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TREATMENT OF POTATO PROCESSING WASTEWATER ON AGRICULTURAL LAND: WATER AND ORGANIC LOADING, AND THE FATE OF APPLIED PLANT NUTRIENTS

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INTRODUCTION

Potato processors discharge large volumes of wastewater that contain large amounts of organic matter, suspended solids, and various inorganic constituents including nitrogen, phosphorus, and potassium (1, 2, 3). Until recently, the wastewater was discharged into rivers and streams, but governmental regulations now prohibit this practice. The potato processors must either treat their wastewater to meet established quality standards before discharging it into streams or find an alternative disposal method. Irrigating agricultural cropland is the disposal and treatment method that many potato processors have chosen.

Little was known about the chemical composition of potato processing wastewater until recently. Loehr (4) cited data on water requirements for processing and waste loading per ton of processed potatoes. More recently Smith and associates published the nutrient content of potato processing wastewater (5), water loading, organic loading, reduction of COD and nitrates in soil (6), denitrification in potato processing waste treatment fields (7) and a guideline for irrigation with potato processing wastewater (8). De Haan and Zwerman (9) reported research results in the Netherlands on land disposal of potato starch wastewater. They concluded that the systems worked well and that oxygen demand and other constituents except potassium were satisfactorily removed in sandy soil if the applications did not exceed 100 to 500 mm per dose.

Sprinkler irrigation with food processing wastes was first tried in 1947, and since that time its use has greatly increased in the U.S. (10, 11, 12). Several potato processors formerly using other systems, such as secondary treatment, recently have converted to land disposal. Many newer potato processing plants are using some form of land disposal for their wastewater.

The processing season begins with freshly harvested potatoes and continues throughout the winter months and part of the next summer using potatoes from storage. Irrigation with the wastewater has been as successful with flooding of graded fields as with sprinkling when using equipment designed to operate at temperatures below freezing.

The objectives of this chapter are to summarize data for sprinkler and flood irrigation with potato processing wastewater, loading with nutrients and organic matter, water cleanup through filtration and microbiological activity, some aspects of nutrient utilization, and to discuss the feasibility of continued irrigation with these wastewaters.

METHODS AND MATERIALS

This study was conducted at five potato processing plants in southern Idaho where the wastewater is used to irrigate cropped fields. Three fields are irrigated by flooding bordered, nearly level land and two are irrigated by sprinkling. Orchard grass, tall fescue, reed canary grass, or mixtures of these species are grown on the fields and harvested for hay or grazed by livestock. Wastewater was sampled at each potato processing plant at monthly intervals during most of three processing seasons. An automatic sampler, activated at 20-minute intervals for 24 hours, delivered water into a freezer where it was frozen in a plastic container for storage until analyzed in the laboratory (13).

Soil water was sampled monthly using 3.8-cm diameter polyvinylchloride sampling tubes with porous ceramic cups cemented to one end. The sampling tubes were inserted vertically into the soil to depths of 15, 30, 60, 90, 120, and 150 cm at each sampling site. When taking samples, approximately 0.7 bar suction was applied to the tubes for about 48 hours. The extracted water was pumped into a suction flask, transferred to a plastic bottle, and taken to the laboratory for refrigerated storage until analyzed. Not every tube yielded a water sample at every sampling.

The water samples were analyzed for COD according to *Standard Methods for the Examination of Water and Wastewater* (14).

Nitrate-N was determined with a nitrate-specific ion electrode, and total nitrogen was determined by a Kjeldahl procedure, modified by substitution of copper for the mercury catalyst (14). Total phosphorus was determined using persulfate oxidation (15) and potassium by flame photometry. Water applications to the fields were measured by the treatment field operators using meters or other devices. Processing plant waste effluents, water samples extracted with extraction cups, and saturated soil extracts were also analyzed for sodium, calcium, magnesium, chloride, bicarbonate, sulfate, pH, and electrical conductivity. Soils sampled annually were analyzed for the above constituents and the first sampling for cation exchange capacity. Particle-size analyses of the soils were made from each sampling depth (Table 1). One site, where a shallow water table developed in the summer because of irrigating, the surrounding agricultural area was instrumented for redox potential measurements in the soil (7).

Table 1. Soil mechanical analyses of wastewater treatment fields.

Treatment	*Fields*	*Sampling Depth (cm)*	*Clay*	*Sand*	*Silt*	*Textural Class*
			(Percent)			
1-F	Site 1	0–150	18	43	39	Loam
	Site 2	0–60	17	50	33	Loam
		60–150	3	89	8	Sand
2-F	Site 1	0–30	12	65	23	Sandy loam
		30–150	2	97	1	Sand
	Site 2	0–150	10	62	28	Sandy loam
3-S	Site 1	0–150	13	63	24	Sandy loam
	Site 2	0–150	11	62	27	Sandy loam
4-S	Site 1	0–60	19	46	35	Loam
		60–150	6	81	13	Loamy sand
5-F	Site 1	0–150	15	56	29	Sandy loam
	Site 2	0–150	19	37	44	Loam

The processing plants with the flood irrigated fields are referred to as 1-F, 2-F, and 5-F and the sprinkler fields as 3-S and 4-S. Plants 2-F, 4-S, and 5-F use steam peeling and produce dehydrated potato products. Plant 1-F uses dry lye peeling and produces frozen french fried potatoes and other products. Plant 3-S used wet lye peeling the first season of the study, and then converted to dry lye peeling. It produces dehydrated potato products and starch.

RESULTS AND DISCUSSION

Waste Effluent Analyses and Application

The nitrogen, phosphorus, and potassium concentrations in the wastewater are reported in Table 2 as averages by years of all the samples obtained from each processing plant during 1973, 1974, and 1975. The nitrogen is primarily organic, with mean concentrations less than 2 mg nitrate-N/l. Phosphorus in the wastewater averaged 32 percent ortho, 22 percent acid hydrolyzable, and 46 percent organic. Nitrogen in the wastewater ranged from 32 to 133 mg/l, phosphorus from 6 to 21 mg/l and potassium from 75 to 158 mg/l for all plants.

Table 2. Annual wastewater applications; mean nitrogen, phosphorus and potassium concentrations, and annual applications in wastewater from five potato processing plants.[a]

Treatment Fields	*Year*	*Water Applied (cm)*	*Nitrogen*		*Phosphorus*		*Potassium*	
			(mg/l)	*(kg/ha)*	*(mg/l)*	*(kg/ha)*	*(mg/l)*	*(kg/ha)*
1-F	1973	546	52	2550	10	630	114	5750
	1974	460	47	2130	13	630	162	7730
	1975	260	50	1500	12	300	130	3180
2-F	1973	115	32	400	6	80	75	930
	1974	209	33	610	6	110	94	1880
	1975	174	35	640	6	120	88	1840
3-S	1974	119	91	1500	21	150	180	2670
	1975	161	133	1720	16	220	250	3540
4-S	1973	246	52	760	9	120	132	2490
	1974	78	52	670	8	110	111	1910
	1975	27	43	350	8	70	77	680
5-F	1973	266	59	980	9	160	150	2540
	1974	201	44	950	8	170	158	2670
	1975	278	51	1420	10	280	104	2830

[a]Monthly applications and concentrations were used for calculating annual values.

The amount of wastewater applied annually ranged from 27 to 546 cm (Table 2). The wastewater at most of the potato processing plants is screened for removal of rocks and potato pieces, then passed through a clarifier, and the settled solids are removed by a vacuum filter. The filter cake containing 10–15 percent solid material was ensiled and later used for livestock feed.

Nitrogen applied in the wastewater ranged from 350 kg/ha

(310 lb/acre) to 2550 kg/ha (2280 lb/acre) annually. The lowest nitrogen application can probably be utilized by a good grass crop in this climatic area but the highest rate exceeds crop requirements.

Phosphorus applied in the wastewater ranged from 70 kg/ha (60 lb/acre) to 630 kg/ha (565 lb/acre). These applications exceed phosphorus requirements for most crops, and phosphorus will increase in the soil as a result of irrigation with potato processing wastewater. During three years of irrigation with these wastes, the bicarbonate extractable phosphorus increased about 40 ppm in the top 30 cm of soil, with much smaller increases below that depth (Table 3).

Table 3. Bicarbonate extractable soil phosphorus in two potato processing waste treatment fields for three years.

Depth in Soil (cm)	*Bicarbonate Extractable (P, ppm)*					
	Treatment Field 5-F			*Treatment Field 3-S*		
	1972	*1973*	*1974*	*1973*	*1974*	*1975*
0–30	11.0	25.7	51.3	16.6	54.4	53.0
30–60	4.1	17.6	15.7	10.0	21.9	19.2
60–90	–	18.2	17.5	3.8	10.7	6.3
90-120	3.6	16.9	15.4	2.9	12.6	5.6
120–150	3.5	15.1	14.7	1.6	8.8	4.5

Potassium applied in the wastewater exceeded the potassium requirements of grass. Potassium concentration in the soil solution is expected to increase until it reaches an equilibrium with the soil, after which the excess applied will be leached.

Infiltration occurred at each flood irrigation in the winter with 15°C water even when the air temperature was below minus 40°C. With sprinkler irrigation in cold weather, ice accumulated in mounds around the sprinklers, remaining until air temperatures were above freezing. Ice accumulation occurs because water leaving the sprinkler nozzle approaches dewpoint temperature before the droplets reach the ground regardless of the water temperature in the sprinkler nozzle (16). Melting was usually slow enough to allow infiltration, and no major runoff problems were observed. Results with both irrigation methods were similar, although higher nitrates were found in the soils under sprinkling than under flood irrigation. This probably did not result from different irrigation methods. Usually less water was applied on the sprinkler fields than when irrigating by flooding.

COD Applications

Mean concentrations of COD in the wastewater ranged from 765 to 3080 mg/l (Table 4). These differences result from different peeling and potato handling processes in the potato processing plants. The high COD concentrations in the wastewater at plant 3-S resulted from not using vacuum filtration. Maximum COD concentrations usually occurred when poorer quality potatoes were processed late in the winter. Also late in the season, processing plants often operated at less than maximum capacity. Under these conditions they used more water than normal per ton of potatoes and the wastewater was less concentrated in COD and other constituents than during normal operation.

Table 4. COD in potato processing wastewater used for irrigation.

Processing Plant	*Year*	*COD (mg/l)*			*COD Applied (tons/ha)*
		max.	*min.*	*mean*	
1-F	1973	1990	950	1480	58.6
	1974	2680	800	1570	85.1
	1975	2500	740	1440	29.9
2-F	1973	1220	730	940	9.5
	1974	1040	530	760	15.6
	1975	1530	450	880	15.6
3-S	1974	7400	1280	3080	35.2
	1975	2940	1070	2110	34.8
4-S	1973	3510	400	2540	20.2
	1974	3830	490	2540	15.4
	1975	2970	1410	2020	12.1
5-F	1973	2040	1080	1540	40.9
	1974	1660	850	1370	27.0
	1975	1640	410	1250	35.9

Annual COD applied to the treatment field varied from approximately 10 to 85 tons per hectare. At plant 1-F the high application rates in 1973 and 1974 decreased as more land was used for wastewater irrigation. The lower amounts were applied at Plant 2-F because the disposal system was designed and constructed to utilize the total plant effluent. When construction was complete and a grass cover was established, irrigation with wastewater was initiated, and the system has worked exceptionally well from the beginning.

Plant 5-F had the first potato processing wastewater irrigation system in Idaho. Settling of recently leveled land caused ponding in the low areas, which killed the grass. Long stretches of open ditch carrying wastewater in the field became anaerobic and created noxious odors. This was corrected by installing underground pipe for the field water distribution system and eliminating the open ditches. Low spots in the field were filled with soil and reseeded with grass.

COD in Extracted Water Samples

Obtaining soil water samples from the sprinkled fields was difficult. In the winter the soil and sampling sites were covered much of the time with ice. Even when the sites were not covered with ice, generally little or no water could be extracted. In the summer when the processing plants were not running, the fields frequently were under-irrigated for a normal grass crop and the soil was too dry to obtain water samples. Under these conditions, ground water pollution could not be a problem because very little water was passing through the soil. In the surface-irrigated fields water samples could be extracted consistently from the soil during the entire year.

At most of the sampling sites a large number of extracted samples were obtained during two or three years sampling and for this report maximum, minimum, and mean COD are reported at each of six depths from 15 to 150 cm deep in soil (Table 5). At locations 1-F through 5-F the means of COD removal ranged from 95 to 98 percent at the 150 cm depth. The maximum COD remaining at the 150 cm depth ranged from 80 to 98 percent COD removal based on maximum COD concentrations applied to the sites. The minimum COD concentrations reported in Table 5 probably represent normal background, although no data are available for determining normal background COD concentrations.

Nitrogen in Extracted Water Samples

Nitrate-nitrogen in the wastewater was low with the average at all locations and sampling being 1.2 mg/l (Table 6). A few samples were as high as 4.9 to 9 mg N/l. Nitrates in the soil water would correlate more closely with the total nitrogen in the wastewater than with the nitrates in the wastewater because most of the organic nitrogen eventually becomes nitrate through microbiological breakdown of the organic wastes. At two plants, 1-F and 5-F, denitrification probably was an important factor in the

Table 5. Chemical Oxygen Demand (COD) and Kjeldahl-N in water samples extracted from potato processing wastewater treatment fields at five locations for three years.

Treatment Field	Depth in Soil (cm)	Chemical Oxygen Demand (mg/l) max.	min.	mean	Kjeldahl-N (mg/l) max.	min.	mean
1-F	15	400	35	160	10.9	0	4.0
	30	780	25	230	26.5	0.7	10.5
	60	820	20	165	21.8	0.4	4.7
	90	730	25	190	37.1	0	10.1
	120	460	15	155	45.0	0.6	11.2
	150	170	5	70	4.5	0.2	2.0
2-F	15	575	7	74	10.6	0	2.4
	30	485	8	85	15.8	0	4.3
	60	470	5	85	14.0	0	3.7
	90	555	2	120	20.0	0	4.0
	120	425	2	60	2.4	0	0.7
	150	140	1	35	2.0	0	0.6
3-S	15	900	17	124	33.4	2.0	8.5
	30	405	1	120	8.4	0.7	2.4
	60	1180	14	130	4.6	0.7	1.8
	90	1300	12	145	19.2	0.1	4.0
	120	705	10	70	4.3	0	1.3
	150	90	12	40	1.0	0.4	0.7
4-S	15	335	15	70	2.9	0	2.6
	30	235	5	60	3.7	0.1	1.1
	60	100	20	45	1.6	0.7	1.1
	90	110	20	40	2.8	0.1	1.1
	120	70	25	50	–	–	–
	150	145	20	45	1.0	0.3	0.6
5-F	15	200	10	65	4.4	0.4	1.9
	30	585	10	80	4.3	0	1.3
	60	595	10	65	3.0	0	0.8
	90	280	5	50	12.1	0	2.4
	120	170	5	55	19.0	0	1.4
	150	180	4	35	2.6	0	0.7

low nitrate concentrations observed because the water table ranged from 1 to 3 meters below the surface.

At field 5-F, a site was instrumented with platinum electrodes from the surface to 150 cm, and redox potentials were measured. The potentials confirmed that conditions were favorable for denitrification and that denitrification was a major factor in accounting for the low nitrates (7).

At processing plant 2-F the water table is very deep. Redox measurements are now being made and there is some indication that conditions suitable for denitrification occur following some

Table 6. Nitrate-N in potato processing effluent water and water samples extracted from wastewater treatment fields at five locations for three years.

Processing Plant	*Depth in Soil (cm)*	*Nitrate-N (mg/1)*		
		maximum	*minimum*	*mean*
1-F	0[a]	3.6	0	0.6
	15	26.0	0.1	4.6
	30	35.0	0.1	6.4
	60	29.8	0.1	9.0
	90	38.0	0	6.5
	120	12.5	0	2.3
	150	9.0	0	2.0
2-F	0	3.0	0	0.7
	15	33.5	0	4.0
	30	22.5	0	3.9
	60	53.0	0	4.7
	90	19.5	0	3.2
	120	30.0	0	3.1
	150	22.4	0	3.3
3-S	0	4.8	0.1	1.2
	15	110.0	0.2	14.6
	30	59.4	0	17.6
	60	140.0	0	16.9
	90	73.0	0.1	15.6
	120	36.0	0	10.1
	150	17.0	0	7.1
4-S	0	3.6	0	1.0
	15	48.0	0.1	12.8
	30	50.0	0.1	15.8
	60	125.0	3.2	32.7
	90	95.0	1.0	26.0
	120	67.0	18.5	41.4
	150	100.0	6.0	35.3
5-F	0	9.0	0	1.1
	15	25.0	0	2.5
	30	35.0	0	3.3
	60	4.9	0	0.6
	90	2.6	0	1.1
	120	3.4	0	0.8
	150	3.6	0	0.6

[a] The 0 depth water samples are processing wastewater.

irrigations with wastewater during warm weather. The potential for nitrate leaching and for ground water pollution are greater at locations with a deep water table than at locations with shallow water tables because denitrification is greater with a shallow water table. Two water samples at the 120- and 150-cm soil depth had nitrate-nitrogen concentrations of 30 and 22 mg/l. The concentrations of nitrate in the soil water samples were highest in fields 3-S and 4-S. Equipment maintenance shutdown during the early summer at both locations prevented irrigations for maximum growth of grass, and consequently nitrates accumulated to greater concentrations than they might have if the grass had grown all summer.

Kjeldahl nitrogen determined in the water samples extracted from the treatment field soils did not include nitrate-nitrogen. Most Kjeldahl nitrogen concentrations in the soil water were 2 mg N/l or less at the 150-cm depth (Table 5). Kjeldahl nitrogen concentrations in the soil water samples followed the same trends as the COD. Most water samples had COD:N rations of 20:25. These ratios indicate that nitrogen was not a limited factor in decomposition and that the organic wastes should decompose rapidly when the temperature is favorable. The grass crops grown on these fields when irrigated properly in the summer were excellent, with yields of five to ten tons of hay per acre. This hay was high in protein with some samples containing as much as 18 to 20 percent crude protein (total N $\times$ 6.25). Nitrates were generally within acceptable concentrations with most samples below 1800 ppm NO_3N.

Inorganic Constituents

Electrical conductivity, sodium, calcium, and magnesium, were measured in the wastewater, the soil water, and in soil samples. Sample measurements of electrical conductivity in the wastewater and soil water are reported in Table 7. When potatoes are peeled with steam, no sodium hydroxide is used and sodium problems are unlikely from irrigating with the wastewater. Plants 2-F, 4-S, and 5-F used steam peel, and the fields had no previous salinity problems. Plant 3-S used wet lye peeling in 1974 and then was converted to dry lye peeling. When wet lye peeling was used, sodium and salinity in the fields increased. Changing to dry lye peeling should prevent further sodium buildup.

At processing plant 1-F, dry lye peeling was used, with enough of the lye escaping to increase the sodium absorption ratio of the wastewater to values ranging from 3 to 12. The soils that were irrigated with wastewater had a history of salinity problems. Irrigation with wastewater decreased the electrical conductivity markedly (Table 7), and after three years the electrical conductivity of the soil water samples was about the same as the electrical conductivity of the wastewater being applied to the fields. Electrical conductivity in the fields of processing plant 2-F was low at the beginning of wastewater irrigation and increased slightly to equilibrium with the wastewater used for irrigation. These electrical conductivity values are satisfactory for growing most crops and should pose no future problems.

Table 7. Sample electrical conductivity measurements in wastewater and in water extracted from potato processing wastewater disposal fields.

Processing Plant	*Depth in Soil (cm)*	*EC (µmhos/cm)*			
		12/21/72	*10/4/73*	*9/6/74*	*9/15/75*
1-F	0	1215	1040	1260	880
	15	9250	2900	3000	–
	30	8200	2350	1900	1370
	60	7250	4550	–	–
	90	5380	3500	1800	1360
	120	1640	3900	2600	2100
	150	825	1420	2530	–
		4/27/73	*4/5/74*	*12/12/74*	*12/12/75*
2-F	0	1235	1000	1160	1000
	15	790	1000	470	900
	30	970	930	750	935
	60	590	1000	810	890
	90	545	1100	820	1080
	120	510	1060	680	1080
	150	695	1150	710	1000

SUMMARY

Nitrogen, phosphorus, and potassium concentrations in the potato processing wastewater vary widely but, with the amounts of water being applied in these wastewater irrigation systems, provide large amounts of nutrients for crops grown on these fields. In some cases the applications are excessive, and much more efficient use could be made of the nutrients by irrigating larger land areas.

The amount of wastewater applied ranged from approximately 25 to 550 cm per year. With proper land preparation to avoid ponding and with drying periods between irrigations to avoid development of anaerobic conditions in the fields, water for these irrigations infiltrated the fields without waterlogging problems developing.

The organic loading of 10 to 85 tons COD/ha were assimilated by the soils without anaerobiosis developing near the surface, and therefore organic loading is not a limiting factor in operating wastewater treatment and disposal fields like those studied.

With wastewater treatment and disposal fields where a water table lies within 1 to 3 meters of the surface, nitrates are not likely

to be a problem even when 2 to 3 tons of N/ha are applied annually. In fields with a deep water table, nitrogen application may have to be limited to prevent excessive nitrate leaching and possible ground water pollution.

Wastewater from wet lye peel potato processing is not suitable for long term irrigation of agricultural land for growing crops. Wastewater from dry lye peeling systems, which keeps the sodium hydroxide separated from the wastewater effluent, and from steam peel potato processing plants can be used successfully for irrigating cropped agricultural land. Irrigating with wastewater utilizes the water and some of the nutrients that were wasted when the water was discharged into streams and rivers. The research and observations made during several years indicate that wastewater irrigation of cropped agricultural land can be used successfully for a long time to come.

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