pond. The water volume was maintained at 7 L by adding DI water to compensate for evaporation and sampling. When COD lowered to a steady-state concentration, a consecutive run was started by another addition of liquid waste and monitoring continued.

2.3 Plant growth

The compost products, from both the automated composter and the bin composter, were each mixed with a commercial potting soil (Scott) and perlite (BlackGold) at volume ratios of 1:3:0.5 (i.e., about 25% compost) to become amended soils, namely the A-amended soil and B-amended soil, respectively. Three plants of Parlour Palm (*Chamaedorea elegans*) were transplanted into two amended soils and one straight potting soil, and placed under illumination (a T5 high-output light fixture housing four 48-in fluorescent tubes totaling 216 Watts; *Sun blaze*) for observation for two months. The Parlour Palm was selected for its ability to grow into a large plant (2–3 m) and to grow in an indoor laboratory over the winter period of this study. Visual inspections and records were kept by photographing periodically.

2.4 Analysis

Gravimetric solids analyses including total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS), volatile total solids (VTS), volatile dissolved solids (VDS) were measured by use of glass filters to determine solid contents (APHA, 2005). Chemical oxygen demand (COD; HACH), biochemical oxygen demand (BOD; APHA, 2005), and nitrogen contents including total nitrogen (TN), ammonia nitrogen (NH_3-N), nitrate (NO_3-N), nitrite (NO_2-N) were measured using various HACH kits (COD, Cat. No. 21259-15; TN, Cat. No. 2714100; NH_3-N, Cat. No. 26045-45; NO_3-N, Cat. No. 26053-45; NO_2-N, Cat. No. 26083-45) with a spectrophotometer (HACH DR 3800). The pH and DO were measured with a pH meter (Thermo Orion 3 STAR) and a multi-parameter meter (HACH HQ 40d), respectively. Temperature in the pond as well as temperature and humidity at the pile surface were recorded daily. Compost products were analyzed by Utah State University Soil Analytical Laboratory using their Complete Test method.

3. Results and discussion

Fig. 2(a) shows the original olive waste as received with surface impresses made by the container lid. The original waste resembled a wet paste with small solid aggregates (63% moisture content). Analyses of compost characteristics are shown in Table 1. The waste was acidic at pH 5 with high salinity (as shown by conductivity of 21 dS/m) consisting of primarily organic matter (82%). The olive waste was composted in two separate trials, one in a bin composter and another in an automated composter for different durations; it resulted in two composted products that resembled commercially available potting soil, similar in texture among the two but varying in intensities of brown color as shown in Fig. 2(b). The compost characteristics were significantly changed from the original waste. After 48 d, the bin composter produced a product that was more neutral in pH, much reduced in salinity (from 21 to 8.1 dS/m), in sulfate (from 210 to 95 mg/kg), and in organic matter (from 82 to 30%), but with much increased phosphorus (from 40 to 180 mg/kg) and nitrate (from 3.8 to 43 mg/kg). After 11 d, the automated composter produced a product with similar changes of characteristics in the same direction as of the bin composter,

(a) OMW as received

(b) Compost products after 48 days in compost bin at ambient temperature (left) and after 11 days in automated composter at 36-43°C

Fig. 2 Raw olive mill waste pomace and compost products

Table 1 Compost characteristics (Complete Test of USU Soil Laboratory*)

Soil Test	OMW as received	Auto-composter after 11 d	Compost Bin after 48 d
pH	5	5.1	6.4
Salinity (dS/m)	21	12	8.1
P (mg/kg)	40	180	180
K (mg/kg)	900	900	900
NO_3-N (mg/kg)	3.8	19	43
Zn (mg/kg)	7.8	9.8	2.2
Fe (mg/kg)	12	7.5	6.2
Cu (mg/kg)	2.9	5.2	4.4
Mn (mg/kg)	5.4	15	7.9
SO_4-S (mg/kg)	210	140	95
Organic Matter (%)	82	37	30

*pH and EC (salinity) are via saturated paste; P and K via Olsen sodium bicarbonate extraction, analyzed by AA for K and ascorbic acid/ molybdate blue colorimetric for P; NO_3-N extracted by 2N KCl, and analyzed colorimetrically by FIA; Micronutrients Zn, Cu, Fe, and Mn extracted by DTPA, and analyzed by ICP; SO_4-S extracted by $CaHPO_4$ and analyzed by ICP; organic matter by Walkley-Black method although the changes seemed to be more modest. The decrease of organic matter accompanied by increased N and P contents were consistent with aerobic microbial activities in decomposing the organic matter into more basic nitrate and phosphate.

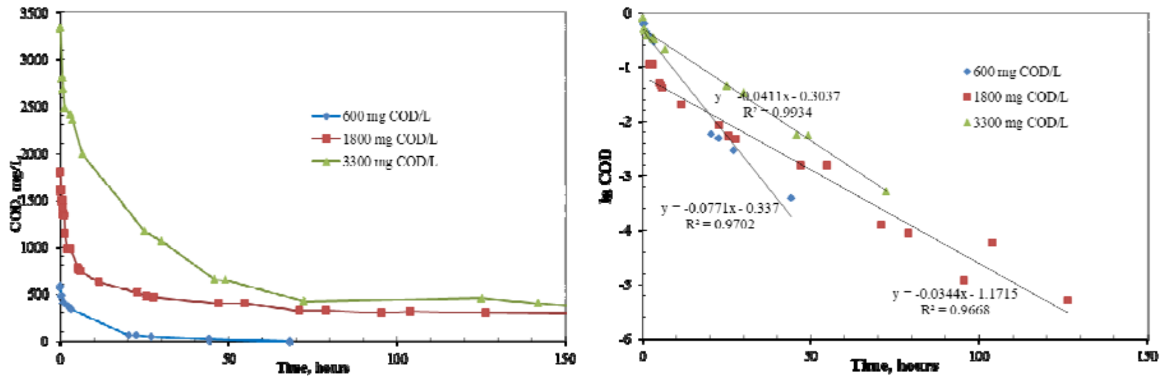
The amended soils were used in transplanting two Palm plants, along with one transplanted with the commercial potting soil without amendment. Fig. 3 shows pictures of the plants at day 0, 15, and 34 days. The plants showed little noticeable differences or signs of distress after one month. It should be noted that prior to this, we have experimented with transplanting of pansies (*V. t. subsp. hortensis*) using potting soil containing 0% (control), 17%, 25%, and 100% of compost obtained after one week of composting in the automated composter; the results indicated withering of plants when transplanted with the 100% compost, some stress (as reduced growth compared to the control) in plants with 17% and 25% compost after 40 d (results/pictures not shown). The results with Palm plants are consistent with other studies using OMW composts for crop cultivation without deleterious effects, but often with positive effects and yields (Cegarra *et al*.

Fig. 3 Parlour plam (*Chamaedorea elegans*) plants at 0 day (left picture), at 15 d (center), and at 34 d (right) after transplanting into control (0% compost), A-amended (25%), and B-amended(25%) soils (volume ratios of compost:potting soil: perlite of 1 : 3 : 0.5)

Table 2 Characteristics of blended slurry of canned olives and of an OMW

	Blended samples	
Parameters	Food olive	Olive mill waste
COD, mg/L	103000	219000
BOD, mg/L	41500	19500
SS, mg/L	465000	645000
VSS, mg/L	409000	631000
TS, mg/L	609000	704000
VTS, mg/L	427000	677000
T-N, mg/L	554	845
NH_4^+-N, mg/L	10	24
NO_2^--N, mg/L	<0.002	<0.002
NO_3^--N, mg/L	33	118
pH	6.4	4.2
Moisture*, %		63
Volatile organics*, %		36

* Pomace as received



(a) COD removal (b) Linear kinetics of loge COD vs. time

Fig. 4 Kinetics of COD removal from artificial olive waste

1996, Tomati *et al*. 1996).

To test the biodegradability of olives and olive mill waste, canned food olives and a sample of OMW were intensely blended into two fine slurries that became the stock slurries for subsequent treatment. The slurries were analyzed with the results shown in Table 2. The slurries were individually subjected to biological treatment in the circulating pond/TF system. Fig. 4(a) shows the COD vs. time profiles from various initial concentrations (600, 1800, and 3000 mg/L) in the pond afterward. The COD, representing the organic content in the water, was nearly completely removed within 2 days (Fig. 4(a)), which indicated a very biodegradable organic content (olive food) in the water. There appeared to be little hindrance to removal of olive constituents in the stock solution.

Using as substrate the blended olive mill waste that represented the comprehensive waste makeup of an OMW, Fig. 5(a) shows the disappearance of COD in the pond/TF system over time. Again, the bulk of COD removal occurred within 2 d, albeit the final steady-state COD level never reached zero or approached close to it. A kinetic model was formulated.

$$\frac{dC}{dt} = -k\left(C - C_{nb}\right) \tag{1}$$

with initial condition

$$C = C_o \quad \text{at} \quad t = 0 \tag{2}$$

where C_o and C represented initial COD and COD (mg/L) at time t (d), respectively, C_{nb} the COD due to non-biodegradable substances in the stock waste solution, and k the first-order rate constant for COD removal (d^{-1}). It should be recognized that the homogenized stock solution contained not only largely biodegradable organics found in olive mill waste but also olive twigs, leaves, pits, and other slowly biodegradable substances (e.g., cellulose) and possibly some biologically inhibitive compounds; thus a fraction factor f was used to distinguish the non-biodegradable fraction (i.e., the slowly degradable or inert plant debris) from the biodegradable, as

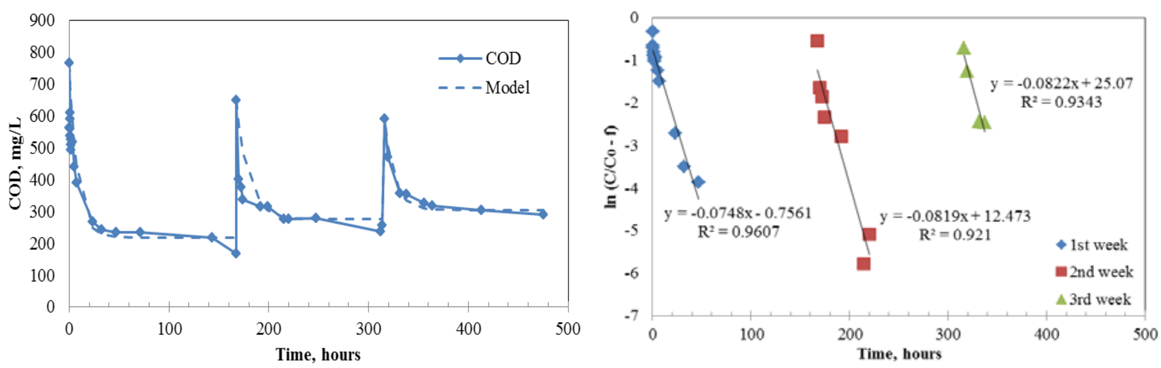
$$C_{nb} = fC_o \tag{3}$$

Integration of the kinetic equation yielded

$$C = C_o\left[f + (1 - f)e^{-kt}\right] \tag{4}$$

This kinetic model and regression analysis were applied to treatment outcomes with the canned olive slurry as well as to California OMW slurry. For the canned olive slurry, the plot of logarithmic COD vs. time, Fig. 4(b), shows strong linearity (R^2 of 0.97 to 0.99), indicating a first-order kinetic profile for COD removal with k to be 0.82 – 1.8 d^{-1}. These k values were much higher than k (0.23 d^{-1} at 20°C) for BOD removal from typical domestic wastewaters. For the blended California OMW, curve-fitting based on nonlinear regression analysis found the mean first-order rate constant k with standard deviation to be 1.9 ± 0.0042 d^{-1}. The fitted concentration-time profiles are shown as dashed curves in Fig. 5(a). The fitted k value was comparable to that of blended olives only. It should be noted that f fractions (non-biodegradable portions) were expected to accumulate in the treatment pond in each subsequent run at which a new dose of olive waste was added. The increasing f fractions are seen as in up-shifting steady-state concentrations as apparent in Fig. 5(a); the f values were fitted to be 0.28, 0.42, and 0.52 for the consecutive runs. Based on mass balance consideration and adjustments for varied doses in the subsequent runs, these accumulated f values were consistent with a readily biodegradable fraction of about 30% in the blended olive mill waste. Despite repeated runs and modestly varied doses, the fitted k values were very close to 1.9 d^{-1} and were significantly faster than typical removal of organics from domestic wastewater.

Table 3 shows BOD, sBOD, COD, and sCOD in the pond water during treatment of the ground slurry. Both sBOD and BOD decreased significantly from 140 and 190 mg/L, respectively, to 29 and 96 mg/L, respectively over one week in the first trial; and they decreased from 54 and 160 mg/L, respectively, to 25 and 47 mg/L, respectively, over 2 weeks in the consecutive, second trial. The COD decreased from 840 mg/L immediately after olive waste addition to 220 mg/L over one week in the first trial and from 1300 mg/L after second addition to 280 mg/L over 2 weeks in the second trial. The sBOD of <30 mg/L after both trials is comparable to typical secondary effluent of treated municipal wastewater being discharged to a receiving water body. However, the



(a) COD removal

(b) First-order kinetic fits, as in Eq. (4), with fitted f values of 0.2842, 0.4237, and 0.5152 during consecutive runs

Fig. 5 COD removal kinetics for blended olive mill waste using the P/TF system

Table 3 Measured COD, sCOD, BOD, and sBOD in the aeration pond during the second and third consecutive runs

Time (hrs)	COD (mg/L)	sCOD (mg/L)	BOD (mg/L)	sBOD (mg/L)	Comments
170	840	--	190	140	Add olive waste
180	390	--	100	52	
200	280	--	79	55	
340	220	190	96	29	
340	1300	270	160	54	Add olive waste
340	560	250	140	85	
360	340	240	87	49	
720	280	260	47	25	

steady-state COD values appeared to have increased from 220 to 280 mg/L, which was due to accumulation of non-biodegradable debris in the pond. Therefore, solids sedimentation would be warranted prior to discharge of the treated water. The results suggested there appeared to be little noticeably strong inhibitive compounds present in the olive mill waste (as the whole waste was ground into slurry before it was introduced into the pond/TF system) that would prevent the proper removal of organic waste before discharge.

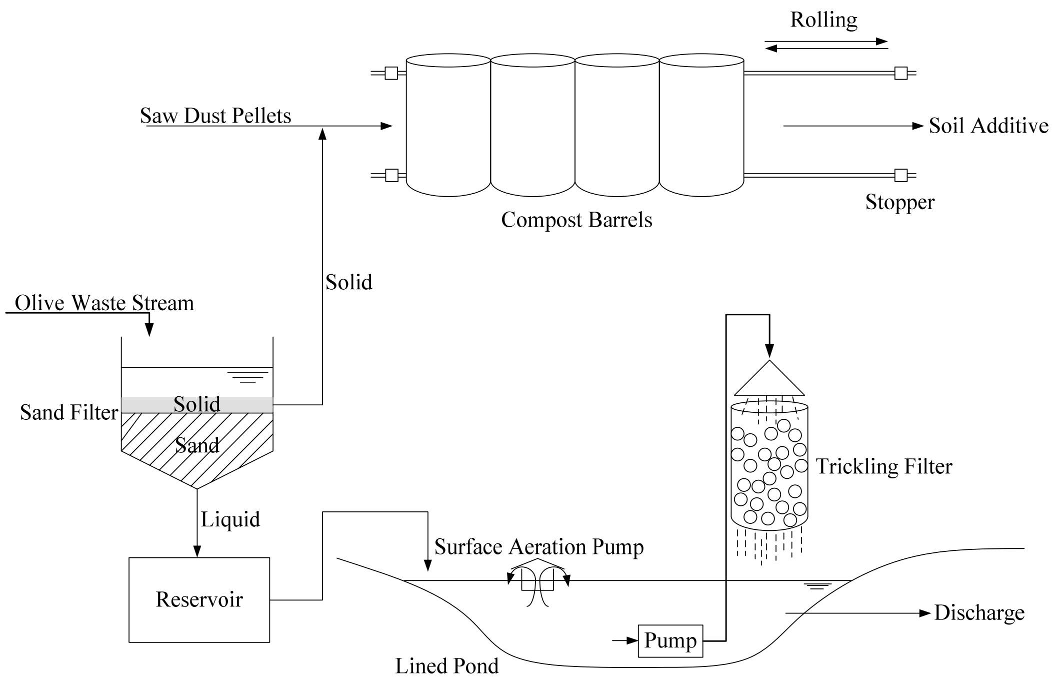


Fig. 6 Onsite treatment design

4. Treatment implementation and conceptual onsite design

To implement treatment of olive mill waste, it is unlikely that a slurry will be ground from the whole mill waste and then fed to the pond/TF system. The liquid and solid wastes need to be processed differently. A two-phase olive oil extraction process produces a wet pomace that is mostly devoid of free liquid and can be most effectively composted into a soil additive. A three-phase olive extraction process increases the yield of olive oil but produces wastes of both liquid and solids. The waste stream should be first separated such as via coarse sand filtration. The solid waste can be composted, and the liquid waste largely free of solids introduced to the P/TF system. The use of a sand filter needs to be tested that may avoid rapid, excessive buildup of solids in the P/TF.

Fig. 6 illustrates an onsite treatment system to process the olive mill waste stream. A rapid sand filter separates the waste stream into a liquid stream that will be introduced into the P/TF system and the solids that will be composted in a series of 55-gal drums. The solids are amended with a carbon source (e.g., saw dust pellets) at olive waste-to-saw dust volume ratio of 5 : 1 (about 2.6 : 1 by weight) and placed in composting drums that are laid side-by-side on two rail tracks. Rolling the train of drums to and from the other end of track for a distance twice of the barrel's circumference would provide mixing of the piles. The treatment of the liquid stream in the P/TF system installed with one or more surface aerators will continue until the designated effluent target (e.g., BOD of 20 mg/L) is reached. Based on determined k of 1.9 d^{-1}, a retention time of 5 days in the treatment pond (that is approximated as a CSTR) will remove over 90% of the organic in the influent liquid waste stream.

5. Conclusions

This study shows that olive mill pomace amended with saw dust pellets was converted in 6 weeks to a soil additive, capable of supporting plant growth even incorporated at a high concentration of 25% in the potting soil. The holistic ground mill waste was treated as a slurry in a circulating pond/TF system with no apparent inhibitive effects on organic removal, but with a rapid first-order degradation rate constant of 1.9 d^{-1}, suggesting strong treatment feasibility. It is anticipated that the treatment of mill waste stream can be carried out at rural sites by separation of the liquid from the solid; the solid is to be composted and the liquid to be treated by a circulating pond and trickling filter system.

Acknowledgements

This work was made possible by an EPA P3 Program grant award, Grant number SU835308. The publication's contents are solely the responsibility of the grantee and do not necessarily represent the official views of the EPA. Further, the EPA does not endorse the purchase of any commercial products or services mentioned in the publication. Further, we thank the project's volunteers James Dansie, Yumiko Sandstrom, Matthew Einarson, Christofer Valenti, Nick Farrenkopf, and Xinyue Zhao for their services in the laboratories. We thank Olea Farm for providing OMW samples for this study.

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