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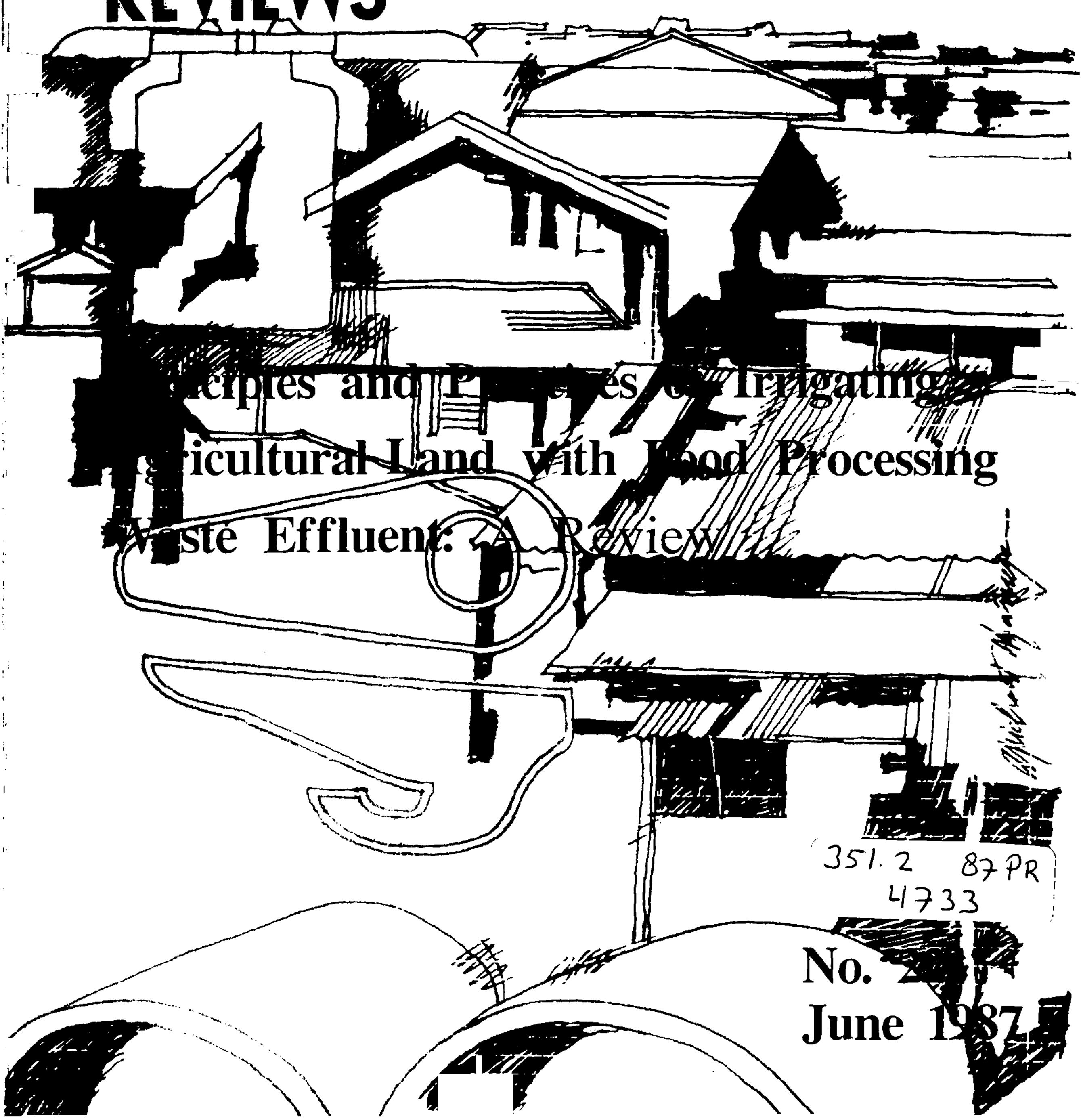

Principles and Practices of Irrigating Agricultural Land with Food Processing Waste Effluent: A Review

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PRINCIPLES AND PRACTICES OF IRRIGATING AGRICULTURAL LAND WITH FOOD PROCESSING WASTE EFFLUENT: A REVIEW

by

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GLOSSARY

Anaerobiosis	Without air or without oxygen.
Anions	Negatively charged ions.
Aspect	Orientation of a slope in relation to the compass.
Cation exchange capacity	The sum total of exchangeable cations (positively charged ions) that a soil can absorb.
Clay-size fraction	A soil separate consisting of particles less than 0.002 mm diameter.
Denitrification	The biochemical reduction of nitrate to gaseous nitrogen either as molecular nitrogen or as an oxide of nitrogen.
Dewpoint	The temperature at which the water vapor in a given sample of air becomes saturated.
Dry lye peeling	Peeling potatoes with a hot lye solution and removing the peel with brushes and a small volume of rinse water. The peel material is kept separated from the procesing plant waste stream.
Electrical conductivity	The measurement of a solution's capacity to conduct electricity. In soils and water, the electrical conductivity is a measurement of the total concentration of soluble salts.
Exchangeable sodium percentage	The percentage of the cation exchange capacity of a soil that is occupied by sodium.
Flood irrigation	Irrigating soils by means of surface application of water in furrows or basins.
Flume	Conveyance structure where sugarbeets are washed and transported into the factory by water.
Graded Fields	Fields that have been mechanically smoothed to a particular grade or slope.
Infiltration failure	Failure of a soil that has had satisfactory downward entry of water into the soil to receive water because of sealing of the soil.

Land disposal	Disposing of waste materials on land.
Leaching	The removal of materials in solution from the soil.
Loading	The amount of organic matter, water, and nutrients applied to land in wastewater. See **Nutrient loading.**
Nutrient loading	The amount of plant nutrients applied to soil in wastes, either solid or liquid.
Organic phosphorus	Phosphorus that is chemically bound to an organic molecule.
Orthophosphate	The highest hydrate of phosphoric acid (PO_4^{-3}).
Oxygen demand	The oxygen required to chemically or biologically oxidize a particular material.
Particle size analysis	Determination of the various amounts of the different separates in a soil sample.
Primary treatment	The first treatment of wastewater, which usually consists of settling of screening out particulate material.
Processing plant waste effluent	Wastewater discharged from a food processing plant.
Redox potential	Oxidation reduction potential in soils or solutions.
Saline	A nonsodic (nonsodium) soil containing sufficient soluble salts to impair its productivity.
Secondary treatment	Additional treatment of primary treated wastewater to remove dissolved organic constitutents, usually by biological oxidation.
Sesquioxides	Oxides containing three atoms oxygen combined with two of the other constituents in the molecule, in soil frequently silica.
Sprinkler irrigation	Irrigating land by means of a pressurized sprinkling system.
Steffen's waste	The filtrate obtained from the precipitation of calcium sucrate in the Steffen process of recovering sugar from sugarbeet molasses.

Total Kjeldahl nitrogen (TKN)	The nitrogen content of a material that is analyzed by a Kjeldahl method.
Vacuum filtration	A process by which settled solids are removed from wastewater pumped from the bottom of a primary clarifier (settling basin).
Water table	The upper surface of ground water or that level below which the soil is saturated with water.
Wet lye peeling	Peeling potatoes with a hot lye solution and removing the peel with high pressure water jets following by rinsing with a large volume of fresh water. The peel and rinse water are discharged into the processing plant waste effluent.

PRINCIPLES AND PRACTICES OF IRRIGATING AGRICULTURAL LAND WITH FOOD PROCESSING WASTE EFFLUENTS: A REVIEW[1]

by

Jay H. Smith[2]

I. INTRODUCTION

A Perspective on Wastewater Irrigation

Wastewater irrigation of agricultural land for treatment and disposal can be an effective management system that should be, where feasible, a consideration for wastewater treatment. Irrigating agricultural land with food processing, municipal, and some industrial effluents has been successful for many years in the USA, the Netherlands, and elsewhere where the systems were conservatively designed and the water and nutrient applications were not excessive (Smith, and others, 1975, 1976, 1977, 1978, 1980, 1983; and DeHaan, et al. 1973,). Some advantages associated with wastewater irrigation systems may relate to lower initial costs of development than the conventional secondary wastewater treatment but the cost advantage does not always remain with irrigation systems.

Utilization of some of the included plant nutrients for crop production rather than wasting them to streams or other bodies of water is an attractive advantage for wastewater irrigation. Maintenance and operation costs may be lower for irrigation systems, but the experience with irrigation systems and continued escalation of groundwater standards, odor abatement, and other problems such as those associated with wintertime irrigation in cold climates has decreased the advantages that were perceived to be with wastewater irrigation in the earlier days of development. Where land is available and the wastewater characteristics are favorable for irrigation, that is, low in salt and other potentially toxic constituents, wastewater irrigation systems have operated with minimal problems for many years.

In contrast, the experience with wastewater irrigation in

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the State of Victoria, Australia, raises questions about wastewater irrigation with uncontrolled mixtures of municipal and industrial wastewater (Reidy and Samson, 1987). They irrigated a maximum of 900 hectares of land. Wastewater was applied at 1 to 2.6 m per year. Cattle and sheep were raised on the project and production of meat and wool was good with disposal costs of the water ranging from $A5.50 to $A18.00 per megaliter. Good pasture growth was obtained in the early years from the ammonia in the wastewater obtained from a coal gassification operation. The presence of salt from another wastewater source that produced a Sodium Adsorption Ratio (SAR) of 13.1 was ignored. Dark colored lignin residues were present from paper pulp production. The effects of these undesirable constituents in the wastewater caused several problems. The soil pH increased in some cases to about 9. Water infiltration decreased in the irrigated soils as the sodium percentage in the soil increased. Runoff from the wastewater irrigation went to a wetlands area and the colored effluent, while not specifically toxic, decreased light penetration in the wetlands and decreased growth of plants causing damage to the wetlands. The total damage to the environment from irrigating with the inappropriate wastewater was very great, overshadowing the initial savings realized from the wastewater irrigation.

This case and many others where wastewater irrigation has been used inappropriately points to the need for designing and using wastewater irrigation systems with caution. While highly beneficial wastewater irrigation systems have been designed and used for many years, new developments must be approached with caution. They must be designed correctly and operated in conformance with design and management plan constraints. It is with these cautions in mind that this manuscript is prepared in order to aid in the development of a highly effective technology that can and will continue to operate for many years.

Land treatment through wastewater irrigation is an established technique. It plays a significant role in much of America. It can be an end process for treatment and disposition of waste, or it can be the beginning of reclamation problems. Most important, wastewater irrigation land treatment returns nutrients to the natural cycles, and disposes of wastes in a manner in which long-term adverse impacts can be monitored, controlled, and hopefully corrected. Monitoring, control, and correction of operational conditions places land waste management systems high on the list of alternative treatments and should carry this management concept to widespread utilization throughout much of the world.

II. NATURE AND CHARACTERISTICS OF WASTEWATER

Food Processing Wastes

Food processing wastes may be liquid as in the case of effluents from processing potatoes, sugar beets, vegetables, fruits, meats, or dairy products or they may be solid or semisolid materials such as soil, rocks, peel wastes, pulps, or paunch manure. They vary in composition from very low nutrient liquid wastes from dairy washing operations to very high nutrient concentrations from whey or meat processing. Almost all food processing waste effluents may be used for irrigating agricultural land to supply water and nutrients for growing crops. Wastewater containing a high salt or Na concentration that would damage crops and soil cannot be used for irrigation.

The amount of vegetables, fruits, and meats processed in the USA annually was estimated by Hunt et al. (1976), relative to the amount of processed product, the wastewater produced, and the resulting biochemical oxygen demand (BOD) (Table 1). The total N added by irrigation with these wastewaters is significant, ranging from 6,500 metric tons N/year for vegetable processing wastes, somewhat less from fruit processing, and 2,400 metric tons annually from meat-processing wastes.

Table 1. Wastes from processed vegetable, fruits, and animal slaughtering (Hunt, et al., 1976).

Product	Amount processed (10^6 metric tons)	Wastewater (10^6/m)	BOD (10^6/kg)
Vegetables	12.8	185	232
Fruits	10.9	129	131
Meat	32.5	327	557
Total	56.2	641	920

Vegetable Processing Wastes

Large volumes of water are used for washing, transporting, blanching, and cooking vegetables. Each of these processes extracts some vegetable constituents, enriching the water with organic material and plant nutrients. As water is used and recycled to lower level steps in the vegetable processing, its nutrient and organic concentration increases and its quality decreases until the water can no longer be used for processing. Then it is discarded. Results compiled from several publications on wastewater quality, show NO_3^-, total N, and chemical oxygen demand (COD) concentrations in the wastewaters from processing several vegetables (Table 2). Nitrate-N concentrations are generally low (<3 mg/L) in vegetable-processing wastewater. However, the organic N in the wastewater will be converted to nitrate-N during treatment or in the soil when it is used for irrigation. When using vegetable processing wastewater for irrigation, the organic N must be considered as the main N component and evaluated as fertilizer for crops and for its soil and ground water pollution potential.

Table 2. Nitrogen and COD composition of vegetable processing wastes

Crop	NO_3^--N	Total N	COD
	In wastewater (mg/L)		
Snap beans[1]	0.9	31.2	176
Sweet corn[1]	1.7	61.9	1,043
Brussels-sprouts[1]	0.4	5.7	15
Beets[1]	2.9	66.4	854
Peas[1]	0.1	44.7	707
Tomatoes[1]	0.6	6.3	95
Cabbage[1]	1.6	31.3	229
Tomatoes[2]	0.4	6.8	47
Corn[2]	trace	27.3	316
Potatoes[3]	0.9	55.0	1,680
	In solid waste (% N)		
Tomato[4]	-	2.33	-

[1] Shannon, et al., 1968
[2] Stanley Assoc., 1977; values are biochemical oxygen demand, BOD.
[3] Smith, et al., 1977
[4] Timm, H. et al., 1976

The total N content of the vegetable-processing wastewaters ranged from 6 to 66 mg/L with tomato (*Lycopersicon esculentum Mill.*) and Brussels-sprouts (*Brassica oleracea Gemmifera*) processing producing low N wastewater and potato (*solanum tuberosum L.*), corn, cabbage (*Brassica oleracea Capitata*), and beet (*Beta vulgaris L.*) processing producing relatively high N wastewaters (Table 2). The COD concentration of the wastewater is also included because in some waste materials, the COD and N concentrations have some interesting relationships. For example, potato-processing wastewaters have a COD/N ratio in the range of 25:1 to 30:1 representing from 3.3 to 4.0% N in the organic waste materials. Other vegetable processing wastes may have predictable COD/N ratios, but these data are not available.

Food processing wastewater applied to land can supply a large amount of N. Smith et al. (1975, 1978) and Smith (1976) showed that potato processors applied from 1.6 to 4.9 m of wastewater annually, which supplied from 1,080 to 2,200 kg N/ha. Potatoes are processed most of the year and large amounts of wastewater are discharged from the processing plants. Daily discharge ranges from 2.9 to 19 million liters. Their long processing season often results in excessive N applications to the land used for wastewater discharge. Other vegetables such as peas, green beans, sweet corn, tomatoes, and brussels-sprouts are processed for a much shorter season each year. Wastewater from these processing operations is discharged to the land for only a few months, therefore, their fertilizer potential is much less than that from potato processing. The actual fertilizer N obtained from processing these other vegetables is not known, but can be estimated from the data presented in Table 2 if the amount of water available from their processing is known.

Another factor related to N fertilization with wastewater from vegetable processing is the efficiency of conversion from the organic to available N. De Haan et al. (1973) stated that wastewater applications must be adjusted so that plant nutrient as well as purification requirements are met. To meet plant nutrient requirements, the availability of plant nutrients in the wastewater must be known. They developed a "relative efficiency index" for N and other nutrients utilizing potato starch waste. The "relative efficiency index" of potato starch waste N compared to commercial fertilizer N was as follows: potatoes, 0.5; beets, 0.5; cereals, 0.2; and grass, 0.8. These values need further verification in other climatic areas and with other soils, wastewaters, and crops other than those in the Netherlands, but the concept is useful.

Some vegetable processing operations generate a large quantity of solid or semisolid waste. In the potato processing industry, several kinds of solid waste are generated. Wastewater from the processing plants is usually passed through a primary clarifier, where the settleable solids are removed from the clarifier underflow and concentrated on a vacuum filter. These wastes contain from 6 to 15% dry matter with a N concentration similar to that of the soluble COD that passes through the filter. The filter cake is usually fed to livestock as a substantial part of the fattening ration. Some potato processors do not use a clarifier, but apply the solid wastes directly to the fields. In this case, organic C and N loading is increased by the additional solid materials resulting in a higher rate of N addition than with clarified waste effluent alone. Additional land should be used to assimilate the additional nutrients. Other solid wastes include substandard products that must be discarded, soil, rock, and mud from transporting and washing the potatoes. These waste materials are fed to livestock or are discarded on land or in landfills as appropriate. Other solid wastes encountered in vegetable processing include peels from tomatoes and other vegetables, and pomace or pulp from tomato juice processing, or other similar materials. These are generally disposed of on land and contribute substantially to N fertilization because they contain relatively high N concentrations. For example, Timm et al. (1976) reported that tomato wastes contain 2.3% N on a dry mass basis.

Sugarbeet Processing Liquid Wastes

Sugarbeet processors discharge large volumes of wastewater containing relatively low concentrations of organic matter, suspended solids, and various inorganic nutrients. As a result, when large volumes of these wastewaters are used for irrigation, large amounts of nitrogen and organic matter can be applied to the fields. Sugarbeet processing wastewater was evaluated for irrigation use in Idaho, U.S.A. (Smith et al. 1977, Smith and Hayden 1980a and 1980b). Chemical oxygen demand (COD) concentrations in the wastewater ranged from about 300 to 8000 mg/L and applications to the irrigated fields ranged from about 8 to 47 metric tons/ha-year (Table 3).

Table 3. Annual wastewater, chemical oxygen demand (COD), nitrogen, phosphorus, and potassium applied to fields irrigated with sugarbeet processing wastewater (Smith & Hyden, 1982b)

Location	Water applied (cm)	COD (Ton/ha)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)
Twin Falls, Idaho					
1976-77	42	17	555	14	1,095
1977-78	169	47	1,425	13	3,405
Rupert, Idaho					
1976-77	50	10	335	11	510
1977-78	28	8	370	13	490
Nampa, Idaho					
1976-77	116	10	277	15	3,080
1977-78	114	10	383	16	3,410

Nitrogen applied in the wastewater most of the years was utilized by growing grass crops in the area. The phosphorus concentration of the wastewater was rather low because the phosphorus was precipitated by lime added to prevent slime buildup in the sugarbeet flumes. The wastewater was used to transport the beets into the factory.

Nitrogen concentrations were determined in the wastewater and soil water extracted from 1.5 m depth (Table 4). High total nitrogen was found in the wastewater from the Twin Falls plant in the first two samplings. The high N resulted from Steffen house waste discharge into the wastewater system. The average total nitrogen for three seasons was 132 mg/L. The average total N remaining in the water extracted from the 1.5 m depth in the field was 4 mg/L, which represented a 97% decrease with passage through 1.5 m of soil. Average total N for three seasons at Rupert was 75 mg/L and average soil water N at the 1.5 m depth was 2.4 mg/L, which represented a 98% decrease from the wastewater applied to the field. The average total N in the wastewater at the Nampa plant was 36 mg/L in the wastewater. The total N in the soil water at the 1.5 m depth was 4 mg/L. This represented an 88% decrease in total N concentration from the wastewater.

Table 4. Total nitrogen in sugarbeet processing wastewater and in water extracted from 150 cm deep in wastewater irrigation fields

Location (Irrigation frequency)	Soil Depth (cm)	mg/L									
		1975			1976						
		Oct	Nov	Dec	Jan	Mar	Apr	May	June	July	Nov
Twin falls	0	-	682	202	134	72	44	1	1	1	93
4 wks	150	1.6	76	131	64	82	52	-	6	4	4
		1976	1977								
		Dec	Jan	Feb	Mar	June	July	Sep	Nov	Dec	
	0	148	120	90	53	1	2	0	83	99	
4 wks	150	-	22	15	15	-	-	-	30	50	
		1975			1976						
		Oct	Nov	Dec	Jan	Mar	Apr	June	Aug	Oct	Nov
Rupert	0	1	136	84	84	55	2	1	1	79	60
4 wks	150	1	2	3	1	-	3	2	1	2	4
		1976	1977							1978	
		Dec	Jan	Apr	June	July	Sep	Oct	Dec	July	Aug
	0	76	61	1	1	1	7	78	59	1	1
4 wks	150	2	3	2	2	2	2	7	4	5	4
		1976			1977					1978	
		Oct	Nov	Dec	Jan	Mar	July	Nov	Dec	Mar	May
Nampa	0	47	54	54	54	15	-	56	78	16	16
4 wks	150	2	1	2	-	-	1	1	1	1	1

Potassium concentrations in the wastewater at Twin Falls averaged 5.6 and ranged from 1.1 to 13.2 meq K/L. At the Rupert plant, the average was 3.2 and ranged from 1.6 to 7.3 meq K/L. At the Nampa plant, the average was 7.3 and ranged from 3.2 to 14.8 meq K/L. Potassium concentrations in the soil water extracted from the 1.5 m depth were 2.3, 0.21, and 0.21 meq K/L for the three respective locations.

A large amount of potassium is being applied to these wastewater irrigation fields and varying amounts are being leached through the soil profile. A potassium equilibrium will probably be reached in a few years of wastewater irrigation in which the K leached from the fields will approximately equal that applied in the wastewater minus K used by crops.

A relatively large amount of salt is being applied to wastewater irrigation fields from sugar factory wastes. In cold climates, where the manufacturing is going on mostly in the cool season, the salty water is used in the season when crops are not growing. The salts are soluble and can be leached from the fields with good quality irrigation water in the early part of the growing season and growing crops are not seriously damaged by the salt accumulation (Smith & Hayden 1980a, 1980b, 1983).

Fruit Processing Wastes

Fruit processing wastewater data are rather scarce, but some available data indicated that except for grape wastes, these wastes are usually low in N (Table 5).

Table 5. Liquid fruit processing waste N and COD in wastewater

Crop	NO_3^--N (mg/L)	Total-N (mg/L)	COD (mg/L)
Apple products[1]	trace	2.2	170
Pear (*Pyrus communis L.*)[1]	trace	2.6	1,230
Grapes (*Vitus sp.*)[2]	2.0	49.9	909
Citrus (*Citrus sp.*)[3]	3.0	7.8	150

[1] Stanley Assoc., 1977; values are BOD.
[2] Shannon et al., 1968.
[3] Koo, 1974.

Solid wastes from the fruit processing industry consist of fruit peels, pits, pomace, seeds, and stems. These wastes as applied to land for disposal are high in water. The N concentrations range from 0.77 to 1.37% and when applied to land, will supply from 1.2 to 1.8 kg N/metric ton of the wet fruit processing waste material (Table 6). From 50 to 200 metric tons/ha of the wet waste material can be applied to meet the fertilization needs of crops grown on these lands.

Table 6. "Solid" wastes from fruit processing (Reed et al., 1973)

Crop	Water (%)	Total N (%)
Peach-pear	86.7	0.77
Peach [*Prunus persica (L.) Batsch*]	85.1	0.75
Pear	87.2	1.37
Mixed fruit[1]	88.9	0.85

[1] Mixed fruit was peach, pear, plum, grape, and cherry.

Meat and Dairy Processing Wastes

Meat processing liquid wastes are generally low in NO_3^- during conventional wastewater treatment (Table 7). The N and COD concentrations in meat packaging wastewater are relatively high and probably inversely related to water use efficiency in processing plants. The N and COD concentrations in wastewater are highest for slaughter wastes and lowest for meat cutting wastes (Table 7). Meat processing wastewater is generally easily treated in conventional waste treatment systems and is well suited for use on irrigated cropped land.

Dairy manufacturing wastes are extremely variable in composition (Table 7). Whey has the highest NO_3^-, total N, and COD concentrations. While whey is perhaps best suited for use as a livestock feed rather than land application, considerable whey is disposed of by irrigation. The high N and COD concentration pose some special problems when irrigating with whey. Extremely high N fertilization can result. The high COD causes rapid microbial growth and can produce odor problems and anaerobic conditions in and on the soil which damage growing crops. Dilution of whey with water is usually necessary for irrigation to decrease the severity of the problems in the field.

Other dairy manufacturing wastewaters contain much less N and COD than whey and should be well suited for irrigation with no greater problems than balancing the N content of the wastewater with the cropping requirements. Nitrogen efficiency factors for meat and dairy processing wastewater N are not yet available.

Table 7. Meat and dairy processing waste N and COD concentrations

Source	NO_3^--N (mg/L)	Total N (mg/L)	COD (mg/L)
In meat packing wastes			
Catch basin effluent[1]	-	124	4,180
Extended aeration influent[2]	0.4	92	1,630
Extended aeration effluent[2]	2.6	10	122
Slaughter waste, nontreated[3]	0	69	2,029
Slaughter waste, treated[3]	0.4	10	139
Custom meat cutting[3]	0	20	139
In dairy manufacturing wastes			
Whey[3]	7.8	685	53,225
Fresh milk packaging[3]	0	24	2,290
Curds (waste not whey)[3]	0	18	725
Condensed milk[3]	2.5	1	96
Ice cream[3]	0	1	21

[1] Tarquin et al., 1974.
[2] Witherow, 1975.
[3] Smith & Peterson, 1982.

Paunch manure is probably the major waste from livestock slaughtering that would be used for fertilizer. According to Baumann (1971) paunch manure contains approximately 2% total N on a dry mass basis. This material can be applied to fields and would be expected to produce an almost immediate fertilizer benefit. Values for availability of paunch manure N should be similar to those of fresh livestock manure. There are no solid wastes associated with dairy manufacturing that would normally be used for fertilizer.

In a series of experiments with rendering plant wastewater irrigation, Bole and Gould (1985) reported that 100 to 200 mm applications supplied nutrients in excess of crop needs (Table 8). 100 mm of wastewater supplied 624 kg N and 31.3 kg P/ha each year. Typical wastewater samples averaged about 700 mg N/L of which about 95% was ammonium. The wastewater averaged about 36 mg P/L.

Application of N in the rendering plant wastewater exceeded the N requirements of the forages, even when the wastewater was diluted with irrigation water so that only 50 mm of wastewater was applied following each harvest for a total of 100 mm of wastewater. This treatment supplied 624 kg N/ha, which was double the maximum N uptake by alfalfa and considerably more N than was utilized by reed canarygrass.

Table 8. Nitrogen uptake by forages irrigated with rendering plant wastewater (adapted from Bole & Gould, 1985)

	N uptake, kg/ha					
Treatment	1977	1978	1979	1980	1981	mean
Alfalfa						
Wastewater	143	309	225	251	258	237
Reed Canarygrass						
Wastewater	200	423	342	300	434	340

Alfalfa and grass yields were determined following irrigation with wastewater from the rendering plant (Table 9). Grass yields were increased much more by wastewater irrigation and fertilizing than were the alfalfa yields. Alfalfa that was not fertilized fixed N and yielded more than the nonfertilized grass; therefore, N response was less with alfalfa than with the reed canarygrass.

Table 9. Dry matter yield of forages irrigated with rendering plant wastewater (adapted from Bole & Gould, 1985)

	Forage yield, Mg/ha					
Treatment	1977	1978	1979	1980	1981	mean
Alfalfa						
Check	4.29	11.01	6.12	7.44	8.43	7.46
Wastewater	5.48	10.65	7.28	8.50	8.55	8.09
Reed Canarygrass						
Check	3.91	9.30	4.85	4.84	6.32	5.48
Wastewater	6.36	14.26	10.42	9.82	14.20	11.01

III. NITRIFICATION

The organic materials contained in the wastewater from vegetable and fruit processing are mostly water soluble, readily decomposable, and have a relatively low molecular weight. Before application, much of the wastewater is filtered leaving only the soluble and reflocculated organic materials. Rapid decomposition of the dissolved organic matter was observed by Jewell (1976) with vegetable processing wastewater organic materials. As these organic materials decompose rapidly, the organic N is also rapidly converted to NH_4^+ and then to NO_3^-. Ammonification is seldom a rate-limiting step and crops grown on the wastewater treated fields will usually have adequate or excessive N. The wastewater organic matter is usually adequate to high in N and decomposition is seldom slowed by N deficiency.

The biological and chemical changes referred to in the introduction to this section are similar for wastewater organic materials to the normal processes that occur in agricultural soils. A discussion of the processes as they are defined for agricultural systems in the literature will be useful in understanding wastewater organic matter biochemical reactions that occur in the wastewater irrigation systems. An overview of nitrogen transformation and their universal N cycle are presented by Jansson and Persson (1982) (Fig. 1).

Relations to the Universal N Cycle

The interaction of individual N-transforming processes in the soil eco-system leads to a pattern of N pools connected by biochemical pathways along which N is translocated. This functional pattern is commonly known as the N cycle. Both mineralization and immobilization have fundamental functions in the universal N cycle (Fig. 1).

A major feature of the universal N cycle operating in all ecosystems is the interaction between autotrophic and heterotrophic biological activity. Through photosynthesis, green plants trap and store solar energy in the form of plant tissue. On return to the soil, the plant material is used as a source of energy by heterotrophic microorganisms, and the organic N is transformed back into the simple inorganic compounds originally taken up by the plants. Thereby the cycle becomes closed. Part of the inorganic N is utilized by a new generation of plants. In this way, a stream of the original solar energy passes through the various ecosystems without any possibility of reuse. In contrast, N and other nutrient elements are repeatedly used and reused by continuous circulation between the autotrophic and heterotrophic phases of the ecosystem.

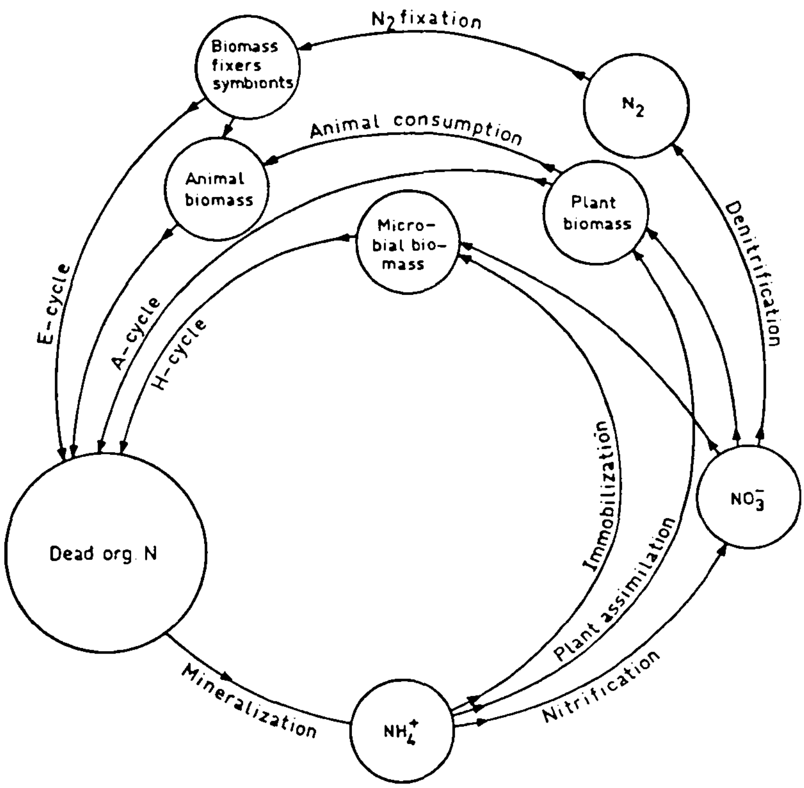

Fig. 1 The universal nitrogen cycle divided into three subcycles: the elemental (E), the autotrophic (A), and the heterotrophic (H). (Jansson & Persson, 1982)

The process of mineralization plays a key role in this universal N cycle, being responsible for the fundamental transformation of organic N in plant remains back into the simple inorganic forms originally used by the plants in their photosynthetic activities. Immobilization is an indispensable and integrated prerequisite for mineralization. The heterotrophic phase of the ecosystems, carrying out mineralization, is a living, biological phenomenon. As such, it not only is respiring and mineralizing but is also developing by processes of multiplication, growth, change, and renewal. These processes result in the formation of organic matter, microbial cells, and tissues.

Thus, in all mineralization activities there is a component of immobilization, a renewal of organic matter, and an assimilation of mineral nutrients providing the multiplication, growth, and maintenance of the living and active microbial flora or biomass. This renewal will normally be restricted to a minor part of the organic matter (organic C) utilized by the microbes; the major part will be mineralized into simple inorganic compounds.

Soil organisms, chiefly microbes, constitute the living agency carrying out the heterotrophic phase of the N cycle. Mineralization is one of the basic activities of soil organism. In addition, mineralization is important for functioning of the cycle, for the autotrophic phase proliferating on its mineral end products (NH_4^+ and NH_3^-).

For the heterotrophic phase, immobilization is as important as mineralization. In dealing with mineralization and its role in the autotrophic phase of the biological cycle, i.e., plant production, one cannot neglect immobilization. This simple fact justifies special consideration of mineralization-immobilization relationships.

Partition of the Universal N Cycle into Three Subcycles

In reality the simple and schematic universal N cycles built up of three interdependent partial cycles having one or more common pathways. These three subcycles may be called the elemental cycle (E), the autotrophic cycle (A), and the heterotrophic cycle (H) (Fig. 1).

The elemental subcycle (E) includes the connection of biological life to the dominating N pool of the earth, the atmosphere. Its specific N pathways are biological N_2 fixation and denitrification under certain environmental conditions (restricted O_2 supply). The autotrophic subcycle (A) includes the activities of green plants, their photosynthetic binding of solar energy, and the build-up of primary organic N substances.

The heterotrophic subcycle (H) is determined by the activities of heterotrophic microorganisms. The specific ecological characteristic of this cycle is mineralization, energy dissipation from organic matter, whereby the nitrogenous organic substances are converted to NH_3 or NH_4^+. The functioning of all three subcycles is dependent on this mineralized N. Partly, but invariably, this mineralized N will be immobilized in the heterotrophic subcycle, partly taken up by plants of the autotrophic subcycle, and partly nitrified and denitrified in the elemental subcycle.

Thus, mineralization and immobilization are by definition bound to the heterotrophic subcycle. They are the basic functions of the heterotrophic biomass. The two processes work in opposite directions, building up and breaking down organic matter, respectively. The difference between the two processes will be a net effect, net mineralization, or net immobilization. Because the basic activity of heterotrophic organisms is dissipation of organically bound energy, net mineralization will be the normal and dominating reaction. Net mineralization of organic matter (organic C compounds) will always be less than gross mineralization. The resulting effect of the two opposing processes - suitably expressed as net mineralization or net immobilization - will determine the N supply to the other two subcycles and, thus, the production of nonleguminous plants under nonfertilizer conditions.

In all three subcycles organic-N is built up in the biomass, from N_2 in the elemental cycle and from NH_4^+-N or NO_3^--N in the other two cycles. Parts of the biomasses are continuously transformed into the dead organic matter pool, whereby the N becomes mineralized to NH_4^+-N or NH_3-N (Jansson & Persson, 1982).

Nitrification takes place in virtually all soils where NH_4^+ is present and conditions are favorable with respect to the major factors of temperature, moisture, pH, and aeration. Oxidation of NO_2^- is more rapid than that of ammonium ion so that only rarely in natural soils is there more than trace amounts of nitrite ion present. Arable soils in the temperate regions have a fairly constant but low content of ammonium, but a variable and often high nitrate content. The main factors that limit nitrification in soil are substrate NH_4^+, O_2, CO_2, pH, and temperature. Cold and wet soils are essentially inactive with respect to nitrification (Schmidt, 1982).

IV. DENITRIFICATION

Denitrification is the major biological process through which fixed N is returned from the soil to the atmosphere. When irrigating with food processing wastewater, nitrogen is frequently applied at rates that are greater than the growing crop can utilize. When excessive nitrogen is applied in the organic form, mineralization and nitrification convert the nitrogen to nitrate, which can be utilized by growing crops or will leach into the deeper soil or ground water. A detailed description of the denitrification process is presented by Firestone (1982). In this description the potential for ground water pollution is described and the chemical and biological processes in soil that decrease pollution are presented.

Factors Affecting Denitrification

Excessive amounts of N are often added in food processing wastewater, indicating that denitrification must also be considered. Smith et al., (1976) determined the potential for denitrification in a field irrigated with potato processing wastewater. About 2,400 kg N/ha was applied during 2 years of irrigation. The water table in the soil rose from below 1.4 m to the 0.65 m depth. Anaerobic conditions were measured at the 0.65 m depth by platinum electrodes. The soluble organic material that leached to 0.65 m provided energy for the denitrifying microorganisms, and denitrification removed nearly all of the NO_3^-. In another experiment with a deep water table (>25 m), Smith et al. (1978) showed that denitrification could be enhanced by irrigating with high organic wastewater at strategic times during the warm season. This lowered redox potentials and promoted denitrification. All irrigations lowered redox potentials, but only irrigations with high organic wastewater during warm weather lowered the redox potential sufficiently that denitrification occurred. These studies showed that denitrification can be managed and used as a tool to decrease leaching of N to the ground water in wastewater treatment and disposal fields.

Denitrification in Wetlands

Wastewater is applied to agricultural fields for disposal and treatment in many areas where crops are grown. In some coastal and inland areas, wetlands are receiving wastewater from municipalities and industrial sources. The potential for wetland renovation of wastewater and especially the capacity to handle nitrogen has had limited investigation. Work by Bartlett et al. (1979) in Massachusetts was conducted to evaluate denitrification in swamps and marshy lands. They indicated that there are at least three pathways for nitrate loss; one assimilatory pathway and two dissimilatory pathways. The assimilatory pathway, which is not considered to be true denitrification, is the uptake of nitrate in bacterial cell protein. One of the dissimilatory pathways is the formation of nitrogenous gasses, N_2 and N_2O, which is considered to be true denitrification. The other pathway results in formation of ammonia, which is not necessarily utilized by denitrifying bacteria. Biological denitrification has been reported to be inhibited at pH 5 to 6 in wetland soils. Their studies showed that biological denitrification in wetland soils will reduce at least 90% of the nitrate present in the wastewater source and that the end products will be nitrous oxide and nitrogen gas.

Denitrification in Overland Flow Systems

Overland flow waste treatment systems may be another area where N losses can occur through denitrification. Chen & Patrick (1981) reported that in a simulated overland flow wastewater treatment system, vertical measurements of redox potential showed that both oxidized and reduced zones in the soil would provide conditions for simultaneous nitrification and denitrification reactions. Addition of an energy source substantially decreased the redox potential and enhanced the rate of nitrate reduction.

Absorption and retention of NH_4^+-N on the soil exchange complex accounted for 70-90% of the applied ammonium in simulated wastewater. Nitrification occurred in surface oxidized zones, resulting in conversion of wastewater N to nitrate and nitrite. Downward movement of the nitrate to reduced soils layers in the overland flow system during subsequent application of wastewater lead to denitrification and assimilatory nitrate reduction.

Inducing Denitrification

In cases where excess nitrogen is present and applied to either agricultural or wetland soils, systems can be managed to produce conditions where oxygen concentrations in the soils will be low. Under these conditions where oxygen is limiting, where an energy source is present, and where nitrate is in excess, denitrification can be expected to occur when the O_2 level drops to 6 to 8%. The redox potential where denitrification occurs is about 225 millivolts as measured with a platinum electrode operating against a calomel reference electrode using a millivolt meter.

V. POLLUTION POTENTIAL

Irrigating with food processing wastewater in many cases applies N greatly in excess of that required for growing crops and management becomes the key to pollution control. Adriano et al. (1974, 1975) measured N leaching in the study cited previously and found that when the grass grown on the fields treated with wastewater was not harvested and removed, most of the applied N was leached. For fields receiving 365 kg and 359 kg N/ha per year, 76% and 69% of the added N was leached, respectively. Much of the leaching loss probably represented N that had been returned to the field in unharvested quackgrass.

In contrast to Adriano's experience, Smith et al. (1976) showed that organic matter from potato processing wastewater applied to soil the previous winter decomposed as soil temperatures increased in the summer, releasing N that was utilized by growing grass. The excess N was denitrified as it leached into the anaerobic zone near the water table. In this case, a large excess of N was disposed of without polluting the ground water. When irrigating with relatively high organic wastewater, it is possible to manage the soil redox potentials to develop occasional low redox conditions that will denitrify any excess NO_3^- when needed, even in soil without a high water table. Temporary artificial water tables develop in the soil at soil particle size phase changes such as a change from silt loam to gravel, and these can be made anaerobic rather readily by irrigating with water with a high oxygen demand.

In a well-managed system in California, Meyer (1974) reported NO_3^- buildup in the soil at depths to 0.9 m when irrigating with wastewater from fruit and vegetable processing. He was able to grow a winter cereal crop in addition to the summer vegetation and remove most of the residual N from the soil profile that had accumulated during wastewater irrigation. This decreased NO_3^- leaching and ground water pollutions.

Timm et al. (1976) applied large quantities of tomato processing waste solids to fields at rates from 448 to 1,792 metric tons/ha. This applied 1,461-5,844 kg N/ha which created a lodging problem when growing barley. Excessive NO_3^--N accumulated (up to 8,700 microgram/g in the growing crop), with severe potential for NO_3^- leaching through the soil and into the ground water.

Pollution potential must be evaluated on each wastewater irrigation site and this evaluation can be made when the system is designed. Nitrogen will frequently be the first limiting factor in designing a wastewater irrigation system. Knowledge of the wastewater chemical composition, the volume of wastewater produced, and the duration of wastewater production during the year are factors that must be evaluated. If this knowledge is available when the system is designed, a soil scientist and an irrigation engineer can determine the area of land that will be needed for disposing of the wastewater. Nitrogen needed by a growing crop, or the maximum amount of nitrogen that a crop can utilize will be the starting point in defining nitrogen treatments. The conversion efficiency factors for nitrogen from the form present in the wastewater to a form in which plants can utilize the nitrogen is necessary. Wastewater irrigation systems cannot be designed in which nitrogen addition in wastewater equals expected plant utilization. Plants and soil systems are not 100% efficient in converting nitrogen from the organic to the inorganic to the plant systems. Therefore, utilization efficiency factors must be employed. These factors are specific for the wastewater systems.

At various places in this publication mention has been made of the principles of limiting factors in wastewater irrigation. This refers to limitations on waste application to agricultural land that result from maximum amounts of nutrients that crops will utilize, maximum amounts of organic constituents that can be applied to land without producing unacceptable odors, of maximum amounts of water that can be applied to land without producing unacceptable amounts of runoff from the field. As mentioned elsewhere, N fertilization is usually the first limiting factor because of the relatively high total N contents of various wastewaters. The next limiting factor in many cases will be organic matter loading, which can produce objectionable odors when excessive organic material is applied to land. The next limiting factor can be the amount of water applied to land. Limiting factors are not always in this order. In cases where denitrification limits N pollution, organic matter may become the first limiting factor and in very slow infiltration soils, water application may be the most limiting factor. Limiting factors must be determined and evaluated on the proposed wastewater irrigation site.

VI. SALINITY IN WASTEWATER AND ITS INFLUENCE ON IRRIGATED SOILS

Sodium Hazards

Food processors in the past and to some extent still use sodium hydroxide or caustic soda for peeling various vegetables and fruits in preparing them for canning, dehydrating, or freezing. When sodium hydroxide is used in the food processing system, there are usually high concentrations of sodium found in the wastewater. Smith et al. (1976) concluded that wastewater from wet lye peeling processes is not suitable for long term irrigation of agricultural land. If the wet lye peeling contributes a major share of the wastewater, or if the sodium to calcium ratio cannot be modified to meet wastewater discharge guidelines that will be discussed later, this statement is still true and wet lye peel wastewater should not be used for irrigating agricultural land. Conversely, if the lye stream makes up a small part of the plant operation, and if the proper ratios can be developed for calcium and sodium through waste stream mixing or treatment, then the wastewater may be used for irrigation with the proper management. Water quality is an important consideration in any appraisal of saline or sodic conditions in an irrigated area. The characteristics of an irrigation water that are most important in determining its quality are: (1) total concentration of soluble salts; (2) relative proportion of sodium to other cations; (3) concentration of boron or other cations that may be toxic; and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium.

Electrical Conductivity

The total concentration of soluble salts in irrigation waters can be adequately expressed for purposes of diagnosis and classification in terms of electrical conductivity. The conductivity is useful because it can be determined readily and precisely.

Nearly all irrigation waters that have been used successfully for a considerable time have conductivity values less than 2,250 micromhos/cm. Waters of higher conductivity have been used occasionally, but crop production except in unusual conditions, has not been satisfactory.

Saline soils are those in which the conductivity of the saturation extract is greater than 4 millimhos/cm. It has been found that the conductivity of the saturation extract of a soil, in the absence of salt accumulation from the ground water, usually ranges from 2 to 10 times as high as the conductivity of the applied irrigation water. This increase in the salt concentration is the result of continual water extraction by plant roots and evaporation. Therefore, the use of waters of moderate to high salt content may result in saline conditions, even where drainage is satisfactory.

Water in the range of 750 to 2,250 micromhos/cm are widely used, and satisfactory crop growth is obtained under good management conditions, but salinity will develop if leaching and drainage are inadequate. Use of waters with conductivity values above 2,250 micromhos/cm is the exception, and very few instances can be cited where such waters have been used successfully. Only the more salt tolerant crops can be grown with such waters and then only when the water is carefully controlled and the subsoil drainage is good.

The steady-state leaching requirements for soils where no precipitation of salts occurs is directly related to the electrical conductivity of the irrigation water and the permissible conductivity of the water draining from the root zone. The leaching requirements for specified electrical conductivity values of the irrigation and drainage waters have been determined (Table 10).

Table 10. Leaching requirement[1] as related to the electrical conductivities of the irrigation and drainage waters

Electrical conductivity of irrigation waters (micromhos/cm)	Leaching requirement for the indicated maximum values of the conductivity of the drainage water at the bottom of the root zone			
	4 mmhos/cm	8 mmhos/cm	12 mmhos/cm	16 mmhos/cm
100	2.5	1.2	0.8	0.6
250	6.2	3.1	2.1	1.6
750	18.8	9.4	6.2	4.7
2,250	56.2	28.1	18.8	14.1
5,000		62.5	41.7	31.2

1 Fraction of the applied irrigation water that must be leached through the root zone expressed as percent

Although these leaching requirement values are probably somewhat high, they illustrate the manner in which the electrical conductivity of irrigation waters influences the leaching requirement under various levels of soil salinity, expressed in terms of electrical conductivity of the soil solution at the bottom of the root zone. It is apparent that the water-transmission and drainage properties of the soil and the salt tolerance of the crop to be grown are important factors in appraising irrigation waters from the standpoint of total salt concentration.

Sodium-Adsorption-Ratio (SAR)

The soluble inorganic constituents of irrigation waters react with soils as ions rather than as molecules. The principal cations are calcium, magnesium, and sodium, with small quantities of potassium ordinarily present. The principal anions are carbonate, bicarbonate, sulfate, and chloride, with fluoride and nitrate occurring in low concentrations. The alkali hazard involved in the use of a water for irrigation is determined by the absolute and relative concentrations of the cations. If the proportion of sodium is high, the alkali hazard is high; and, conversely, if calcium and magnesium predominate, the alkali hazard is low. The importance of the cationic constituents of an irrigation water in relation to the chemical and physical properties of the soil was recognized even before cation exchange reactions were widely understood. Hard water makes soft land and soft water makes hard land. Alkali soils are formed by accumulation of exchangeable sodium and are often characterized by dispersed soil particles and low permeability.

In the past the relative proportion of sodium to other cations in an irrigation water usually has been expressed in terms of the soluble-sodium percentage. However, the sodium-adsorption-ratio of a soil solution is simply related to the adsorption of sodium by the soil; consequently, this ratio has certain advantages for use as an index of the sodium or alkali hazard of the water. The sodium absorption ratio is defined by the equation:

$$SAR = Na^{+} \ / \ (Ca^{++} + Mg^{++})/2^{\ 1/2}$$

where Na^{+}, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter of the respective ions.

The concentration of the soil solution is increased by the extraction of water from the soil by roots and by evaporation. Because the quantity of salt absorbed by plants is relatively small, the solution remaining in the soil becomes more concentrated than the applied irrigation water. At the next irrigation this more concentrated solution may be displaced downward or diluted, and so the concentration of the solution in contact with the soil varies with time and location in the profile. It is not unusual to find shallow ground water or drainage water that is from 2 to 10 times more concentrated than the irrigation water. It is reasonable to assume, however, that for a limited depth of soil, such as the top 12 inches, the concentration of the soil solution is not, on the average, more than 2 or 3 times more concentrated than the irrigation water.

Under conditions in soil where it is permissible to neglect precipitation and absorption of soluble salts by roots, it is clear that irrigation water, after entering the soil, becomes more concentrated without change in relative composition, i.e., the soluble-sodium percentage does not change. The SAR value, however, increases in proportion to the square root of the total concentration, i.e., if the concentration is doubled the SAR value increases by a factor of 1.41. If the concentration is quadrupled, the SAR value will be doubled.

Management of the salt load in a wastewater irrigation system is one of the major responsibilities in the design and management of the system. The nature and amount of salts in the system must be determined before designing a wastewater irrigation system. While nitrogen levels are often the first factor to limit wastewater irrigation, salt content and leaching factors will determine success or failure over the long time irrigation program. Therefore, the statement was made earlier that wet lye peeling wastewater from potato, fruit, and other vegetables is probably incompatible with irrigating agricultural lands. The salinity status must be evaluated and a rational decision based on all factors built into the system design.

VII. SOIL CHARACTERISTICS RELATED TO WASTEWATER IRRIGATION

Much of the discussion on soil characteristics and wastewater irrigation are excerpted from G. W. Olson (1976) from Cornell University. This discussion outlines the soil characteristics that are significant to the application of wastes to land, gives criteria by which soils are rated for their limitations for accepting wastes, and introduces the concept of soil potential for matching designs of land management systems and costs with soils for waste application in the future. Soils are considered to be the most important resource in the country in the long run; inventory and use of that resource will determine to a large extent the survival and progress of the nation.

Soil texture is one of the most important characteristics of a soil in relation to soil's capacity to accept and transmit water. The U. S. Department of Agriculture has established a classification for soil particle size (Table 11).

Table 11. Particles sizes of soil separates

Name	Diameter, mm
Fine gravel	2.00 - 1.00
Coarse sand	1.00 - 0.50
Medium sand	0.50 - 0.25
Fine sand	0.25 - 0.10
Very fine sand	0.10 - 0.02
Silt	0.02 - 0.002
Clay	below 0.002

Sand particles are comparatively large and have less surface area than silt and clay. Because of the large size and small surface area, sand has little chemical reaction and effect in soil. While the sand particles are inert, they function as a framework around which the active part of the soil is associated. Sands increase the size of spaces between particles, facilitating water and air movement. In predominantly sandy soils, infiltration and drainage are the most rapid of any soil type.

The coarser silt particles are similar to the finer sands in their limited chemical activity. The smaller silt particles have greater surface and chemical activity. There is an appreciable tendency for the very fine clay to adhere to the silt particle surface and provide some reactivity. Silt's range of particle sizes, being intermediate between sand and clay particles provide less space between particles than sand and more than clay. Water movement in silt soils is therefore intermediate between sand and clay.

The clay separate is composed of the smallest particles. The surface area of clays is much greater than sand or silt and the chemical reactivity of soil is predominantly supplied by the clay and organic matter in soil. Because a large part of the water held in soil is held on the surface of clay particles in a thin film, the amount of clay in a soil has a great influence on the water holding capacity of the soil. Because of the small particles in clay soil and the resulting small pore spaces and capillaries, water absorption and passage through clay soils is slower than through sand or silt soils. Therefore, clay acts as a storage reservoir for both water and nutrients.

Waste infiltration into and through soils is influenced by many factors other than just particle size of the various separates of soil.

Compaction in all soils influences water infiltration, but in non-compacted soils general assumptions may be made about infiltration (Table 12).

Table 12. A general estimate of water infiltration into soils of different texture

Soil texture	Infiltration, cm/hr
Sand	2.5 to 25
Silt	0.5 to 2.5
Clay	0 to 0.5

For more information on the structure of soil separates, you may consult a reference textbook on introductory soils or soil mineralogy, such as Donahue _et al_., 1983.

Soil Classes

The proportions of soil particles are used to determine soil classes (Fig. 2). The sum of percentages of sand, silt, and clay at any point on the diagram equals 100. A soil composed of a mixture of separates such that the properties of no one separate or group of separates dominates its characteristics is called a loam. The stickiness of the clay and the flour-like nature of the silt are balanced by the non-sticky and mealy or gritty characteristics of the fine and coarse sands. Water drains freely through the loam, yet a considerable amount is retained for plant use in the small pores. In addition to the loam soil classification, various combinations of sand, silt, and clay are combined to produce other textural classes (Fig. 2). The heavier textures are represented by silty clays, silty clay loams, etc. while the lighter textures are sandy loams and loamy sands. Other textural classes are shown in Millar et al., 1958.

The various soil classes are separated from each other by definite lines of division in Fig. 2. However, their properties do not change abruptly at these boundary lines, but one class grades into the adjoining classes of lighter or heavier texture. It is difficult therefore for those not well acquainted with the specific properties that characterize the different soil classes to distinguish accurately between them, and therefore a more generalized textural classification of soils is sometimes used. For instance, in general terms, loams and silt loams may be referred to as medium-textured soils, to clay loams, silty-clay loams, and clays as fine-textures, and to sandy loams, loamy sands, and sands as coarse-textured soils (Millar et al., 1957).

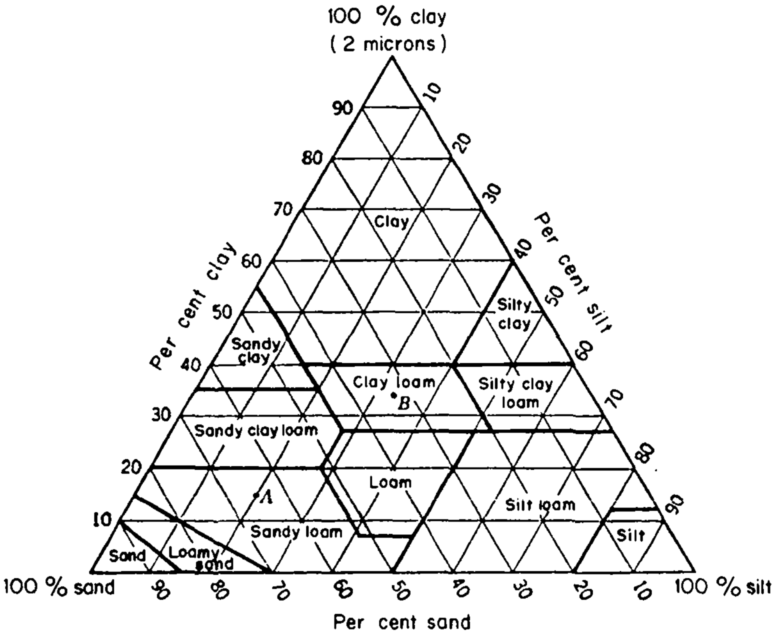

Fig. 2. The percentages of sand, silt, and clay in the textural classes of soil may be determined from this diagram. (Courtesy of Bureau of Plant, Soils, and Agricultural Engineering, U.S.D.A.)

Soil texture is not necessarily uniform from one field to another or at all locations in a field. There are likely to be differences in soil texture with depth in the soil. Older well developed soils have easily distinguished textural horizons that change with depth in the soil. In the humid and sub-humid, temperate climates, it is typical for the subsoil to have a finer texture than the surface soil. When this gradation occurs the soil is said to have a texture profile.

Soils are formed from rock or volcanic ash that are called parent materials. When the soil first develops, it inherits the texture of the parent material. If the texture of the parent material was uniform with depth, the same will be true with the young soil. When conditions are favorable for the weathering of minerals, the texture in time will slowly change as clay is formed throughout the soil. When water percolates through the soil, the finely divided clay may be gradually moved downward, decreasing the amount of clay in the surface horizon. The deposition of some of the clay in the subsoil increases the clay content of that zone so that the texture of that zone becomes finer than that of the surface. The soil now possesses a texture profile. The zone of clay accumulation in the subsoil is called the "B" horizon.

The development of a texture profile is also enhanced if clay formation proceeds more rapidly in the surface soil than in the subsoil. On flood plains there may be layers of different materials deposited on top of each other. It is possible that soils developing in these layered sediments may inherit a more finely textured subsoil than surface soil (Millar et al., 1958).

Irrigation systems must be designed with the soil texture in mind. Loading rates of water must be matched with the capacity of the soil to absorb it in order for the water to be assimilated and treated and not run off to undesirable locations. Soil survey maps, where they are available, will provide valuable information on soils, their texture, water holding capacity, infiltration, subsoil, and other physical characteristics. If maps are not available, the designer of wastewater systems must visit the site, sample the soil to some practical depth, and develop the needed information on soil physical conditions before designing the wastewater irrigation system.

Soil Texture and Wastewater Treatment Efficiency

Soils are discrete, describable, geographic bodies produced by interactions of climate, vegetation and fauna changing surficial geologic materials in geomorphic landscapes. Soil series are designated by names which indicate specific sets of mappable characteristics and ranges of characteristics. Each soil series is unique and mappable in the field and has characteristics associated with certain geomorphic positions in local landscapes. In making the description, the three-dimensional (pedon) attributes of each soil are also recorded. Each soil is then classified according to its properties into a natural classification system. Since 1960 all of the soils currently being mapped in the U.S. have been classified into the natural system. Each soil has unique properties which enable it to be identified and mapped; each soil is also unique for use and management of the areas it occupies in the landscape. The natural classification enables convenient groupings to be made to stratify the many separate soils into sets or categories that can be managed similarly for different purposes. Groupings, for example, segregate different soils into classes with similar drainage or wetness conditions, similar particle size classes, and similar mineralogy. Groupings like these have implications for development and maintenance of waste application systems and other engineering uses of soils.

Soil Description

Description of a soil in a field involves a comparison of the properties of that soil with established descriptive standards that have been set up for describing all soil. Both internal and external properties are described. The internal characteristics of soils include genetic horizon (layer) designations, depth and thickness of each horizon or layer, color patterns (dry, moist, wet), texture, structure, consistence (dry, moist, wet), reaction (pH), boundary distinctness and boundary surface topography, rocks and coarse fragments, concretions, organic matter, roots, aggregate (ped) coatings, soil cracking and shrink-swell behavior, temperature, water movement, cementation, compaction, leached and precipitated materials, reduced and oxidized microenvironments, iron and manganese accumulations, claypan and hardpan conditions, and other significant and special features. The external characteristics described by soil scientists include slope, landform, relief, runoff, land use, vegetation, erosion, stoniness, geology, ground water, elevation, aspect, climate and weather conditions, relation of each soil to the landscape positions of the other associated soils, and all other observable soil and land use conditions and correlations. The descriptions made in the field constitute the most valuable and important data and information about soils; at the same time that the descriptions are made, however, samples of selected soils are also collected for laboratory analyses and characterizations which include analyses for particle size, bulk density, shrink-swell, water retention and release, organic matter and carbon and nitrogen, phosphorus, cations, anions, sesquioxides, acidity and alkalinity, cation exchange capacity, base saturation, clay mineralogy, and other routine and special analyses. The laboratory data are becoming increasingly important for prediction of the behavior of the soils when subjected to applications of wastes and other engineering manipulations. The laboratory data, however, are always supplementary and accessory to the data collected from the soils in place in the natural environment under field conditions.

Descriptions of soil characteristics made in the field are particularly valuable because predictions about behavior under waste management systems and other land uses can be made from them. Soil properties observed, described and measured in the field are "real"; characteristics or performances predicted from those real properties are "inferred". Thus, soil characteristics like color, texture and slope are "real" properties; characteristics like wetness, high shrink-swell and erosion hazard are "inferred" properties influencing waste management techniques and other land uses. For example, if upper horizons have mottles of different colors in certain soils in humid environments, then those soils will have water tables (free water in those zones) close to the surface in the wet seasons. Clayey soils with a high content of montmorillonite will have a tendency to shrink and swell with drying and wetting as the moisture status changes; these clayey soils will also have slow permeability to wastewater effluents and other liquids. Soils on steep slopes will have greater hazards of erosion, landslides, and seepage than soils on nearly level slopes. Although water tables, soil shrinking and swelling, and soil erosion and landslides ("inferred" soil properties) may not be observed in the field at the moment they occur in the soils, the "real" soil properties influencing the "inferred" behavior can be readily described and mapped. The principle of the transfer of "real" data from observations to "inferred" performance also enables data collected at pits or points of measurement to be extended to predictions of behavior to all areas where those soils are mapped - with an acceptable degree of reliability which can be expressed statistically. These principles of landscape description and prediction of future behavior under specified treatments are the bases for the potential usefulness of soil information for waste management systems.

Principles of soil description and mapping can best be illustrated by example. A landscape of Honeoye-Lima-Kendaia-Lyons soil association found in central New York State is described. During the soil survey fieldwork in Cayuga County, many pits and auger holes were dug in these soils to describe them and delineate their boundaries. About 120 hectares can be mapped in detail on an aerial photograph by a soil scientist in a day of good hard fieldwork; fewer hectares can be mapped as the scale and intensity of mapping increases. Maximum use is made of aerial photographic interpretation and other remote sensing techniques, but most of the effort in mapping goes into fieldwork for which there is no substitute in the office or in the laboratory. Honeoye, Lima, Kendaia and Lyons soils all have formed in calcareous glacial till, but they are vastly different in their morphology and in their patterns of soil water states during the year. Tables 13, 14, and 15 are profile descriptions of the Honeoye, Kendaia and Lyons soils illustrating the format of the descriptions and the morphology of these contrasting soils formed in the same geologic materials. All the soils have silt loam surface horizons of aeolian origin and loam or silt loam glacial till in the deepest layers. The Honeoye, however, has silty clay loam B horizons with clay enrichment from pedogenic processes of weathering and leaching. The Honeoye soil does not have mottles in the profile and is classified as well drained. Although the Honeoye soil is almost always moist, it rarely has free water above 0.5 m during the growing season. This moist condition, along with a high nutrient status, is nearly ideal for plant growth and is well suited for many waste application systems. The good potential of Honeoye areas for many land uses can be readily predicted by soil scientists who are familiar with the landscape and internal characteristics of the profile.

Kendaia and Lyons soils, in contrast to the Honeoye, have numerous wetness problems which would adversely affect most waste application systems. Many states have regulations about minimum depth to water table for land application of wastes, so that this soil information is particularly valuable. Mottles indicating perched water tables are distinct at 200 mm in the Kendaia profile, and prominent in the B2g horizon at 430 mm (Table 14). The nature of these Kendaia mottles enables soil scientists to predict that free water will rise above 500 mm in the Kendaia profile for about half of the year, and that part of that wetness period extends into the planting, growing and harvesting seasons in critical early spring and late fall periods. Based on the morphology, Kendaia soils are classified by mappers as somewhat poorly drained and are commonly wet in the field. Although their fertility status is high, Kendaia areas have many problems for cropping and waste applications due to their wetness. With engineering structures like water diversions, terraces, and artificial drainage systems, of course, the Kendaia sites can be developed or improved for waste disposal. Costs and problems of land management systems, however, are usually of much greater magnitude in the Kendaia areas than in the Honeoye areas.

Lyons soils (Table 15), in contrast to the Honeoye and Kendaia (Tables 13-14), are exceedingly wet. Lyons soils occupy the wettest parts of these landscapes where water accumulates and stands for long periods. The Lyons profile has a thick, dark, mucky surface layer and gray reduced and mottled colors as shallow as 300 mm; the Lyons soil colors and landscape positions inform mappers that free water stands above 500 mm for most of the year in these places - and is near the surface for much of that time. As a result of the wet condition, Lyons soils are generally not suitable for many kinds of applications of wastes. Except under special conditions, feasibility of modification of soils at a Lyons site to make it suitable to accept many kinds of wastes is most likely to be negative. Lyons areas are suitable for wildlife marshes, ponds or sewage lagoons in some situations, and can be fit into a pattern of harmonious land use if given good inventory and planning considerations. (Olson, 1976).

The preceeding discussion of soil profile characteristics designed to illustrate how morphological characteristics can be used to predict behavior of soils in wastewater management system operations. The principles illustrated here can be imposed on the soil situation at the site under consideration and can help to determine whether or not the proposed site is suitable for wastewater irrigation or other waste management use. However, the advice of a soil scientist, expert in site selection and evaluation, should be secured for making the final decision for locating a wastewater irrigation system.

Table 13. Soil profile description of typical Honyeoye (Glossoboric Hapludalf; fine loamy, mixed mesic) site

Ap	0 to 10 in.(0 to 25 cm), very dark brown (10YR 3/2) silt loam with few angular coarse fragments; moderate medium granular structure; friable consistence; abundant fine fibrous roots; pH 6.2; clear wavy boundary; 7 to 12 in. (18 to 30 cm) thick;
A2	10 to 15 in.(25 to 38 cm), brown (10YR 5/3) silt loam with pockets of dark brown (10YR 3/2) earthworm casts and few coarse fragments of angular, subangular, and rounded shapes; weak granular in upper part grading into moderate medium to fine subangular blocky structure in lower part; very friable consistence; common fine fibrous roots; pH 6.6; clear wavy boundary; 3 to 6 in.(8 to 15 cm) thick.
B21t	15 to 18 in.(38 to 46 cm), mosaic of dark-brown (10YR 4/3) silty clay loam and brown (10YR 5/3) and pale-brown (10YR 6/3) silty material with few angular coarse fragments; clayskins; moderate medium subangular blocky structure; friable consistence; common fine fibrous roots; pH 6.7; clear wavy boundary; 3 to 7 in. (8 to 18 cm) thick.
B22t	18 to 24 in.(46 to 61 cm), dark-brown (10YR 4/3) silty clay loam with common small pale silty pockets and strands; clayskins on ped faces; moderate coarse subangular blocky structure; firm consistence; few fibrous roots; pH 6.8; gradual irregular boundary; 4 to 15 in. (10 to 38 cm) thick.
C	24 to 40+ in.(61 to 102 cm), grayish-brown (2.5Y 4/4) gravelly loam with thin brown (10YR 3/3) clayskins and sprinkling of fine silt on upper side of some plates and few coarse fragments; weak moderate platy structure; firm consistence; pH 7.9; strongly calcareous.

Table 14. Soil profile description of typical Kendaia (Aeric Haplaquept; fine loamy, mixed, nonacid, mesic) site

Ap	0 to 8 in. (0 to 20 cm), very dark grayish-brown (10YR 3/2) fine-textured silt loam; moderate fine and medium crumb structure; very friable consistence; many fine roots; pH 5.8; abrupt smooth boundary; 6 to 9 in.(15 to 23 cm) thick.
A2g	8 to 17 in.(20 to 43 cm), pale-brown (10YR 6/3) silt loam with light grayish-brown (10YR 6/2) ped coatings and common medium distinct yellowish brown (10YR 5/4) and grayish-brown (2.5Y 5/2) mottles; moderate fine and medium subangular blocky structure breaking into weak medium and coarse plates; very thin discontinuous clayskins on peds; friable consistence; many fine roots; pH 5.6; gradual wavy boundary; 5 to 9 in.(13 to 23 cm) thick.
B2g	17 to 24 in.(43 to 61 cm), dark grayish-brown (10YR 4/2) silty clay loam with very dark grayish-brown (10YR 3/2) ped faces and many fine distinct to prominent yellowish-brown (10YR 5/4-5/8) and light olive-gray (5Y 6/2) mottles; thick continuous clayskins that are pale brown (10YR 6/3) in upper part and very dark grayish-brown (10 YR 3/2) in lower part; sub-angular blocky structure; firm to very firm consistence; pH 6.6; clear wavy boundary; 6 to 10 in. (15 to 15 cm) thick.
Cg	24 to 33+ in.(61 to 84 cm), dark grayish-brown (2.5Y 4/2) and grayish-brown (2.5Y 5/2) silt loam; many fine faint light olive-brown (2.5Y 5/4) mottles; gray (10YR 6/1) ped coatings; moderate coarse platy structure; firm consistence; calcareous.

Table 15. Soil profile description of typical Lyons (Mollic Haplaquept; fine loamy, mixed nonacid, mesic) site

A1	0 to 12 in.(0 to 30 cm), very dark gray (10YR 3/1) to black (10YR 2/1) mucky silt loam; weak fine crumb structure; very friable consistence; pH 7.0; clear wavy boundary; 8 to 18 in.(20 to 46 cm) thick.
B2g	12 to 23 in.(30 to 58 cm), gray (N 5/0) fine-textured silt loam; common medium distinct grayish-brown (2.5Y 5/2) and olive-brown (2.5Y 4/4) mottles; moderate medium and coarse subangu-lar blocky structure; friable to slightly firm consis-tence; pH 7.2; diffuse smooth boundary; 11 to 13 in.(28 to 33 cm) thick.
Cg	23 to 36+ in.(58 to 91 cm), olive (5Y 4/4-5/4) silt loam with gray (N 5/0) vertical streaks 18 to 24 in.(46 cm to 61 cm) apart; massive (structureless); firm consistence; calcareous.

When applying wastewater to soils for treatment and disposal, it is usually true that treatment efficiency is inversely proportional to the rate at which the water passes through the soil profile. In sandy soils where the water drains rapidly, treatment is usually poor. As the soil texture changes to more silt and clay, the treatment efficiency improves. This trend continues until the soil permeability decreases to the point where the soil will not absorb water at a rate sufficient to meet the disposal needs.

The best soils for application of nontoxic solids and liquids have moderate permeability, good drainage and infiltration rates, high water-holding capacity, and no flood hazards. Soils to be avoided for waste applications are those with very rapid or very slow permeability, excessively good or very poor drainage, rapid runoff, frequent flooding, and low water-holding capacity. Flood hazards are more important for solids than for liquid wastes, and a large water holding capacity of the soil for crop growth is not as critical in arid regions where leaching losses are minimal. Special high-rate infiltration systems are best suited to highly permeable soils to be treated with relatively clean water. Overland flow systems are adaptable to slowly permeable soils within narrow slope ranges. Success of the application of solid and liquid wastes to soil surfaces or to shallow depths is also very dependent upon management factors. Where suitable soils are carefully prepared according to good design criteria and where good plant cover is maintained, heavy waste applications probably can be handled with resultant good crop production and low environmental hazards. Where soils with severe limitations are inadequately managed, pollution and degradation of the environment are almost certain to occur. As more is learned about waste management, it will be possible to develop waste application systems that maximize recycling of nutrients and protection of the environment (Olson, 1976).

VIII. NITROGEN REMOVAL FROM WASTEWATER

Crop nutrients contained in wastewater are mostly in the organic form. In most food processing wastes, nitrogen is the most important and frequently the most abundant nutrient, while phosphorus and potassium as well as the lesser abundant nutrients such as zinc, copper, etc. are also present. For nitrogen to be available for utilization by growing plants, it must be converted from the organic to an inorganic form. The processes affecting these conversions are physical, chemical, and biological. Microorganisms play an important role in converting organic forms of nitrogen to the inorganic forms that can be used by plants. Various pathways and products are associated with decomposition and utilization of the organic nitrogen containing waste materials found in food processing effluents (Fig. 3).

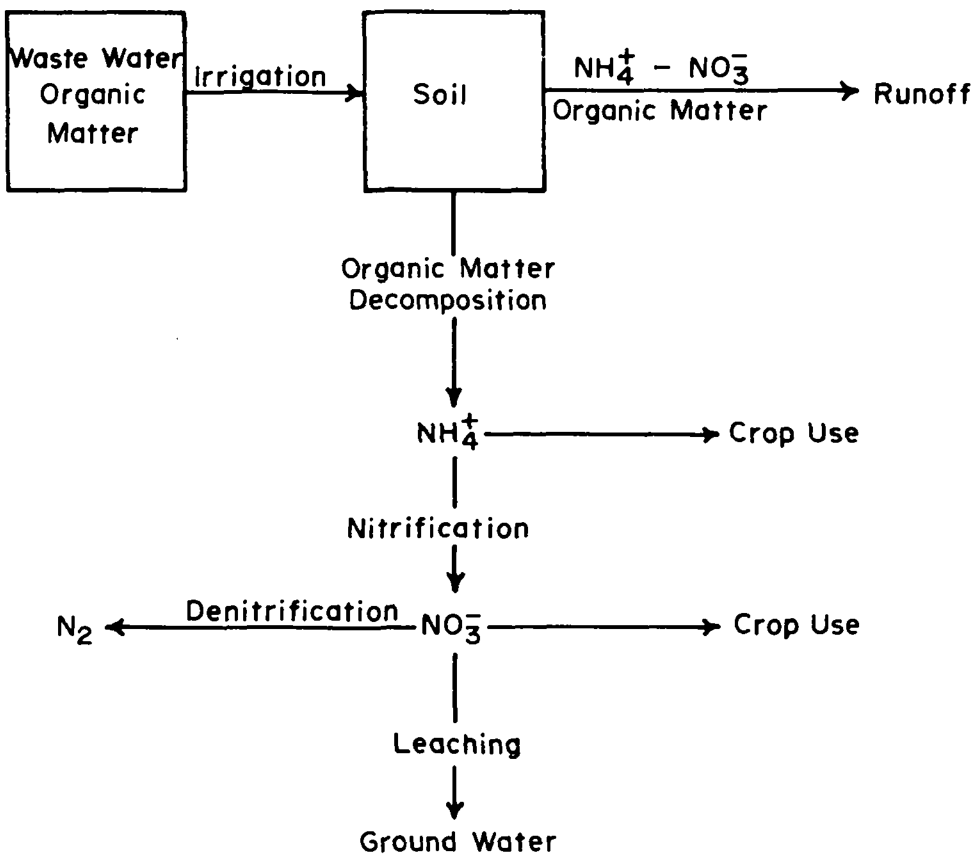

Fig. 3. Wastewater organic matter decomposition and utilization pathways. (adapted from Elliott & McCalla, 1973)

When water containing organic wastes is applied to land for treatment and disposal, the suspended and dissolved organic material filters into the soil where the conversion reactions begin. As shown in Fig. 3, the first avenue for nutrient loss is in runoff of water containing ammonia, nitrate, and organic matter. Most wastewater irrigation permits, that are issued for the regulation of wastewater use and renovation, prohibit runoff from the applicator's property or from a specific designated area. Therefore, runoff must usually be prevented or contained in a pond and returned to the field by a pump for reuse in irrigation.

Wastewater that penetrates the soil will be treated by filtration and the organic residues that are retained in the soil will be consumed by soil microorganisms. The first step in the decomposition of organic residues releases ammonia from the organic residues in a process called ammonification. The ammonia that is released will be contained in the soil in a complicated equilibrium involving the exchange complex of the soil and an association of ammonia and ammonium ions. Some of these forms of nitrogen are utilized by plants and taken from the soil system. The ammonia that remains in the soil and soil solution is further used by soil microorganisms and converted to nitrate. Nitrate is a major source of nitrogen for growing plants and will be utilized by the crops growing in the fields irrigated with the wastewater.

Nitrogen left by the growing crop may be removed in two ways. Denitrification is one of the disposal routes and it will be discussed in detail later. The remaining nitrate will probably be leached in time through the soil and possibly into the ground water where it can become a pollution hazard for drinking water.

Nitrogen Loading and Utilization on Land

When food processing wastewater is applied to agricultural land for treatment and disposal, the first limiting factor in the system design is usually the N application. Reasonable predictions of acceptable loading rates can be made for a given site if soil conditions, type of crop to be grown, depth to water table, frequency and intensity of rainfall, and similar pertinent information is available (Loehr 1974). Nitrogen concentrations in food processing wastewater varies widely, as discussed earlier. When designing or evaluating a food processing wastewater irrigation field it is necessary to know the N concentrations in the wastewater and the amount of water being applied.

Loading rates for food processing wastewater irrigation are available for a few cases. Smith, et al. (1975) studied waste disposal at five potato processing wastewater irrigation systems in Idaho and calculated N application rates for the fields.

Nitrogen applications ranged from 800 to 2,200 kg/ha annually. These values are higher than the grass crops grown on the fields can be expected to utilize and soil NO_3^- will increase and possibly pollute ground water under the fields. Adriano, et al. (1974, 1975) measured N fertilization and utilization at two sites in lower Michigan. At one site vegetables, fruit, and occasionally meats were processed for 20 years before the study was initiated and the wastewater was applied to land that grew quackgrass (*Agropyron repens (L.) Beauv.*) that was clipped but not harvested. Average annual N application was 365 kg/ha. At the other site, dairy products were processed and the waste also applied to a field that grew quackgrass. Annual N application was 359 kg/ha. These application rates were not excessive if the grass had been harvested and removed from the fields.

The data reported earlier showed that most food processing wastewater contains highly variable concentrations of NH_4^+ and organic N. During waste treatment or decomposition in soil, the organic N is converted to NH_4^+. The capacity of soils to absorb NH_4^+ is generally quite high. However, in cases where large amounts of NH_4^+ or readily mineralized organic wastes are applied to soil, the exchange capacity of the soil may be exceeded and NH_4^+ may be leached. Lance (1972) developed a method for calculating potential NH_4^+ leaching in soil and related it to the NH_4^+ adsorption ratio (AAR). This relationship is similar to the Na adsorption ratio that is used extensively in evaluating Na movement in soils. The AAR is calculated as:

$$AAR = \frac{NH_4^+}{[\ 1/2\ (Ca^{2+}) + 1/2\ (Mg^{2+})\ ]^{1/2}}$$

where concentrations are expressed in meq/L. As this ratio increases the exchangeable NH_4^+ percentage increases. In high infiltration rate soils, the adsorption of NH_4^+ is not a very important N removal factor because the soils are soon saturated with NH_4^+. But in agricultural soils that have a high CEC, most of the NH_4^+-N can be removed from the wastewater used for irrigating crops. The NH_4^+ will subsequently be converted to NO_3^- in the aerated soil between wastewater irrigations.

Organic Matter Loading and Utlization on Land

While N loading should be a primary consideration in designing food processing wastewater irrigation systems, the question of organic loading should also be considered. If the limits of N application are the amount of N that can be utilized by crops, then organic matter application rates will seldom be excessive. Organic matter applications in wastewater should be limited to the amount that will decompose without producing unacceptable odors. Jewell (1976) and Jewell and Loehr (1975) in field and laboratory experiments showed that under favorable containing organic matter can utilize high loading rates. In laboratory experiments, they found that at 26°C the removal efficiency was nearly 100% at a vegetable processing wastewater application rate of 19,000 kg COD/ha-day. Field sampling of wastewater at two vegetable processing plant sprinkler irrigation fields indicated that loadings up to 9,000 kg COD/ha per day were removed with >99% efficiency. While these removal rates may not be widely obtainable, the reports showed that food processing wastes are readily decomposed in the field and that the capacity of the soil to assimilate these types of organic wastes is very large. However, to avoid odor problems, organic loading will probably need to be limited to 100 kg organic matter/ ha-day.

IX. PHOSPHORUS REMOVAL FROM WASTEWATER

The phosphorus reactions in soil have generally led researchers to believe that the phosphorus would be adsorbed on the soil and would not leach or move and would therefore not pose problems with movement into ground water. Research with municipal wastewater that would also apply to food processing wastewater has indicated contrary results from those expected. The retention of phosphorus in soil is related to soil texture as shown by several researchers. Iskandar and Syers (1980) suggested that irrigating with municipal wastes invariably involves application of much more phosphorus than growing plants can utilize. They also suggested that much of the P in municipal wastewater is present as inorganic phosphorus, which is plant-available. In a sandy soil at Manteca, California, fields that had been irrigated with municipal wastewater for 4 to 13 years had performed poorly in phosphorus removal. The phosphorus in soil solution was 7 to 13 mg/L. In the ground water, phosphorus at the site had increased from 0.4 to 0.6 mg/L up to 1.7 mg/L after several years' irrigation. The poor performance of the Manteca site in phosphorus removal was attributed to failure to remove vegetation from the site and therefore, failure to remove added phosphorus, excessive wastewater application rates, and the poor phosphorus precipitation and adsorption in the coarse textured soils.

In a 2.5 year experiment in Connecticut, Hill & Shawney (1981) studied phosphorus movement through a fine sandy loam soil that was irrigated with a simulated wastewater containing 12 mg P/L two or three times weekly. They found that the phosphorus in the soil increased about 190 mg/kg and that the leaching loss of P was directly related to the amount of P applied to the soil column. They also found that anaerobic conditions in the soil enhanced phosphorus leaching through the soil into the ground water. The soil was finer in texture than that used by Iskandar and Syers (1980) and appeared to retain somewhat more phosphorus than the lighter soil.

In studies comparing phosphorus movement from municipal wastewater and commercial fertilizer in the field in Minnesota, Latterell et al. (1982) found that P from either source performed similarly. Sommer et al. (1979) found that a majority of P added to soils during 11-12 years of wastewater irrigation remained in the upper 300 mm of Hublersburg clay loam soil, while appreciable amounts of P had leached to the 300- to 600-mm depths in Morrison sandy clay loam soil. There is general agreement that the mechanism of phosphate removal involves adsorption on soil surfaces and precipitation. Adsorption is rapid and the precipitation process is slow.

While the reports above have dealt with municipal wastewater as a source of phosphorus where the form was mostly inorganic, the same principles will apply to food processing wastewater where the phosphorus is primarily organic. The main difference in the process is that the organic forms will need to be converted by microorganisms in the decomposition process to the inorganic forms. There is also some indication that the organic phosphorus forms will tend to leach to a greater extent than the inorganic forms, therefore, enhancing leaching losses and ground water contamination.

The observation that phosphorus leaches more readily through coarse textured sandy soils than through finer textured soils is verified by Robbins & Smith (1977) and an empirical relationship was developed between phosphorus movement and soil particle size distribution. They reported that total, organic, and acid-hydrolizable phosphorus and ortho-phosphorus concentrations were determined in wastewaters from five potato (*Solanum tuberosum, L.*) processing plants and the wastewater volumes applied to cropped land were measured monthly for three processing seasons. These P forms mentioned above were also measured in the soil water samples extracted from soils at depths to 1.5 m. Organic plus hydrolizable P fractions comprised 60 to 70% of the total P in the wastewater and 30 to 40% in the soil water extracts. When the numerical value of the relationships (kg P/ha applied per month) x (mm of clay size material in 1.5 m)$^{-1}$ was less than 0.4, the total P concentration in the extracts at 1.5 m was less than 0.05 mg/L. When the value exceeded 0.4, the total P concentrations in the extracts averaged 1 to 2 mg/L. The relationship may provide disposal site selection and wastewater application rate guidelines for land treatment of wastewater high in organic and hydrolizable phosphorus.

In evaluating a site for wastewater irrigation, the soil texture and depth should be considered and an estimation made of the site capacity to absorb phosphorus. Phosphorus loading will usually be excessive and should be calculated for each potential site, recognizing that sandy soils have much less retention capacity than silt loam or clay loam soils. Heavy loading of light textured soils probably will lead to ground water contamination with phosphorus.

X. CROP GROWTH AND UTILIZATION OF NITROGEN, PHOSPHORUS, AND POTASSIUM FROM WASTEWATER

Irrigating with food-processing wastewater for growing crops is an established practice used by a large segment of the food processing industry in the U.S.A. (Smith & Hayden, 1984). Irrigation with municipal wastewater for the same purpose is also gaining prominence. In many existing systems, emphasis has been placed on disposing of wastewater with maximum applications of both the wastewater and included plant nutrients. Large additions of wastewater and nutrients from potato (*Solanum tuberosum L.*) - processing operations have been applied to land with up to 5.5 m of water and 2550 kg N/ha in one year (Smith et al. 1976, 1978a). These seemingly excessive applications have not always created ground water pollution problems, but in some cases have promoted almost total denitrification because of the anaerobic conditions below the root zone in the soil related to the high water applications and the high energy contents of the organic constituents of the wastewater. Well-managed wastewater irrigation fields growing grass for hay or forage look good and yield well because of the heavy fertilization with wastewater nutrients. Consequently, there has been interest from farmers in obtaining wastewater for crop production in areas adjacent to fields already irrigated with wastewater.

Smith & Hayden (1984) grew corn (*Zea mays*) on a Moulton fine sandy loam (mixed mesic Typic Haplaquoll) at Caldwell, Idaho during the years of 1979-80-81 and irrigated with various amounts of potato processing wastewater. Corn grain yields were increased with increasing wastewater nitrogen fertilization up to 200 to 250 kg nitrogen per hectare with optimum wastewater fertilization yielding approximately 10 metric tons corn grain per ha. Nitrogen uptake by the corn also increased with increasing wastewater applications up to about the 200 to 250 kg nitrogen applications. The nitrogen, which was applied mostly in the organic form, was utilized by the corn plants after conversion to inorganic forms by the soil microorganisms. Utilization efficiency was high at the low application rates but decreased when applications of 300 to 600 kg N/ha were applied annually in the wastewater. Phosphorus and potassium were also applied in the wastewater but their utilization and efficiency of uptake were not monitored in the study.

Nitrogen, phosphorus, and potassium uptake by bromegrass and corn were studied by Grant et al. (1982) from a simulated secondary wastewater. Nutrients in the simulated wastewater were utilized more efficiently by corn than by bromegrass (Table 16).

Table 16. Uptake of Nitrogen, Phosphorus, and Potassium from a simulated wastewater (Adapted from Grant et al., 1982)

Treatment	Nutrient uptake (kg/ha)		
	N	P	K
Crop			
		1977	
Bromegrass	98 (35)*	23 (52)	94 (67)
Corn	169 (52)	72 (113)	188 (109)
L.S.D.	62	21	68
		1988	
Bromegrass	119 (42)	31 (67)	208 (149)
Corn	166 (51)	51 (79)	182 (105)
L.S.D.	(NS)	19	63

* Numbers in parentheses represent the percentage of added nutrient that was recovered in the crop

Wastewater from a rendering plant was used for irrigation by Bole and Gould (1985) in Alberta, Canada. The wastewater contained an average of 655 mg/L nitrogen, of which 616 mg/L was ammonium N; phosphorus was 36 mg/L. 100 mm of the wastewater applied contained 624 and 31.3 kg/ha of N and P, respectively. This application exceeded the crop nutrient requirements of alfalfa and reed canarygrass. Nitrogen was removed at rates of 143 to 309 and averaged 237 kg/ha for alfalfa and 200 to 423 averaging 340 kg/ha for reed canarygrass for five years. Alfalfa yields up to 10.6 Mg/ha and reed canarygrass yields up to 14.3 Mg/ha were obtained with wastewater irrigation.

Soil and plant potassium was studied on a Windsor sandy loam or a Charlton silt loam soil in New Hampshire irrigated with wastewater by Palazzo and Jenkins (1979), over a five year period. The wastewater supplied from 231 to 433 kg N/ha and 36 to 153 kg K/ha. A forage mixture containing reed canarygrass, timothy, and smooth bromegrass was seeded on the plot areas. Application and recovery of potassium and forage grass yields were similar for the two soils. Potassium application was 878 kg/ha, recovery in grass was 1175 kg/ha, and forage yield was 46.8 Mg/ha for five years' accumulation. Potassium applications were lower than nitrogen applications and were less than needed by the growing crops, therefore soil potassium was depleted during the five years wastewater irrigation.

Potassium application in wastewater from food processing is usually higher than cropping requirements for potassium. In the potato processing industry, potassium applications reached several thousand kg/ha at some of the wastewater irrigation sites in Idaho (Smith, et al. 1978b).

XI. LAND PREPARATION FOR WASTEWATER IRRIGATION

Land Leveling or Shaping

Based on the requirement that wastewater must be confined to the property of the applicator, and with the requirement of uniform water distribution on the land, it is highly desirable to shape or level the land to meet these goals. With surface irrigation on nearly level land, where soil texture is light enough to have moderate water infiltration, it is desirable to level the land to a nearly constant grade. Some of the best wastewater irrigation fields in the state of Idaho are those at the Amalgamated Sugar company plant at Nampa, Idaho.

There a total of about 70 ha of land was divided into several smaller fields where the elevation facilitated leveling with a minimum of land movement on each smaller field. The fields were then graded to a 0.1 percent grade (0.1 m fall for 100 m run) for the top half of the field and the remaining part of the field was graded level. A small dike of not more than about 0.3 m was constructed around the lower half of the field to confine wastewater that ponded in that area. Application of the wastewater at the top of the field by gated pipe distributed the water relatively uniformly across the top of the field. The water ran down the graded field area and infiltrated a part of the water. The remaining wastewater then covered the flat part of the field and ponded to a desirable depth, usually not more than 100 mm, and was stored there until infiltration was complete. This system allows for relatively good water distribution and storage of a few mm of water without runoff. It also facilitates irrigation in cold weather with warm water and allows for food processing in climates where freezing occurs (Smith and Hayden 1980b).

In other situations where it is not possible to level the lower half of a field completely flat, it is either necessary to build larger dikes to confine the water or to build a wastewater recovery system where the wastewater leaving the bottom of the field is pumped back to the head of the field or diverted to another field for further distribution.

The two situations described in the previous two paragraphs apply only when the soil texture provides moderate water infiltration. If the soil is sandy or gravelly, distribution of wastewater may be difficult or impossible by surface application at the top of the field. With high infiltration soil, the water may nearly all penetrate the field in the first few meters of the field and give poor distribution of water and nutrients leading to poor crop growth and potential ground water pollution. With very coarse soils, sprinkler systems may be needed to provide relatively uniform distribution of the water and nutrients.

When the soils contain a high clay content and water infiltration is very slow in the surface or B horizon, overland flow may be a method that will give some wastewater treatment. Preparation of the land for overland flow requires grading the field to a relatively uniform cross grade so that the water will be distributed to a uniform depth and not collect and channel. The field can then be smoothed and seeded to a desirable grass or other vegetation and a collection structure constructed at the foot of the slope. The water will then be distributed from a ditch, pipe, or sprinkler across the top of the slope, allowed to run down the field, and collected at the bottom of the field. The water can then be treated further if needed, pumped or transported in a ditch or pipe to another field or discharged into a waterway if it meets discharge quality guidelines.

Wastewater can in some situations be distributed on rough grassed or forested lands by sprinkler distribution. In these cases little or no land treatment or leveling may be necessary. Natural waterways will need to be observed and if the wastewater runs off without proper treatment, it may be necessary to build retaining reservoirs or pumpback structures. The water from the field can be collected in the structure and pumped back onto the original area or to another area for further treatment, or discharged if it meets discharge quality requirements.

Irrigating Agricultural Land

Application systems for food processing wastewater fall into three different categories

1) **Irrigation** - Irrigating agricultural land to produce crops is the system most often used and has the advantage of conserving and using at least part of the nutrients contained in the wastewater. The water may be applied by surface methods or by sprinkling. Surface application lessens NH_3 volatilization compared to sprinkling and can be used on some soils even in midwinter, as the heat in the water thaws the soils and maintains infiltration. Sprinkling increases volatile NH_3 losses and creates some aerosol problems without utilizing the temperature advantages of surface application.

2) **High-rate Infiltration** - When large volumes of wastewater are applied to sandy or gravelly soil where infiltration and percolation rates are very high, many nutrients are lost by percolation and plant nutrients are used inefficiently. Groundwater may be polluted.

3) **Overland Flow** - This is a method of water application where soils are relatively impermeable and the water is purified to some extent by contact with the growing vegetation, the organic matter lying on the surface, and by limited contact with the soil. This method has been studied by Gilde et al. (1971) and by Smith and Schroeder (1983).

The most desirable wastewater application method will be determined by several factors that must be evaluated at each site when the systems are designed. The system used will influence nutrient recovery and the utilization of N. Two concepts of waste handling in relation to the nutrient content are the disposal concept (the main consideration in infiltration-percolation systems), and the recycling-reuse concept. The recycling-reuse concept is becoming much more important with developing energy shortages and increased fertilizer cost. Many food processing waste treatment and disposal systems were designed to utilize the maximum rate of water and nutrients. Frequently, there was no other consideration than that a crop could be grown to keep an acceptable appearance and to avoid wastewater applications that would create nuisance situations such as ponding and objectionable odor. High land cost, and the cost of land leveling and water retention or recycling on the disposal and treatment site have led to applying as much wastewater as possible to small land areas. In many cases, applying excessive wastewater leads to excessive N, pollution of soil and ground water, and the production of high NO_3^- toxic forage.

XII. WASTEWATER IRRIGATION SYSTEMS

Surface Irrigation

There are two general types of surface gravity irrigation, furrow and basin. They require fairly gentle slopes and in many instances will require some leveling or forming before irrigation can be practiced effectively.

1) **Furrow Irrigation** - The furrow system is best adapted to lands with some slope. Two of the serious problems with furrow irrigation are variation in water application from the top to the bottom of the field, and soil erosion. Because water is applied to the furrow at the top of the field, considerable time may elapse before water arrives at the bottom of the furrow. If sufficient water is added to the bottom of the field for adequate soil water storage, excess water will be applied at the top of the field, and the excess percolation may occur there. Runoff of water from the bottom of the field always occurs, and this must be controlled to avoid erosion and flooding of neighboring lands. Thus, there is interaction between the amount of water applied and the length of time of application, and the soil water infiltration properties, land slope, and depth of root zone, as shown in Table 17. These data show that for clay type soils with low infiltration rates, the length of run should be 175 m for a 2% slope, decreasing to 75 m for 10% slope for the deep rooted crops on deep soils. For shallow rooted crops on the same soils, the recommended length of run for a 2% slope is 120 m and for a 10% slope, 52 m. As the infiltration of the soil increases (going to medium- or coarse-textured soils) the length of run decreases. Thus, if the soil is coarse textured and the slope is high, the length of run is short. Conversely, if the soil is fine textured with a low slope, the length of run may be long.

The size of furrow stream that gives little or no soil erosion is related to the soil type, and thus the length of run, the slope, and the depth of water application. As the slope increases, the maximum allowable stream decreases as the length of run increases. As the depth of applied water increases, the maximum length of run increases for the same slope (Table 18).

The application efficiency of furrow-applied water may be increased by recycling runoff water on the farm. This practice is practically mandatory with wastewater irrigation. The runoff may be recycled to another field lower in elevation in the same wastewater irrigation system or it may be recycled by pumping it back to the head of the same field.

2) **Basin Irrigation** - The basin or ponding method of irrigation has some advantages over the furrow method in that no runoff takes place and wetting depth may be more uniform. Thus, the irrigation water can be applied more evenly. The even distribution and lack of runoff are great advantages in wastewater irrigation systems.

Basin irrigation is best adapted to soils having a moderate to slow infiltration, so water can be ponded over the entire basin quickly. As the infiltration rate of the soil increases, the size of the basin must be decreased to get uniform distribution. The water can be distributed more evenly over the basin if larger streams are used. To estimate the stream size required Q (L/min) or the size of the basin A, the following relationship has been suggested by Quackenbush:

$$Q = n \times A$$

where n = 10-20 for sandy soil, 2-10 for loam, and 0.5-2 for clays. One of the problems with this method is that the soil must be graded or leveled to close tolerances, usually no more than 30 mm between cross border ridges (James et al. 1982).

Table 17. Recommended Length of Run and Spacing of Furrows*

Slope %	Fine-Textured Clay Soils		Medium-Textured Loam Soils		Coarse-Textured Sandy Soils	
	Length m	Spacing cm	Length m	Spacing cm	Length m	Spacing cm
A. Deep-Rooted Crops on Deep Soils						
2	175	60	130	60	70	45
4	120	53	90	60	45	45
6	90	45	75	53	38	38
8	80	45	60	45	30	38
10	75	45	82	45		
B. Shallow-Rooted Crops on Deep Soils						
2	120	53	90	53	45	38
4	80	45	60	45	30	38
6	70	45	52	38		
8	60	38	45	38		
10	52	38	38	38		

* Adapted from Irrigation, Drainage, and Salinity, FAO, UNESCO (from James et al., 1982).

Table 18. Furrow-Irrigation Relationships for Various North American Soils, Slopes, and Depths of Application*

Depth of Application (mm)	Furrow Slope (%) (Maximum allowable nonerosive furrow stream, L/min)							
	0.25 (150)	0.50 (75)	0.75 (49)	1.00 (38)	1.50 (26)	2.00 (19)	3.00 (11)	5.00 (7.5)
	Maximum allowable length of run (m)							
Coarse								
50	150	150	80	72	57	50	38	30
100	220	145	115	100	80	70	55	40
150	270	180	145	120	100	80	65	50
200	300	205	165	140	115	95	75	58
Medium								
50	250	170	135	112	105	280	65	50
100	350	240	190	165	135	115	90	70
150	440	295	135	200	160	140	110	80
200	500	340	270	230	190	160	130	95
Fine								
50	320	200	175	150	120	105	80	65
100	450	305	250	225	175	145	115	88
150	530	380	300	255	210	180	140	105
200	650	445	350	300	240	205	165	125

* Adapted from Irrigation, Drainage, and Salinity, FAO, UNESCO (from James et al., 1982).

3) **Sprinkler Irrigation** - The use of sprinkler irrigation with wastewater has grown dramatically in the last few years. Sprinkler irrigation is especially well suited to wastewater distribution in warm climates and where freezing does not occur and may be the system of choice unless energy costs are prohibitive. Sprinkler systems have the advantage over gravity systems because little, if any, land leveling or smoothing is needed. Sprinkling systems commonly deliver water to the soil at a much lower rate than gravity systems, so runoff and erosion can be minimized or eliminated. Well-designed sprinkler systems usually deliver water to the fields more uniformly than gravity systems.

Rotating sprinklers apply water in a circular pattern; the rate of application decreases from a maximum value near the sprinkler head to zero at the perimeter of the circle of application. This nonuniform application pattern is overcome in practice by spacing the sprinklers so that there is considerable overlap among individual patterns. The closer spacing gives more uniform water application but also increases the system cost. Typical sprinkler spacing in the field is 12x18 or 12x12 m between sprinklers.

An index of application uniformity has been developed to characterize sprinkler irrigation. This is called the coefficient of uniformity (CU) and is computed by the formula

$$CU = 100 \times \left[1 - \frac{SD}{M} \right]$$

where SD is the standard deviation (a statistical expression of variability or scatter about the mean) and M is the mean of all observations. The CU is determined by measuring the depth of water application in a square grid array (for example, 3-m spacing) of catchment cans set out along sprinkler lines. Commercially designed sprinkler irrigation systems typically have CU of 80% in still air, but vary from 70 to 90%. If there is wind, of course, the CU is drastically altered. Concepts of water application uniformity are especially important when irrigation systems are used for field distribution of fertilizers, insecticides, herbicides, and when wastewater is distributed for its nutrient content (James et al. 1982).

Several types of sprinkler irrigation systems are available for distributing wastewater. The least expensive system is a single sprinkler line that operates off a main line and is moved by hand at 12 or 24 hour intervals. This system is labor intensive, requiring daily attention. An adaptation of the hand moved line is a similar line of pipe mounted on wheels. The line may be 200 m long and is equipped with a gasoline engine that rolls the wheels and uses that pipeline as an axle of rotation, moving the sprinkler system across the field. The cost of the side roll system is greater than the hand move line but is easier to move and requires less labor than hand moving the lines.

Next in increasing cost is a center pivot system that may be 400 m or more in length and is supported on wheels with towers supporting the main irrigation line at an elevation above the growing crop. Sprinklers are mounted on the top or bottom of the line and are sized to deliver increasing volumes of water as the radius of the circle increases from the center to the outside end of the sprinkler system. The sprinkler system operates automatically traveling around in a circle in the time programmed into the controller and irrigating at the rate desired. Center pivot systems require little operating manpower but are expensive to purchase, require considerable power to operate, and have fairly high maintenance requirements. Maintenance must be by skilled mechanics who are familiar with sprinkler systems, electric motors, and drive systems, and electronic controllers. Center pivot irrigation systems operate best in warm climates, but can be designed and structurally constructed to withstand freezing weather operation. The nozzles must be aimed and adjusted to prevent watering the pipeline and transport structures to prevent ice build-up. Ice accumulation on the machinery can destroy the irrigation system when the accumulation gets too heavy.

Probably the most expensive systems to install and the least expensive to maintain are the solid set buried systems. These systems should be designed with the same specifications as an irrigation system and the water lines buried below the frost line in cold climate areas. Valves must be installed underground to drain the vertical risers and prevent their freezing in cold climates. Wastewater distribution with solid set buried systems can be excellent with CU of 80% or better. However, they frequently are installed with the sprinklers too far apart and the distribution is relatively poor. For more detail about theoretical considerations related to soil moisture movement, irrigation rates, crop water requirements, and design specifications, refer to Hansen et al. (1979). For design information for wastewater irrigation systems consult the Sprinkler Irrigation Association Wastewater Resource Manual chapter titled, "Systems for Application of Municipal Sewage Effluent by Harrison (1975)." Harrison deals with important information such as systems capacity, water distribution efficiency, permanent and movable systems, maintenance, drainage, and pump specifications.

4) **Overland Flow Irrigation** - The overland flow discussion was adapted from Hunt and Lee (1976). Overland flow treatment systems are located on soils of low permeability. This low permeability may result from a number of factors, but most commonly it is either a heavy-textured soil or a soil containing a barrier to water percolation within the upper three feet. In addition to low permeability, a slight slope is required; slopes up to 8% are generally satisfactory. The slopes are covered with vegetation and normally are 50 to 70 m in length with collection channels located at the bottom of the slope (Fig. 4). The water is applied at the upper end of the slopes and flows as a sheet over the soil surface and through a surface organic mat into the collection channels. The renovated water then flows to a central channel where the water quality can easily be monitored. The renovated water can then be used for a host of purposes varying from industrial cooling to groundwater recharge.

Operationally, overland flow systems have slow rates of application; volumes are normally less than 10 mm per day, and application times vary from 6 to 18 hours. However, wastewater can be applied on 4 to 6 days per week giving a weekly application of 50 to 80 mm. These rates compare favorably with slow infiltration systems. High rates of application invariably cause poor treatment. Most overland flow systems have been established in humid areas where the vegetation did not rely on irrigation.

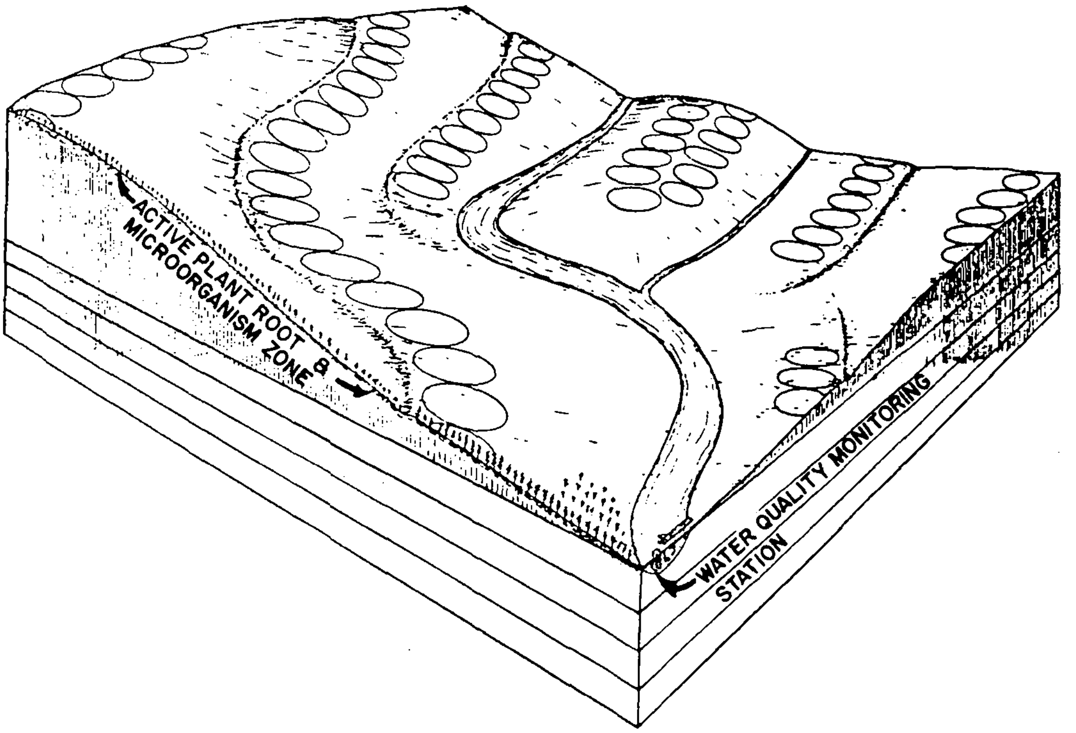

Fig. 4. Schematic diagram of an overland flow system. Circles show areas of wastewater application (Hunt & Lee, 1976)

a) **Mechanism of Overland Flow Treatment** - The fact that overland flow treatment of wastewater removes a very high percentage of the applied nitrogen is somewhat surprising. The wastewater does not flow into the soil where nitrogen could easily be absorbed on the clay particle surfaces or be removed by plant uptake. In addition, the fact that the surface water is aerobic would tend to eliminate denitrification. However, upon further investigation, other conditions make nitrogen removal seem quite likely. The organic layer on the soil surface as well as the shallow root system of the flooded cover crop usually removes from 50 to 85% of the applied nitrogen. Significant denitrification appears to remove the remaining nitrogen.

Nitrification and denitrification occur simultaneously in an overland flow system. The water film and underlying soil form an aerobic-anaerobic double layer similar to that found in rice fields or marshes. In the overlying water film and organic matter, aerobic processes occur and ammonium is mineralized to nitrate. In the underlying anaerobic zone, the nitrate is denitrified.

Nitrogen removal by grass on overland flow is also an interesting phenomenon in which a grass growth gradient is established down the slope. This gradient has been observed on slopes from 55 m long in the field to 0.5 m in the greenhouse. It appears that in both the field and greenhouse systems that are functioning properly, the nitrogen concentration of the wastewater is 1 to 2 ppm at approximately two thirds of the slope length. Grass is very responsive to nitrogen and a growth gradient associated with the low nitrogen in the tail slope is established.

b) **Phosphorus and Trace Element Treatment in Overland Flow Systems** - Phosphorus removal via land treatment is best when the wastewater is in close contact with the surface area of clay size particles as the water moves through the soil. Overland flow would therefore intuitively seem to be the poorest method of phosphorus removal. This is in fact true; wastewater flowing over the soil surface does not have extensive contact with the iron and aluminum compounds in the soil that normally fix phosphorus.

On a practical basis, it has been shown that more than 80% of the phosphorus in raw wastewater can be removed by overland flow if stoichiometric amounts of aluminum sulfate are added to the wastewater before application to the sloped soil.

Trace element removal by overland flow is greater than 90% for all and more than 98% for some heavy metals. This high removal is attributed to the surface organic mat where most of the heavy metals are bound. As with phosphorus, the surface concentration of trace elements could be reduced periodically by plowing the layer under.

5) **High Rate Infiltration Systems** - While high rate infiltration systems are seldom adaptable for treatment of food processing wastes, the following discussion of the system is included for completeness in this wastewater treatment discussion.

High rate infiltration is best adapted as tertiary treatment of water that is low in settleable solids and organic wastes. Wastewater with a high organic content, or high settleable solids content will rapidly plug the soils in a high rate system. It has been reported that water containing over about 20 mg/L of settleable solids cannot be used successfully in a high rate infiltration system. High rate systems, of course, will only work in coarse textured soils.

High-rate infiltration relies on the physical, chemical, and biological properties of the soil profile to remove impurities from wastewater. An intensive study of this method was conducted at Phoenix, Arizona (Bouwer et al., 1974b). The site is the Salt River Valley with a fine loamy sand (0-0.9 m deep) underlain with layers of sand, gravel, boulders, and traces of clay to a depth of 75 m, where there was an impermeable clay layer. The static water table was at 3 m.

Secondary effluent was applied to the infiltration bed for 10-30 days followed by a 10- to 20-day drying period. The maximum hydraulic loading was 122 m/year using a 20- to 30-day effluent loading and a 10- and 20-day drying period for summer and winter, respectively. However, Bouwer et al. (1974a) found that a loading of 91 m effluent/year resulted in removal of 30% of the applied N. The effluent contained 20-40 mg NH_4^+-N, 0-3 mg NO_2^--N, 0-1 mg NO_3^--N, and 1-6 mg organic N/L which resulted in a N addition of about 28,000 kg/ha. The wet-dry cycle used was 10 days wet and 10-20 days of drying. Oxygen and organic C were the limiting factors for denitrification. The effluent from the infiltration basin was suitable for unrestricted crop irrigation and recreation in Arizona.

Satterwhite et al. (1976) reported on a year-round rapid infiltration system at Fort Deven, Massachusetts, which has been receiving unchlorinated Imhoff effluent since 1942. The infiltration beds were underlain with silty sand to sandy gravel with 10 to 15% silt and clay. The annual effluent application was 27.1 m with a 2-day application and a 14-day drying period. A total-N balance showed a 60-80% reduction in total N, primarily by denitrification. The ground water in the immediate area contained from 10-20 mg NO_3^--N/L.

In comparing the warm-arid and the cold-humid locations from the previously noted studies, the cold-humid site had a greater N reduction. This reduction may possibly have been caused by higher organic C in the Imhoff effluent, lower loading rate, and long drying cycles, which allowed more time for N mineralization at the cold-humid site. Bouwer, et al. (1974a) showed 80-90% denitrification when glucose was added to the system to supply organic C. In both of these locations the ground water quantity and quality were affected. The NO_3^- concentration of the ground water was increased, but this impact was ameliorated by lateral NO_3^- movement at the Fort Deven site and pumping NO_3^- containing water to the surface for crop irrigation and nutrient utilization by growing plants at Phoenix.

High-rate infiltration is best suited to areas where water conservation is essential and the soil is deep and permeable. Control of the ground water at the site is necessary and this can be done using tile drains or recovery pumps (Reed, 1972). The high-rate infiltration system may also be suited to some seasonal operations such as canners. With proper management, high infiltration systems can be successful. The N in the infiltrated water is readily available to growing crops.

Much additional detail is available in publications on design, operation, and maintenance of wastewater irrigation systems. A few good ones are found in Overcash & Pal 1979, Pettygrove & Asano 1985, Loehr, et al. 1979, and USEPA 1981.

XIII. SUMMARY

Irrigation with food processing wastewater is a viable system of wastewater treatment. Irrigating agricultural land with this material conserves nutrients that would otherwise be lost and at least partially solves a difficult environmental pollution problem. All newly constructed food processing plants or those in the planning stages need to have wastewater irrigation considered as a possible method for treatment and disposal of the processing effluents.

Soil Characterization

Soils available for wastewater irrigation in relation to a food processing operation need to be evaluated for suitability to receive wastewater. Soil textural classification, slope, depth, permeability, soil cracking and shrink-swell behavior, temperature, water movement, cementation, hardpans, compaction, leached and cemented materials, and other significant features need to be considered in selecting wastewater irrigation sites. Soil chemical and physical analyses such as organic matter, carbon, nitrogen, phosphorus, cations, anions, acidity, alkalinity, cation exchange capacity, base saturation, clay mineralogy, and other routine analyses need to be made and evaluated. Cropping capability and potential yields, in relation to nutrient utilization must be considered.

Cropping and Management

An individual cropping and management plan needs to be developed for each wastewater irrigation field system. The climate at the location, rainfall, wintertime freezing if it occurs, crop yield potential, nutrient extraction and utilization in relation to nutrient loading, the amount of water that can be applied to the land in relation to soil permeability and nutrient loading, and other management factors must be integrated into the overall management plan.

Site Preparation

Land preparation for wastewater irrigation could include land leveling or shaping for surface wastewater application systems. Selection of a water application method or system such as surface application in furrows, border irrigation, sprinkler irrigation by hand move systems, center pivot circular systems, or buried lateral solid set systems. Each irrigation system requires different degrees of land preparation and different wastewater application rates and efficiencies. Costs of the various systems is greatly different and must be evaluated for the proposed application.

Application Method

Irrigation methods by the slow infiltration, rapid infiltration, (although this is unlikely with food processing wastes), or overland flow (for soils with very slow percolation and infiltration), must be selected for each wastewater irrigation site. Sizes of fields, lengths of irrigation runs, duration of irrigations, frequency of irrigations, and drying periods between irrigations must become part of the management plan for the site specific system that is developed and installed.

Wastewater Characteristics

The nature of the wastewater must be considered. Food processing wastewater contains low concentrations of organic constituents and plant nutrients. The amounts of these materials in various wastewaters will vary and this information is needed in planning for appropriate wastewater loading for crop utilization and pollution control. Much information is included herein of this type.

Nutrient Balance

Most of the nitrogen in food processing wastewater is in the organic form. The organic nitrogen is converted to ammonia and nitrate by soil microorganisms after which it can be utilized by growing plants. When excessive fertilization with nitrogen occurs, the excess nitrogen will leach into the ground water or soil system. Methods are available for stimulating or managing denitrification to remove excess nitrate from the soil system and prevent ground water pollution. Pollution in soil and ground water is always a possible result from wastewater irrigation but with proper management, wastewater spreading to larger areas of land when possible, controlled denitrification, crop management and removal, and other appropriate management practices, benefits can be enhanced and pollution limited.

Salinity Management

Salinity from wastewater irrigation is always a factor that must be evaluated and if a problem exists, solutions must be designed into the system. SAR ratios of wastewater must be maintained below 10 or the soils can become sodium saturated and upon leaching the excess salts, will seal up because of particle dispersion and will not absorb water. These problems can all be evaluated and often controlled if the proper information is available in the design and development stages.

Wastewater irrigation systems, in which the water and part of the included nutrients are used in a beneficial manner for growing crops, can be successful. Pollution problems can be eliminated for the most part and environmentally acceptable, attractive fields can be developed where the nutrients in the wastewater will be utilized by growing crops. The crops can be fed to livestock, or in some cases, to people, making an unattractive sometimes nuisance into a valuable asset.

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