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Mountain dairy wastewater treatment with the use of a 'irregularly shaped' constructed wetland (Aosta Valley, Italy)

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ABSTRACT

In mountain areas, economical activities related to milk processing represent both a key source of income and job opportunities. One of the main characteristics of cheese production is the seasonal variability in the volume of milk processed and wastewater production that tend to limit the capacity of ecosystems to absorb their inputs. In alpine environment, the scarcity of plain surfaces and the climatic conditions results in the need for high CW performances of variable nutrient inputs in different seasons. By evaluating a CW seasonal efficiency for dairy wastewaters in a mountain region (Aosta Valley-NW Italy), this research was aimed to understand how performances of nutrient removal could be affected by seasonal shift in temperature and loadings. Results indicate that the "irregularly shaped" CW, designed to fit the natural landscape, shows best organic removal efficiency in winter (93 and 96% mass removal for BOD_5 in summer and winter respectively), in presence of high organic loadings and low temperatures. Even if nitrate removal is more variable during seasons (71 and 33% mass removal in summer and winter respectively) and differently affected by environmental conditions, overall performance meet the need of high removal efficiency.

1. Introduction

The difficulties of agriculture in mountain areas are conditioned by their intrinsic features: restricted accessibility, fragility, marginality, steep slopes, altitudinal affected temperatures, and specific niches. These specificities generate circumstances that present at the same time limitations and opportunities (Jodha, 2000). For instance, in Vallée d'Aoste Region (VdA) in NW Italy one of these specificities is the production of cheese (Bassanino et al., 2011). Just as a term of comparison in Europe, EU28, the average annual production of cheese is 1 kg per citizen (source Eurostat) while VdA produces over 30 kg (source Fontina Protected Designation of Origin Cheese Association). This confirms that mountainous European areas are the traditional crib of most typical cheeses: pasture and cheese are in fact both linked to the survival of many familiar activities, being a key source of income. Nevertheless, in mountain areas one of the most significant problems is that of milk processing. In the late 90's, the EU issued guidelines for the production of cheese in the mountains in order to: (i) protect consumers by ensuring hygienically perfect products; (ii) improve the level of hygiene of the structures respecting the tradition (iii) safeguard traditional products. In this sense, the guidelines established the minimum structural requirements of local processing and maturation for which they have been granted derogations for plants of small capacity and sewage processing. In order to ensure quality standards and cost effectiveness cheeses are collectively produced in lowland areas where the main problem is the waste management due to the intrinsic seasonal variability in the volume of milk processed and of wastewater produced (Penati et al., 2011). In fact, during summer, the animals remain at high altitudes and the cheese production in the valley is limited. Conversely in winters everything is concentrated in the low valley. In particular, the production of wastewaters, from both livestock and dairy products under mountain conditions typically tend to limit the capacity of ecosystems to absorb their inputs. The situation is complicated by the fact that the elements of landscape also should be used to valorise Protected Designation of Origin special cheeses in their area of production (Vollet et al., 2008).

A solution to treat wastewater produced by cheesemaking factories could come from constructed wetlands (CWs). CWs systems are designed and constructed to utilize the natural

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processes involving plants, filling materials and microbial communities to treat wastewater. CWs filling substrata support the growth of diverse microbial guilds which contribute as catalysts for the removal of organic and inorganic wastewater components (Faulwetter et al., 2009). Therefore, microbial abundance strongly influences treatment performance but may be heavily affected by operating conditions (Akratos and Tsihrintzis, 2007).

CWs are largely used in areas with mild winters, but there is limited understanding about the control of seasonal pattern under cold winter conditions (Albuzio et al., 2009; Comino et al., 2011; Foladori et al., 2012; Kowalik et al., 1998; Sharma et al., 2013; Zust and Schonborn, 2003). Moreover, most literature about CWs is related to systems designed on larger dedicated surfaces, with defined and regular shapes, without any integration with the pre-existing landscape.

This paper is concerned with the seasonal performance of a CW for the treatment of wastewaters from a medium-size cheese-making factory, designed to fit on the existing landscape. The objective was to evaluate the performances of wastewater purification with particular reference to the nitrogen forms and BOD_5 removal.

2. Materials and methods

The sub-surface flow constructed wetland (SSF-CW) is located in NW Italy at 500 m a.s.l., where a mean annual air temperature (MAT) of 12 °C and mean annual total precipitation (MAP) of 430 mm characterize the local climate. It has been built in the summer 2000 to treat the wastewater from a medium-size dairy factory (*Fromagerie de Champagne*), and its design criteria have been adapted to create a system compatible with the landscape, established in a public garden adjacent to the factory (Fig. 1). This SSF-CW was designed to fit the natural landscape; high performance filling substrata were chosen to overcome the scarcity of plain surface and the problems related to cold climatic conditions. The SSF-CW, has been previously studied by Gorra et al. (2007) for the diversity and stability of ammonia-oxidizing communities. It is irregularly shaped and starts with a narrow ditch of 1 m in depth that continues following the topography of the terrain occupying a total surface of 200 m^2. The bottom of the ditch is covered with a plastic film to prevent wastewater from leaching out of the system. The CW is divided into five sections, each one filled with a different material: (1) gravel from metamorphosed limestone, (2) ground ceramic wastes, (3) by-products from magnetite extraction, (4) zeolitite and (5) a horizon of a Dystrict Endoskeletic (Siltic) Cambisol (IUSS WG WRB, 2014) sampled ten meters on the East of the CW, under a permanent meadow. As one of the key issues associated with SSF-CW is its self-clogging (Pozo-Morales et al., 2013), a bed in the first sector was filled with sharp stones of decreasing size. The SSF-CW had been originally planted with *Pragmites australis* (Cav.) Trin. ex Steud (Table 1,Fig. 2); Within sectors 3 and 4 reeds were originally intercalated with *Typha latifolia* L. and *Scirpus lacustris* L., and after three years they were completely substituted by the predominant *Phragmites*.

The treatment system starts physically where wastewaters are collected in a settling tank within the plant. From there they are pumped into the SSF-CW where the five sections are connected to each other by a system of pipes. The natural slope of approximately 3–5% facilitates the flow of the wastewater from the tank through the sections by a horizontal sub-surface flow. After the treatment the effluent, depending on treatment efficiency, can be used directly in agriculture or pumped again to the wastewater tank. The wastewater enters the CW at intervals with daily volumes of 9–13 m^3. Two flow-meters monitor hourly the influent and effluent from the system. The daily mean temperature of the substrata is monitored by data loggers UTL-1 (Geotest, Zollikofen CH) buried at 10 cm depth in two sections of the CW (section 3 and 5, Fig. 2).

Wastewaters entering the system and the final effluents were sampled twice-monthly for a 3-year period and analysed for pH (pH meter Crison Instruments), Biochemical Oxygen Demand (BOD_5) (APHA, 1992), Total Kjeldahl Nitrogen (TKN) (APHA, 1992). Ammonium nitrogen ($N—NH_4^+$) was measured colorimetrically

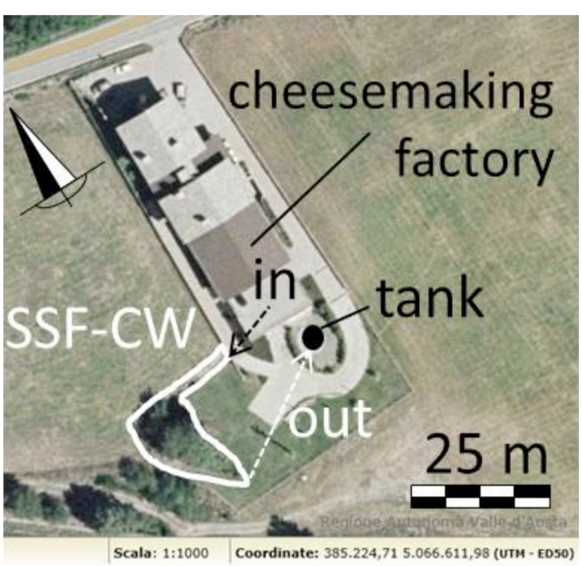

Fig. 1. Sub-surface flow-constructed wetland (SSF-CW) by the *Fromagerie de Champagne* that produces Fontina cheese and butter. Fontina Vallée d'Aoste is made from unpasteurised milk from a single milking, with two batches per day. In the whole region the Fontina producers are around 400 to market 3500 tons of cheese per year. The "*Champagne Società Cooperativa*" processes about 8 ± 4 m^3 of milk produced by small less than hundred farms. A settling tank is located at the bottom of the factory by the CW inlet pipe; the entire flux within the SSF-CW sectors occurs by gravity. The outlet pipe runs into the tank.

Table 1
Sub-surface flow-constructed wetland (SSF-CW) by the *Fromagerie de Champagne*.

		Champagne 45°44′30.86″N 7°31′32.92″E
	m a.s.l.	534
Pre-treatment		ST[b]
Pump station	kW	no
Flow system		SSF[a]-V1 SSF[a]-V2 SSF[a]-V3 SSF[a]-V4 SSF[a]-V5 tank
Tank	m^3	45
Total area	m^2	500
Pool (total operative surface)	m^2	200
Inflow	m^3 d^{-1}	9
Load (BOD_5)	mg L^{-1}	≈800
HRT[e]	d	8
HLR[f]	m^3 m^{-2} d^{-1}	44
Vegetation		(TYL, SCL), PHA[c]
Investment (total costs)	EUR m^{-2}	67[d]

[a] SSF sub-surface flow.
[b] ST settling tank.
[c] PHA *Phragmites australis* (Cav.) Trin. ex Steud., TYL *Typha latifolia* L., SCL *Scirpus lacustris* L.
[d] Inflation adjustment, cost actualised at year 2014.
[e] HRT (hydraulic retention time) calculated according to Kowalik et al. (1998) where V = capillary capacity equal to active volume in m^3 and Q = mean average flow rate per day of wastewater through the system m^3 d^{-1}). For the volumes calculation an average 20% porosity was assumed.
[f] HLR (hydraulic loading rate) calculated according to the Kadlec and Knight (1996) equation.