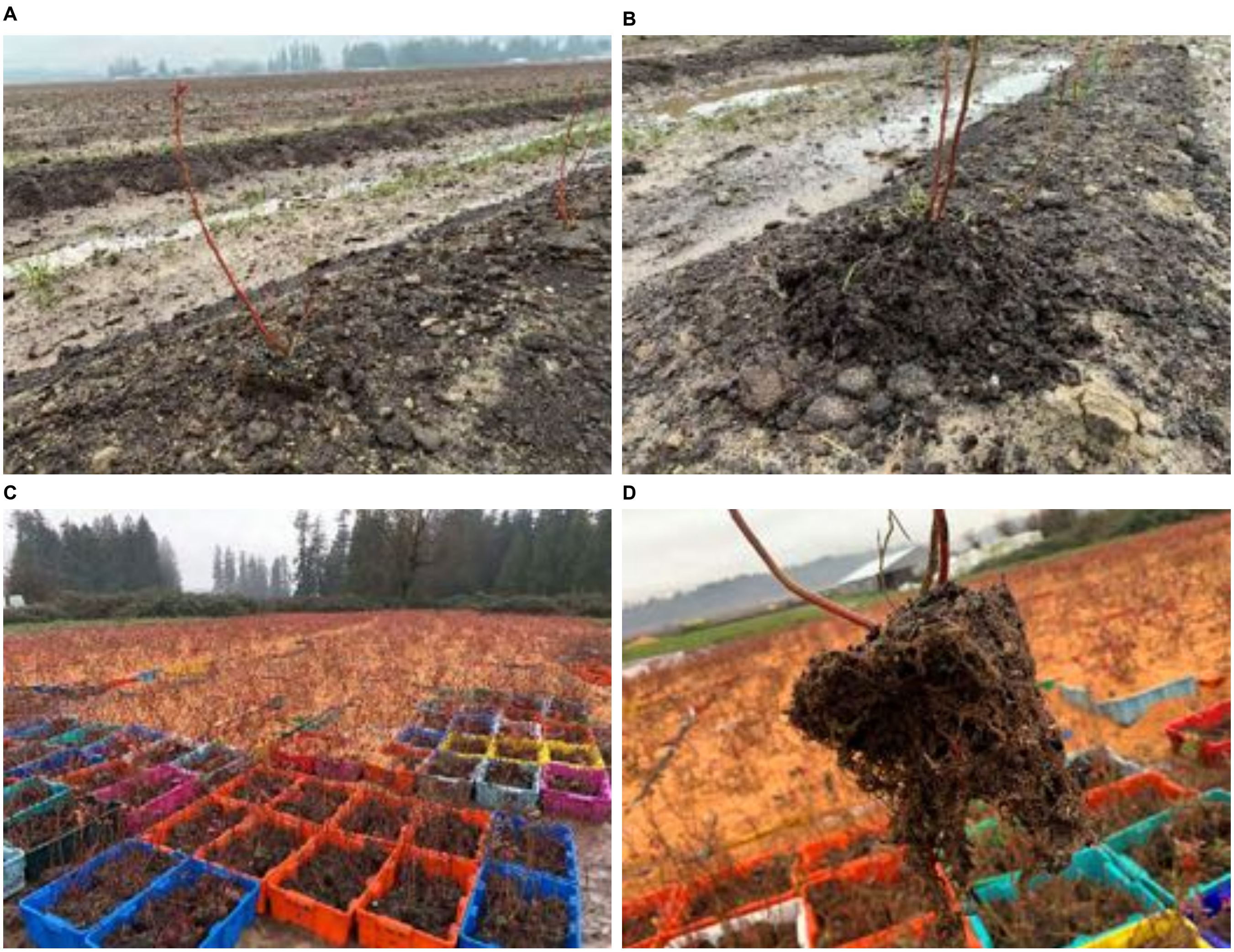

Figure 1. Remedial actions to repair new plantings following moderately severe flooding in British Columbia. **A.** Top of plant exposed due to erosion, **B.** Soil mounded to re-cover exposed roots, **C.** Uprooted plants healed in with sawdust until planting beds can be repaired, and **D.** A severely damaged root ball caused by flowing water after uprooting.

Progression of Flooding in the Sumas Flats

The first rainfall event in mid-November resulted in flooding that was initially worse on the west side of the Sumas canal near the Whatcom area. During the subsequent three “atmospheric rivers”, when the Nooksack river overflowed and the Sumas dike failed at two locations, more severe and sustained flooding was experienced to the east of the Sumas canal. Failure of the dike was partially due to the height of the Fraser River, which made it impossible for the floodgates at the Barrowtown pump station to quickly evacuate water from the Sumas. Removal of water from the Sumas Flats into the Fraser River, therefore, relied on the Barrowtown pumps that are capable of pumping water at a very fast rate of 500,000 gallons per minute, which is still several times slower than via the floodgates.

Consequently, flooding of blueberry fields in the Sumas Flats east of the Sumas canal became severe on November 16th and peaked within a few days with up to 10 feet of water in the bottom of the bowl of the old Sumas Lake, which was originally drained during the 1920’s to create fertile farmland (**Figure 2**). With rapid repairs to the dike and removal of water from the Sumas Flats by the Barrowtown pump station, fields around the perimeter of the old lake bottom began to be cleared of standing water in the last couple days of November, but the severely flooded acreage was not cleared for another week (**Figure 3**). Due to the duration of time required to clear the region of water, a gradient in the severity of flooding ranges from high (>10 days) to extreme (>14 days). Of note, there are a few isolated fields that remain under water at the time of this report, having now been flooded for a full four weeks.

Figure 2. Aerial photo of completely submerged mature blueberry plantings in the Sumas Flats.

Potential Impact of Severe Flooding on Soils and Roots

The rate of gas diffusion to roots is severely reduced during flooding events, and the concentration of oxygen is lower at greater depths of water. Plant cells require oxygen supply to perform normal metabolic processes such as cellular respiration, which generates the energy required to maintain cellular life and tissue functionality. Metabolic rates are highest under peak active growth, but respiration continues at a slower rate even under dormant conditions. Apart from the direct impact of flooding on plant cells caused by oxygen starvation is the effect on microbial action in the soil under low/no oxygen conditions. Though rates of these reactions are much slower in the fall and winter there is still some activity of soil microbes, which typically decompose plant material and transform some nutrients to plant-available forms. In low-oxygen (anaerobic) conditions, microbes that use oxygen for respiration will go dormant or switch to using another molecule like nitrate (NO_3), increasing gaseous N losses (though soil available N is likely to already be low at this time of the year). As nitrate is depleted, microbes rely on a sequence of other elements, including manganese, iron, and sulfur. Thus, anaerobic conditions can cause increased loss/consumption of plant-available N and changes to chemical forms of some other micronutrients. However, long-term impacts on soil nutrient availability, beyond those that typically occur each winter, are not likely.

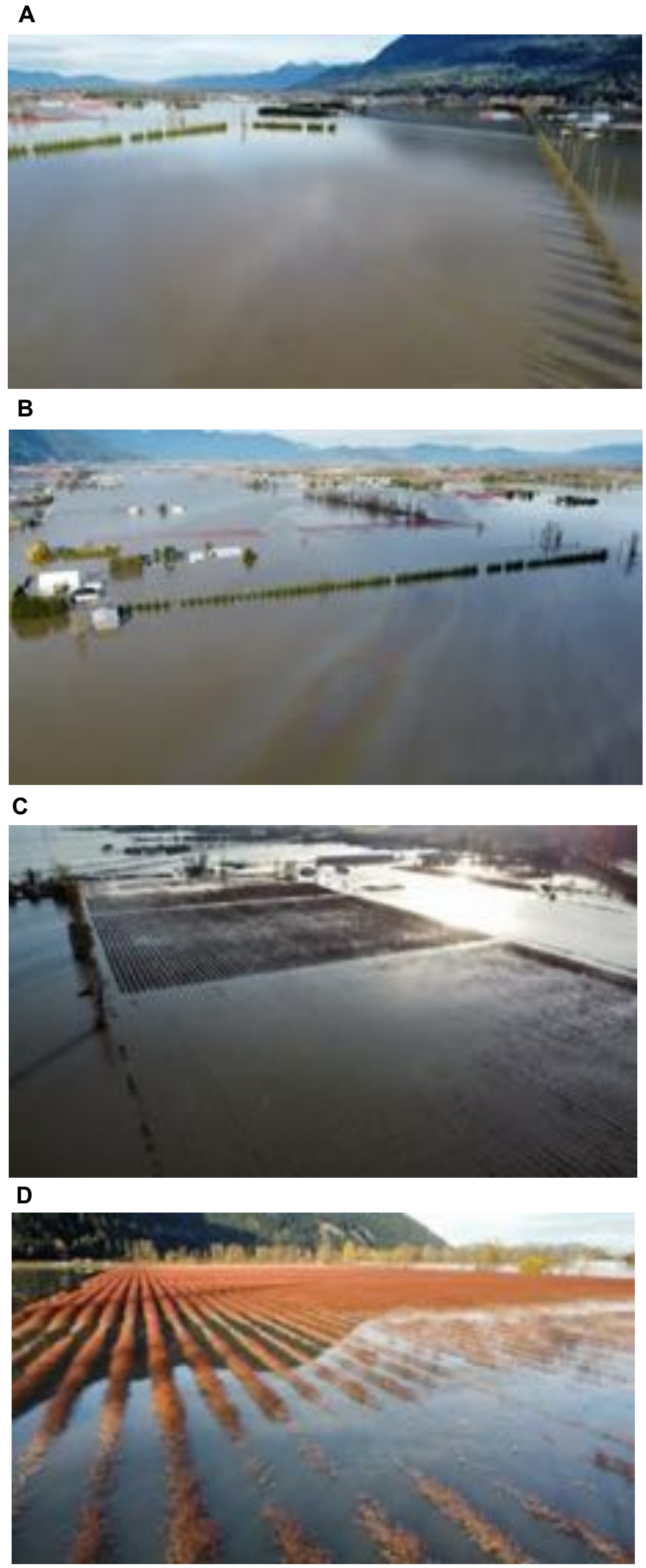

Figure 3. Aerial photos of flooding in the Sumas Flats. A and B. Completely submerged mature plantings experiencing extreme severity flooding conditions, C and D. Partially submerged mature blueberry plantings experiencing high severity flooding conditions.

Regarding the state of blueberry plants at the time of flooding, please note that dormancy is a separate process from cold hardiness. The type of dormancy we are concerned with at this time of the year is called "endodormancy". Endodormancy is governed by internal biochemical mechanisms that control the degree to which buds will resist active growth under warm conditions – this is not the same thing as cold hardiness or tolerance to some other abiotic stress. In woody perennials, peak endodormancy coincides with the end of leaf drop, which occurs in November for most blueberry cultivars in our region. At the time of the flooding, cultivars such as 'Duke' were nearing the stage of leaf drop that would confer peak endodormancy when root growth would be at a low level. This is despite the relatively warm weather that accompanied the weather systems that caused the flooding. On the other hand, while cold hardiness is increasing at the time of leaf drop, it continues to increase well into the winter months, peaking between mid-December and mid-January. It is important to distinguish between these two parallel but separate processes.

As discussed in the previous report, short-term flooding can be tolerated by crops such as blueberry, especially during dormancy. This is due to metabolic acclimation to low oxygen availability wherein plants shift their biochemistry to produce energy through alternative pathways, but this is only a short-term solution for plant energy needs. On this basis, the previous report indicated that the severity of impact on plants will vary based on the age of the planting, duration of flooding, and degree of uprooting and/or root exposure due to erosion. Now that the water has receded, we have been able to make direct field observations, and we can add to this list, the original health and vigour of the plants (i.e., pre-existing challenges to the root system) and the depth of the water under which the plants were submerged. In the Sumas Flats, the depth of the flood waters tended to correlate with the duration of flooding due to the topography of the old lake bottom. Moreover, in the Sumas Flats, movement of water causing uprooting and/or exposing roots was apparently much less of a concern in this severely impacted region compared with the effects of sediment deposition on top of the beds as well as the impact of very deep water on soil structure and potentially on compaction. Also, some larger soil organisms (e.g., earthworms) were negatively impacted (**Figure 4**) and may take time to repopulate the soil while other smaller soil organisms (e.g., fungi and bacteria) may repopulate the soil or come out of dormancy more quickly. However, re-establishment of a fully functioning soil microbial ecosystem will take time, and this may slow future improvement in soil structure.

The primary concern is that soil structure has been severely impacted and that this will result in a lasting challenge to the root systems of plantings that experienced the most severe flooding. As outlined in the previous report, flooding can have a negative impact on soil structure. Flooding breaks down large aggregates and silt or clay particles suspended in water an clog soil pores as the water recedes. This may reduce the mean pore size and pore connectivity in the soil,

Figure 4. Dead earthworms in a puddle after three weeks of soil inundation.

and this is important because it is in the pore spaces that roots grow and gases interact with the soil-water interface to support root growth and development. This means that the ability of the soil to receive oxygen from the air is reduced with loss of soil structure. Consequently, roots will have more limited access to oxygen after flooding than before flooding. Furthermore, the pressure created by the force of gravity on water will have had a compacting effect on the soil, but the extent to which this is the case for various soil textures in the affected area will require validation through direct measurement. At 10 feet of water, this equates to approximately 15 pounds per square inch (PSI) of additional pressure on the soil beneath.

Root penetration during active growth is required for plants to access water and nutrient resources, and this will be further limited by compaction and reduced pore size. Even once these fields have drained to "field capacity", the roots will still suffer from relatively hypoxic (i.e., low oxygen) conditions and could continue to accrue cellular damage initiated under the anoxic (i.e., no oxygen) conditions experienced during the flooding event. In other words, the root systems in fields that had extremely severe flooding are likely still sustaining damage because of hypoxia due to loss of pore spaces even after they have drained. This is likely to be most severe in the heavier silt and clay loams found near the bottom of the old lake bottom where flooding was most extreme. With negative impacts on soil organisms (e.g., earthworms), as well as cool temperatures, there will be little improvement in soil structure and aeration in the coming months. Furthermore, while the layer of structureless silty clay sediment deposited by the flood waters will likely not have any large impact on the texture of these soils in general, water movement in the soil is controlled by the most limiting layer, and as such, it may impede air and water penetration to the native soil beneath.

It is possible that the sequential wetting/draining and freezing/thawing cycles during the winter will return some degree of structure to compacted soils. During the season, use of inter-row cover cropping, subsoiling, and organic amendments should be considered for their potential to remediate soil

Figure 5. Shoot tissue necrosis in response to extremely severe flooding conditions in the Sumas Flats.

structure. Organic matter inputs can feed aerobic microbes that then turn part of this carbon into sticky substances that promote aggregation. Not all composts are appropriate for blueberries, and qualities such as liming potential and salt content should be considered (http://whatcom.wsu.edu/wam/apr15_s2.html). Additionally, field traffic and tillage should be avoided when the soil is too wet (i.e., above field capacity). It is also important to note that the time scale over which these practices are expected to alter soil structure or provide preferential flow pathways for water varies considerably, with subsoiling having a more immediate short-term impact, organic amendments having a slow and longer-term impact, and cover cropping likely in the middle.

Potential Impacts on Shoots, Diseases, and Field Cleanup

From recent observations of blueberry fields in severely flooded areas, damage was not restricted to root systems, for which damage is difficult to assess. Extreme severity of flooding resulted in substantial damage to new, fruit-bearing wood in numerous plantings. During the dormant season, new wood on blueberry plants normally has a vibrant red colour. In cases where plants were under water for a week in areas such as Glen Valley and Matsqui Flats, only a slight darkening of these red tissues was observed. In response to extreme flooding conditions in the Sumas Flats, shoots sustained abiotic cell damage (i.e., physical death due to anoxia) that caused tissues to become necrotic and black as if infected with Pseudomonas blight (**Figure 5**). These symptoms appear worse on lower branches in young plantings than in higher branches of mature plantings, but this is likely because the new wood on smaller plants was under water for much longer. In turn, this is because it took time for the flood waters to rise as well as recede, adding to the amount of time that lower-lying branches were under water on younger plants. The lower concentration of oxygen at greater depth of water may also have played a role in this greater amount of damage.

In the worst cases, the cambium beneath the outer layers of these young shoots also appears to be dead, and much of the floral buds on damaged tissues were brown throughout with dead vascular tissue connecting them to the branches (**Figure 6**). Fortunately, older wood near the base of mature plants did not appear to have sustained the same level of cambial or vascular damage. However, visual assessment of this damage is likely insufficient to determine whether these tissues will remain viable, or fully functional, when plants begin to regrow in the spring. Additional assessments and observations of plant growth will be required to make definitive statements about the full impact on plants in each field. Even in milder cases with only slight darkening of stems, these symptoms should be monitored over the coming months as necrotic processes may have been initiated and reduced vascular capacity may result in the spring. Increased susceptibility of damaged tissues to pathogens is an additional concern even for plants with symptoms that are currently mild.

In the case of both the shoot and root systems, abiotic causes of cell death are the current cause of plant damage *per se*. However, wounding of plant tissues is likely to result in a dramatic increase in biotic challenges (i.e., plant diseases) that will compound the abiotic damages sustained during the flooding event. The previous report mentioned the increased risk of Phytophthora root rot. In addition, the increased risk of Pseudomonas infection in above-ground plant parts should be considered for any damaged plant material that is not removed through pruning as physical damage results in wounds that act as entry points for this bacterial blight pathogen. Crown gall infection of above- and below-ground tissues is possible, and diseases that are normally considered secondary, or of minor concern, under normal circumstances may be greater risks given the magnitude of plant damage. Young plantings, in particular, are at high risk of damage from Pseudomonas infections, which can get into the crown and eventually kill the plant.

A B

Figure 6. Shoot damage in response to extremely severe flooding conditions in the Sumas Flats. **A**. Dead floral buds (note vascular tissue on removed bud at third node), **B**. Dead vascular cambium on new shoot.

Below, we discuss management options, but the compounding effect of biotic challenges to plants that have already been weakened by abiotic stresses should provide growers with an additional reason to prune hard. Aside from the removal of crop load and stimulation of root regrowth mentioned in the previous report, removing damaged shoots through pruning will reduce the risk of severe disease infection.

Furthermore, the 2021 season was particularly stressful due to a relatively dry summer and the extraordinary “heat dome” event at the end of June. Hopefully, these conditions will not be repeated in 2022, as additional plant stress will present more challenges to field remediation.

Comparison of Severe Pruning, Renovation, and Replanting

Based on the range in severity of flooding experienced in different parts of the region, we recommend that future management match the degree of potential impacts on each blueberry planting on a field-by-field basis. In other words, the severity of flooding experienced in each planting, and the pre-existing features (i.e., age, health) of each planting, necessitate a nuanced approach. The details provided above, and in the previous report, are a starting point to inform these decisions.

The bottom line is that growers must decide whether to replace their severely damaged fields or to attempt to bring them back into productivity through remedial management practices such as severe pruning or complete renovation (i.e., “stumping”). Renovation includes pruning off the top growth by cutting canes back to a height of about 18 inches. Thin the canes to the best 6 to 10, preferentially keeping those on the outside to form a vase shape. In the year after renovation, whips will grow from the old cane wood, re-establishing a basic architecture. It will take several years for a planting to return to full productivity. However, whether renovation will be successful will depend upon the degree to which the root system can regenerate, the ability to combat any secondary disease issues arising from the damage caused by flooding, and the resilience of the root system to compromised soil quality.

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The decision to prune very severely, keeping a reduced crop, to renovate/stump or to replant should be made based on the probability that a particular planting will be able to return to its former level of productivity. Replanting offers an opportunity to improve soil structure and drainage/porosity prior to transplanting, which is an important advantage. Also, some growers might want to take this opportunity to change some other things (e.g., cultivar) about their operation. The goal of commercial blueberry production is to maintain consistent, high yields of good quality fruit with the potential for fresh or processed markets. Therefore, the damage sustained by plantings that suffered high and extreme severity of flooding presents a precarious decision for growers. There is significant risk that some plantings will never be able to return to their former level of productivity because of direct abiotic damage to their roots, the potential for increased biotic challenges to both the roots and shoots, and damage to the soil structure. The latter also relates to sustained abiotic damage due to persistent hypoxic conditions and decreased nutrient availability after the flooding is over. In other words, loss of soil structure and organismal activity could have a sustained negative impact on already compromised root systems for years to come, and this could hinder plant recovery.

Guidance for Grower Decisions on Management Practices

In some areas, where flooding severity was low or moderate (i.e., less than 10 days), grower decisions may be relatively simple based on the economics of replanting and the low potential for negative long-term impacts. However, growers will have a greater degree of difficulty in making these decisions for fields that experienced highly severe (10-14 days) and extremely severe (>14 days) flooding. This is because there are so many unknowns about how much these conditions will impact plantings. However, we can provide some guiding recommendations based on the observations and rationale described above:

1. **Low and moderate severity of <10 days of flooding, mostly with less than three feet of water:** Other than covering exposed roots, replacing mulch, and pruning harder in some cases, no further remedial management practices will likely be required to promote recovery.

2. **High severity of 10-14 days of flooding, much of which had more than three feet of water:** Replanting may be required, depending on the age and health of the planting as well as the duration and depth of flooding.

3. **Extreme severity of >14 days of flooding, mostly with 5-10 feet of water:** Considering replanting is strongly recommended as many fields are significantly challenged and regaining full productivity is not guaranteed.

Without replanting, growers will have to assume a degree of risk that increases commensurate with the severity of flooding and the relative resilience of the particular planting. We cannot say with confidence that even dramatic remedial actions (i.e., renovating plants) for fields that experienced extreme flooding will result in a return to full productivity, even after several years. There is little that can be done to assess the degree to which root systems have been compromised. Moreover, damage to soil structure, and to the organismal life that supports soil health, may continue to accrue damage to plant roots in the months and years to come, making it even more difficult for plants to recover.

To reiterate, under extremely severe flooding conditions, choosing not to replant will bear a substantial risk to the grower because we simply do not know how well each field will respond to remedial management. Choosing not to replant will, as a result, be a large-scale experiment in each field, and a potential result will be the failure of some fields to return to their former level of productivity, even over a five-to-seven-year time frame. After several years of waiting to see if their plantings will recover, growers will be back at the same decision point at which they currently stand: whether or not to start again and replant. At that point, their operation will be set back by the same number of years as replanting immediately, plus the delay in years to make such a decision.