CHAPTER 11

Role of Irrigation Water in Crop Contamination by Viruses

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1.0. INTRODUCTION

Foods traditionally eaten raw or receiving minimal processing provide an ideal route for the transmission of viruses. Fruits and vegetables can potentially become contaminated before harvesting by irrigation water, water used for spray application of pesticides, or water used in processing (e.g., washing, hydrocooling with ice, etc.). An increase in the number of produce-associated outbreaks corresponds with the increased consumption of fresh fruits and vegetables and with the expanded global sources of these products over the past two decades (Sivapalasingam et al., 2004). Produce-associated outbreaks have increased from 0.7% of all outbreaks in the 1970s to more than 6% in the 1990s in the United States. In 2002, the number of cases of produce-associated illnesses was almost equal to all of those reported for beef, poultry, and seafood combined (Center for Science in the Public Interest, 2002). Several known and suspected food-borne outbreaks have been ascribed to crops contaminated in the field, suggesting contamination by irrigation or during harvesting (Dentinger et al., 2001; CDC, 2003). Perhaps more significant is the low-level transmission of viruses by food contaminated with irrigation water. Quantitative microbial risk analysis has suggested that low levels of virus in irrigation water can result in a significant level of risk of infection to consumers (Petterson et al., 2001). Stine et al. (2005c) estimated that less than one hepatitis A virus per 10 L of irrigation water could result in a risk exceeding 1:10,000 per year considering the efficiency of transfer of the virus to crop and its survival till harvest time. The 1:10,000 risk of infection per year is currently the acceptable level used by the United States Environmental Protection Agency for Drinking Water (Regli et al., 1991).

The largest use of freshwater in the world is in agriculture with more than 70% being used for irrigation. About 240 million ha, 17% of the world's cropland, are irrigated, producing one third of the world's food supply (Shanan, 1998). Nearly 70% of this area is in developing countries. In the United States, California and Arizona are the major producers of lettuce, carrots, broccoli, and cantaloupe (Arizona Farm Bureau, 2003). All of these crops are grown almost entirely by irrigated agriculture. It is thus surprising that we know little about the microbial quality of irrigation water. Most studies have dealt with the occurrence and fate of enteric pathogens in reclaimed water used for irrigation and not the quality of surface waters currently in use.

Almost no data exist on the occurrence of enteric viruses in irrigation waters, which do not intentionally receive sewage discharges.

2.0. WATER QUALITY STANDARDS FOR IRRIGATION WATER

For more than 100 years, irrigation or fertilization of food crops with feces or fecally contaminated water has been known to play a role in the transmission of enteric microorganisms. For this reason, the use of night soil or irrigation with untreated domestic wastewater is not allowed in the United States and is not recommended by the World Health Organization (Mara and Cairncross, 1989). Most of the research on enteric pathogen contamination of vegetables and fruits during production has been done to evaluate the safety of reclaimed wastewater irrigation. Many states in the United States have standards for the treatment of reclaimed water to be used for food crop irrigation (Asano, 1998), and the World Health Organization has also made recommendations in this regard (Mara and Caincross, 1989). The state of California requires advanced physical-chemical treatment and extended disinfection to produce "virus-free" effluent. A coliform standard of <2/100 ml must also be met (Asano, 1998). The state of Arizona has a virus standard of 1 plaque forming unit (pfu)/40 L and *Giardia* cysts of 1 per 40 L in addition to a fecal coliform standard of 25/100 ml. Although standards for the use of reclaimed wastewater exist for food crops eaten raw in the United States, irrigation using reclaimed water for crop irrigation is seldom practiced. In developing countries, raw or partially treated wastewater is often used to irrigate crops, especially in the arid regions.

There are a few published studies on the quality of nonreclaimed wastewater used as an irrigation source (Steele and Odumeru, 2004). Irrigation agriculture requires approximately 2 acre-feet of water per acre of growing crop. The frequency and volume of application must be carefully programmed to compensate for deficiencies in rainfall distribution and soil moisture content during the growing season. Rivers and streams are tapped by large dams and then diverted into extensive canal systems. In addition, groundwater may also be pumped from wells into canals (which puts this water at risk from surface contamination). Because water availability is often critical, little attention is paid to the microbial quality of the irrigation water. In water-short areas, available sources are subjected to contamination by sewage discharge from small communities (unplumbed housing along canals in developing countries is common), cattle feedlot drainage, grazing animals along canal embankments, storm-water events, and return irrigation water (noninfiltrated water from the field being irrigated is returned to the irrigation channels). Because irrigation channels are frequently small, these changes in pollution discharges can result in rapid deterioration of water quality.

One of the few early studies conducted on irrigation waters documented a wide range in the microbial quality of this water (Geldreich and Bordner, 1971). The wide variation was attributed to the discharge of domestic sewage into streams from which the irrigation water was obtained. This study was conducted in the western United States (Wyoming, Utah, and Colorado). Median fecal coliform values ranged from 70 to 450,000/100 ml. Based on results obtained with the occurrence of *Salmonella* in the same waters, these authors recommend a fecal coliform standard for irrigation waters of 1,000/100 ml.

Guidelines for the microbial quality of surface water tend to be more lenient than those for wastewater because of the belief that enteric viruses and other human pathogens are less likely to be present or less numerous (Steele and Odumeru, 2004). The criteria range from <100 to <1,000 fecal coliforms per 100 ml. Other criteria for *Escherichia coli* and fecal streptococcus are also used by some regulatory agencies (Steele and Odumeru, 2004). The United States Environmental Protection Agency guidelines for surface water recommend fewer than 1,000 fecal coliforms per 100 ml of surface water, including river water, for irrigation of crops (EPA, 1973). The differences among the guidelines reflect widespread uncertainty about the actual risk of disease transmission by irrigation water. Obviously, data on the occurrence of pathogens in irrigation waters would aid in the development of a risk-based approach to the development of standards.

3.0. OCCURRENCE OF VIRUSES IN IRRIGATION WATER

The microbial quality of irrigation water depends on the source of the water. Sources of human enteric viruses may involve sewage discharges into source water, septic tanks, recreational bathers, and so forth. Although groundwater is often considered a microbially safe source for irrigation water, recent studies in the Unites States have indicated that 8% to 31% of the groundwaters may contain viruses (Abbaszadegan et al., 2003; Borchardt et al., 2003). These viruses may originate from septic discharges, leaking sewer lines, or infiltration from lakes, rivers, and oxidation ponds.

Currently, only one study is available on the occurrence of enteric viruses in irrigation waters (Kayed, 2004). In this study, the occurrence of protozoan parasites, indicator bacteria, and noroviruses in irrigation waters in central and western Arizona were investigated. The irrigation waters in central Arizona are derived from a series of dammed reservoirs. The water is then channeled through a series of canals traveling a distance as great as 40 miles before reaching the fields to be irrigated. In western Arizona, the water comes from a reservoir on the Colorado River. Noroviruses were detected in 20.7% of the canal samples from western Arizona and 18.2% of the canal samples from central Arizona. Geometric averages of *E. coli* were 6.4/100 ml in western Arizona canals and 18/100 ml in central Arizona. *Salmonella* and *Campylobacter* spp. were also detected in the irrigation water, especially after rainfall events. Because polymerase chain reaction was used to detect noroviruses, the infectivity of the viruses could not be determined. However, the results demonstrate that contamination of irrigation water by enteric viruses does occur even when there is no intentional discharge of sewage into the system.

4.0. CONTAMINATION OF PRODUCE DURING IRRIGATION

The likelihood of the eatable parts of a crop becoming contaminated during irrigation depends upon a number of factors including growing location, type of irrigation application, and nature of the produce surface. If the eatable part of the crop grows in or near the soil surface, it is more likely to become contaminated than a fruit growing in the aerial parts of a plant. Some produce surfaces are furrowed or have other structures that may retain water (e.g., a tomato vs. a cantaloupe). There are three distinct methods of irrigation: sprinkler systems, gravity-flow (furrow) systems, and microirrigation systems. Microirrigation includes surface drip and subsurface irrigation methods. In 2000, approximately 63 million acres of farmland was irrigated in the United States, 31.5 million acres (50%) with sprinkler irrigation systems, 28.4 million acres (45%) with gravity-flow systems, and the remainder (5%) by microirrigation systems (Anon., 2001).

Studies have been done on contamination of crops by enteric bacteria present in irrigation water, but only a few have evaluated the degree of contamination by viruses. Stine et al. (2005a) quantified the transfer of virus (coliphage PRD-1) and enteric bacteria in water used to prepare pesticide spray to the surface of cantaloupe, iceberg lettuce, and bell peppers. The average transfer of bacteria from the water to the surface of fruit was estimated to range from 0.00021% to 9.4%, while the average viral transfer ranged from 0.055% to 4.2% depending on the type of produce.

Oron et al. (1995) applied irrigation water containing up to 1,000 pfu/ml of poliovirus on tomato plants by subsurface drip irrigation in an outdoors setting using both surface water and wastewater. Some virus was detected in the leaves of the plants but not in the fruits. The authors stated that the high virus content of the water might explain the occurrence of virus in the leaves. No virus was detected in plants irrigated with wastewater containing the same level of virus as the surface water. The authors suggested that this was due to the interaction of the virus with particulate or soluble matter present in the wastewater preventing their entrance into the roots.

Alum (2001) studied the effectiveness of drip irrigation in the control of viral contamination of salad crops (lettuce, tomato, cucumber) in a greenhouse in potted plants. The plants were irrigated with secondary effluent using surface drip and subsurface irrigation. Irrigation water was periodically seeded with coliphage MS-2, phage PRD-1, poliovirus type 1, adenovirus 40, or hepatitis A virus. Surface irrigation always resulted in surface contamination of both above-ground parts and the underground parts of the plants. In lettuce, it was observed that only the outer leaves of the plant became contaminated. No contamination of the plants occurred when subsurface drip irrigation was used. No systemic uptake of viruses was observed in any of the crops.

Choi et al. (2004) assessed viral contamination of lettuce by surface and subsurface drip irrigation using coliphages MS-2 and PRD-1. A greater number of coliphages were recovered from lettuce grown in subsurface pots as compared with those in the furrow-irrigated plots. Shallow drip tape installation and preferential water paths through cracks on the soil surface appeared to be the main cause of high viral contamination. In subsurface drip irrigation plots, penetration of the water to the soil surface was observed, which led to the direct contact of the lettuce stems with the irrigation water. Thus, drip tape depth can influence the probably of produce contamination. Greater contamination by PRD-1 was observed, which might be due to its longer survival time.

Stine et al. (2005b) compared furrow irrigation and subsurface irrigation on the contamination of cantaloupe, iceberg lettuce, and bell peppers when the water was seeded with coliphage PRD-1 under field conditions in Arizona. No coliphage was detected on bell peppers. The maximum virus transfer was 0.046% to lettuce and 0.02% to cantaloupe by furrow irrigation. No viruses were detected on lettuce when subsurface irrigation was used, and the transfer to the cantaloupe was reduced to 0.00039%.

5.0. SURVIVAL OF VIRUSES ON PRODUCE IN THE FIELD

Studies on the survival of viruses on produce postharvest indicate little virus inactivation because of the low temperatures of storage (Seymour and Appleton, 2001). Few studies are available on the survival of viruses on growing crops preharvest. Tierney et al. (1977) found that poliovirus survived on lettuce for 23 days after flooding of outdoor plots with wastewater. The virus persisted in the soil for 2 months during the winter and 2 to 3 days during the summer months. Sadovski et al. (1978) spiked wastewater and tap water used to irrigate cucumbers with high titers of poliovirus. The cucumbers were grown with either (i) surface drip irrigation or with (ii) the soil and drip lines covered with polyethylene sheets to reduce contact of the irrigation water with the plants. Virus was detected on cucumbers by both methods of application. Virus was detected only occasionally on cucumbers that were irrigated with the drip lines covered by plastic sheets. Viruses survived on the cucumbers for at least 8 days after irrigation (hepatitis A virus and coliphage PRD-1 survival on growing produce was found to be similar under high and low humidity conditions) (Stine et al., 2005b). In general, the inactivation rates of the viruses were less than those of *E. coli* 0157:H7, *Shigella sonneri*, and *Salmonella enterica* on cantaloupe, lettuce, and bell peppers. The hepatitis A virus levels were reduced to about 90% after 14 days, indicating that enough viruses could survive from an irrigation event to harvest time to pose a potential risk.

6.0. SUMMARY

Risks from the use of virus-contaminated irrigation water are poorly understood. Information on the occurrence of viruses in irrigation water and potential sources of viruses in irrigation water is sorely needed. Sources of viral contamination from irrigation need to be defined and their transport and survival need to be determined. Irrigation methods and the type of produce also affect the degree of contamination. Although the percent virus transfer from irrigation water to produce is low, it has to be remembered that ingestion of low numbers of viruses can result in a significant risk of infection (Peterson and Ashbolt, 2001). It appears that temperature and the nature of the produce surface are the most important factors in virus persistence on produce surfaces. Limited studies suggest that enteric viruses survive longer than enteric bacteria and may survive from the time of irrigation to harvesting.

7.0. REFERENCES

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