Nutrient management in effluents derived from agricultural industries: an Australian perspective

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Abstract

The effluents derived from agricultural industries are major sources of wastewater with significant amounts of nutrients and organic load. Australia's agricultural industries have experienced rapid growth in recent years, with nearly 152 abattoirs, 1798 wine industries, 9256 dairy farms and 1835 piggeries in operation. Agricultural industries require huge volumes of water for processing the farm products towards commercial value and quality. For instance, around 200 L of water required for processing a cattle in an abattoir; around 2.4-2.5 L for producing 1 L of wine; 500-800 L for 1 L of milk; and 12-45 L for sow and litter management in piggeries. As a result, these industries generate huge volumes of wastewater. For example, Australian meat industries produce an average of 4000 m^3/day wastewater, with high concentration of nitrogen (N) and phosphorus (P). The annual average N and P loads in some of the farm effluents are: abattoir – 722 and 722 t; winery – 280 and 280 t; dairy – 150000 and 110000 t; and piggery – 72895 and 5075t. With Australia's average fertiliser consumption being 1 Mt N and 0.5 Mt P, the huge amounts of N and P from the agricultural effluents can be re-used as a potential alternative for fertiliser usage. Sustainable management of nutrients in the wastewater irrigated soil is a critical step to prevent contamination of both surface and ground-water. The available technologies for wastewater treatment require high investment. Hence, using high biomass-producing plants (e.g., *Pennisetum purpureum* and *Arundo donax*) as remediators, which also has the potential to uptake high amount of nutrients and heavy metals, can serve as a cost effective technology. Consequently, the

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plants used not only act as remediators, but also provide biomass that can also be used for energy generation, paper production and as a feed for animals.
Keywords: agricultural industries, wastewater, nutrients, low-cost technology, sustainable, phytoremediation, biomass and bioenergy.

1 Introduction

Water is the most precious resource that exists naturally on the planet earth; yet, global fresh water is only less than 3%, and growing population density has been increasing the pressure on global fresh water resources. More importantly, freshwater quality and quantity are significantly impacted on by the industrialization, modernization, over exploitation, and poor resource management practices. Agriculture, households and industries are the three sectors which consume the majority of water, and consequently generate large volumes of wastewater [1]. For example, Australian domestic wastewater alone produces 70,000 L/person/year, a total of 1400 GL/year [2].

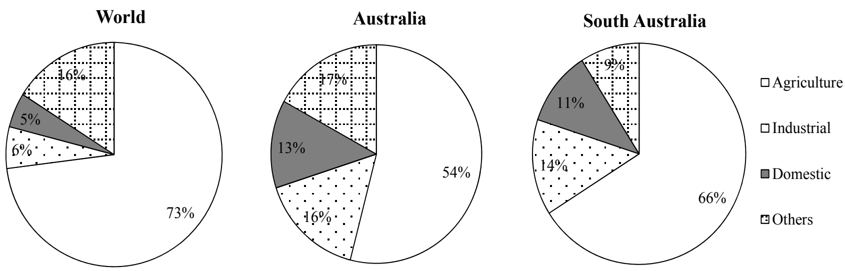

Figure 1: Percentage water consumption by various sectors [3, 13].

Agriculture and allied industries are the largest water consumers and generate similar amount of wastewater. In Australia, the major water consumers in agricultural sector includes abattoirs, wineries, dairy farms and piggeries, with a considerable portion being used by processing industries, where food safety and hygiene are essential [3]. Agricultural industries act as a major source of industrial wastewater, where the meat industry alone generates an average of 5038 kL/day [4]. Like many other developed and developing countries, wastewater is a challenging issue in Australia. Australia's agricultural industries have experienced rapid growth in recent years, with nearly 152 abattoirs, 1798 wine industries, 9256 dairy farms and 1835 piggeries in operation. The rapid growth of Australian abattoirs has been paralleled by the number of animal slaughtered. During 2001-02, the total number of animals slaughtered were 9 million; the rate of slaughtering continues to increase in 2011-12; set to increase up to 38 million by 2013 [5]. Similarly, Australian wine production has increased from 500 ML to 1470 ML from1995 to 2004 [6]. Australia's milk production peaked in the recent years at 10130 ML from more than 2.01 million cows [7].

The ever increasing number and volume of effluents discharged (Figure 2) leads to a range of environmental issues in Australia such as water pollution, soil degradation, accumulation of toxic metals in plants and animals. For instance, the production of meat, milk and wine results in the generation of wastewater with a significant amount of pollutants, nutrients and pathogens. Moreover, these agricultural industries are also responsible for global warming and climate change. To overcome the above problems caused by the agricultural industries, sustainable alternative methods are needed which will not only reduce the pressure on global fresh water resources, but will also help in meeting the demands of water for households, industries, agriculture, and environment.

Figure 2: Number of agricultural industries in Australia.

2 Water use in agricultural industries and wastewater generation

The Agricultural industries consume water for processing to the level of commercial requirements; abattoirs need huge quantity of water for processing meats (cooling, cleaning and rinsing), operating utilities (boilers, cooling towers and pumps) and for ancillary uses such as toilets and washing facilities, thereby discharging large quantity of wastewater [8]. A typical abattoir uses about 15000 litres mainly to clean the floors and walls of the slaughter house [9]. On an average, 200 L of water is required for processing a cattle in abattoirs [10]. A three year study by Meat Livestock Australia (2010) found that 10 kL/tHSCW of clean water is consumed and equally discharged in a meat processing industry.

Among the agricultural industries, dairy farming is one of the major sectors in Australia. Dairy farming is the second largest water consumer after irrigated agriculture [7]. Nearly 500–800 L of water is required for producing 1 L of milk; the dairy industry needs 1 ML of irrigation water to produce 2000 L of milk [7]. National milk production intensity increased from 2750 L (1980) to 5163L (2006) per cow per annum [7, 11]. The increased milk production is being achieved by an increased amount of inputs (fertiliser, feed or nutrient rich concentrated feed and water) resulting in high nutrient loads in wastewater, which poses serious threats to water, soil and air [11].

In piggeries, a huge volume of water is required to manage pigs in a healthy and hygienic condition. Nearly, 12–45 L of water is used for a boar/sow and litter management in piggeries [9]. Water used for drinking, cleaning and cooling is the major contributor of wastewater from a piggery unit. A piggery needs an average of 8 L water/standard pig unit (SPU)/day [9]. Similarly, drinking water spills in piggery are also high at about 10–50%. In Australia, piggeries use an average of 251.4 ML of water per year [9].

Water requirement for producing one litre of wine is about 960 L (2.4–2.5 L/L of wine; excluding viticulture) [13] and around 2500 L of fresh water is required to process one tonne of grapes in winery [6]. Wastewater generation (%) by various processes of agricultural industries are shown in Figure 3.

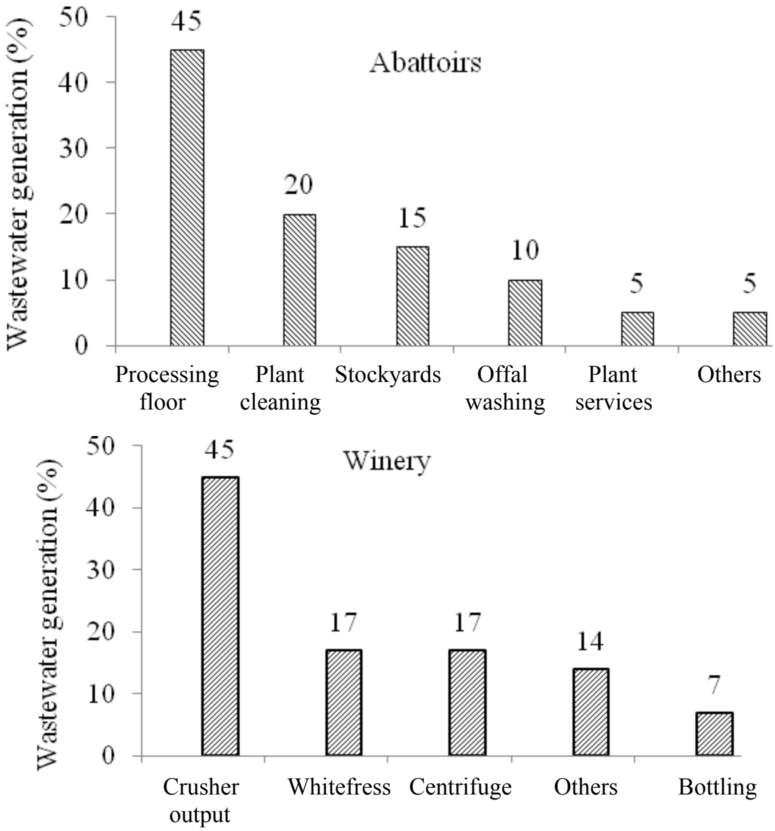

Figure 3: Wastewater generation (%) by various processes of agricultural industries (MLA [4], Kumar *et al*. [6], Gourley *et al*. [11] and APL [9]).

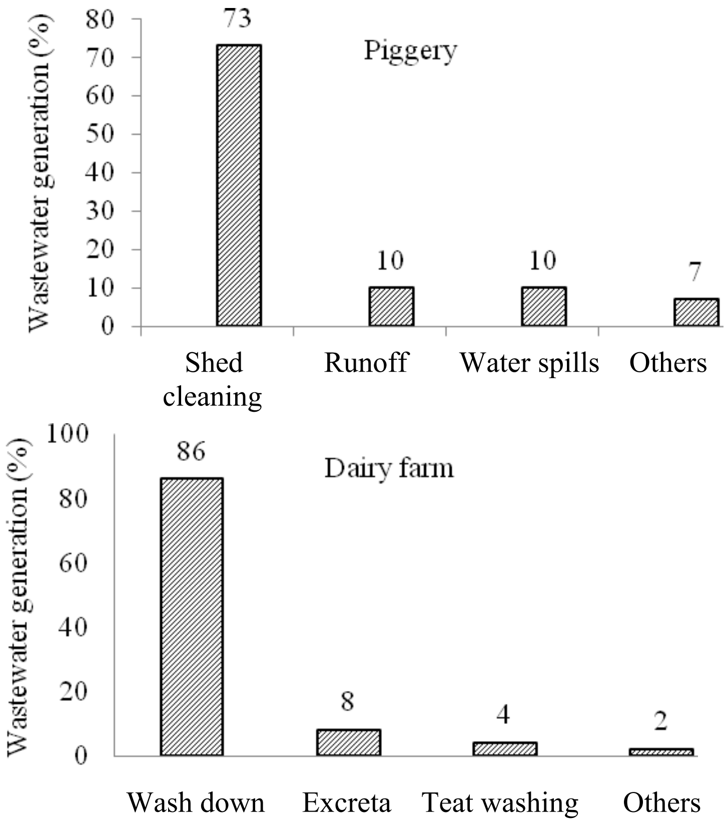

Figure 3: Continued.

3 The nature of agricultural industries wastewater

Abattoir wastewater is a rich source of nutrients; even after primary treatments, resulting in high cost for further treatment and disposal [14]. Abattoir wastewater derives organic loads from different sources. Animal manure contributes significant amount of pollutants to the abattoir effluent containing N, P, and organic carbon [4]. In comparison with other wastewater sources, abattoir wastewater stream possess the highest concentration of organic load, with increased COD (8000 mg/L), proteins (70%) and suspended solids (15–30 mg/L) [15].

Piggery effluent contains 158-1025 mg/L of N; 11-123 mg/L of P; 97–1845 mg/L of K and 103–-2870 mg/L of Na with other beneficial micro nutrients [9, 16]. According to the APL-AMIC –projects report, water usage, feed grain supply and managing nutrients in the piggery effluents are the major environmental challenges faced by Australian piggeries [9]. Piggery effluents and by-products can be used as valuable alternatives for fertiliser for agricultural production [9]. Wastewater discharged from wineries is rich in nutrients; it contains 1–128 mg of N/L; 1–33 mg of P/L; 19–1250 mg of K/L and 18–880 mg of Na/L [16]. Organic load or waste load in the winery wastewater increases the nutrient content (sodium and potassium) and BOD of the wastewater. This leads to salinity and sodicity [6]. Dairy farm generates large volume wastewater with rich in nutrients especially N and P [7]. Dairy farm wastewater comprises of urine, faeces, chemicals from cleaning, and solid waste (cow dung). This contributes 15–200 mg of N/L; 11–160 mg of P/L; 11–160 mg of K/L [17]. Typical characteristics and nutritional composition of different agricultural industries wastewater is shown in Table-1.

Table 1: Characteristics of agricultural industries wastewater.

Constituents	Abattoirs	Piggery	Dairy effluent	Winery
pH	7.3	7.5–8	5.6–8	4–10
TDS (mg/L)	3500	3100–8600	138–8500	500–2200
BOD_5(mg/L)	1300–7500	40	320–1750	
COD (mg/L)	100–250		1120–3360	
N (mg/L)	100–150	854	15–200	1–128
P (mg/L)	100–400	109	11–160	1–33
K (mg/L)	100–400	97–1845	11–160	19–1250
Na (mg/L)	20–150	623	60–807	18–880
Oil and grease (mg/L)	100–1000		68–240	
References	Johns [23], Husband [24]	EPA-SA [16], APL [9]	Marmiroli *et al*. [17], EPA-SA [16]	EPA-SA [16]

4 Wastewater treatments

Effective wastewater treatment methods should remove the pollutants, nutrients, organic load, fat, oil grease, blood and pathogens from the wastewater to ensure the low level of toxicants in the final discharge effluent [4,15]. Pre-treatment methods such as screening and sedimentation helps to reduce 60% of solids and 25-35% of BOD load from wastewater [18]. A two stage system of wastewater treatment is most widely followed to treat and reuse abattoir wastewater for irrigating crops [14]. The primary or first stage of treatment removes the floating materials and large objects, while the next stage helps to reduce the settling solids and reduces the organic matter content and stabilise through biological treatment [10].

A typical abattoir wastewater treatment plant should have three kinds of storage system or pond to reuse the treated wastewater into irrigating agricultural crops, the first one is anaerobic pond, followed by aerobic/facultative ponds then a polishing/irrigation pond [10, 16]. Each wastewater treatment technique is evaluated in the form of its merits and demerits by economic feasibility, technical availability, and socio–environmental acceptability. Anaerobic treatment is the most efficient method to treat abattoir wastewater; with high organic load, this method can give the efficiency of 97, 95 and 96% of removal of BOD, SS and COD, respectively [19]. Anaerobic sequencing batch reactor (ASBR) is effective against the reduction of COD, and it reduces total COD by 90–96% and soluble COD by 95% [19]. Aerobic treatments involve in the disintegration and decomposition of organic material with the help of microbes and presence of oxygen. To reduce the odours and pathogens, aerobic treatment methods are most suitable [19]. The selected treatment techniques and their efficacy (%) listed in the Table. 2.

Table 2: Removal efficiency (%) of selected treatment techniques.

Treatment methods	N	P	BOD	COD	TSS	References
Chemical, DAF	35		35	58	48	Massé and Massé [18], Johns [23]
Fluidised bed AFB	70		90	85		Li *et al.* [14]
Activated sludge	90		99	96		Massé and Massé [18]
FBBR	20–73		71–93		62–73	Li *et al.* [14]
Granulated sludge	86	74			62–73	Yilmaz [20]
Sequencing batch reactor	95	95	95	92		Massé and Massé [18], Mittal [19]
Integrated film reactor	67			93		Del Pozo and Diez [21]
Constructed wetlands	10–88	11–94	51–95	87.4	89	Rivera *et al.* [26]

Nutrient removal is an important treatment process in slaughter house wastewater treatment and is the final or tertiary stage treatment. Nutrients such as N and P are introduced to the receiving area if industries fail to adopt nutrients removal before discharge into sites. Advanced treatment processes (Granulated sludge, sequencing batch reactors, integrated aerobic-anaerobic film reactor, Aerobic-anaerobic stabilisation pond. Advanced treatment methods help to reduce the concentration of nutrients in the effluent, most essentially N and P.

Sequencing Batch Reactor (SBR) removes 95, 60–80 and 40% of COD, TN and TP, respectively [15]. The continuous process of nitrification and denitrification (SND) employed in SBRs can minimise N load in the abattoir wastewater [20]. Activated sludge process by bacterial biomass is also a method of N removal from wastewater during anaerobic removal process of BOD. However, it is not an effective N removal technology for nitrate rich source of wastewater due to less than 20–30% of removal efficiency [20, 21]. Hence, an integrated method of nutrients management in abattoir wastewater is the best approach, where the combination of aerobic and anaerobic processes is important in a biological treatment process. Del Pozo and Diez [21] found 93% and 67% of organic load N removal efficiency, respectively by an integrated aerobic-anaerobic film reactor. Increased level of wastewater generation requires highly efficient and cost effective methods for the continuous removal of N and P [20]. Nitrogen from wastewater can be removed by ammonia stripping, which is relatively a high cost technology to reduce N-concentration in wastewater.

The above mentioned approaches are generally expensive to operate in terms of initial establishment and maintenance. The use of plants to remove excess nutrients and also to produce biomass will be a cost-efficient approach to utilise the wastewater resources. For example, the nutrients in the wastewater can be utilised by plants. However it purely depends on types of soil and plants species used.

Land disposal of waste and wastewater is most common practice of waste disposal by Australian piggeries. Majority of the piggeries (78%) have the wastewater treatment pond. Among these 83% has multiple pond system to treat the effluents [12]. High biomass yielding plant species such as sorghum and maize silage can suitable crops for land treatment of wastewater because of its ability to remove significant amount of nutrients [9].

Dairy farm wastewater is commonly treated with two stage pond systems – aerobic and anaerobic ponds, which are effective only for removing organic load (BOD) and sediments but not effective for N and P removal [22]. The land treatment of dairy effluent with high nutrient uptake or biomass producing plant is most suitable method of managing wastewater and the biomass produced from these plants (i.e., *Salix kinuyanagi*) can be used as a feed for animals [17].

5 Phytoremediation/low - cost technology

Agricultural industries require an additional capital to treat and discharge of effluent. This will be a major limiting factor for the small and medium scale industries. Phytoremediation of contaminated soil irrigated with effluent from agriculture industries by high biomass producing plant species is a cost effective techniques to reduce the risk of nutrients and bioorganic compounds reaching aquatic environment [17]. It is most essential that industries need to adopt various best practices/low cost technologies to reduce their water use and cost. Irrigation of wastewater is a potential low-cost approach of wastewater management and can act as a good source of nutrients for infertile soils [25, 26]. Australia, with several meat based industries need to manage the animal wastes and effluents using low cost technologies [4, 12]. The amount of organic load, N and P, and organic carbon concentration can be reduced by prior collection of manure before wash down, which will reduce effluent loading with high concentration of pollutants [25]. Abattoir wastewater is a richest source of N and P; hence it can be treated as an alternative source of nutrients provider for low fertile soils [26]. Using high biomass-producing plants (e.g. *Pennisetum purpureum* and *Arundo donax*) as remediators, which also has the potential to uptake high amount of nutrients and heavy metals, can serve as a cost effective technology. The brief details about nutrient uptake and biomass yielding capacity of selected plant species are listed in the Table 3.

Table 3: List of high yielding, high nutrient up-take plans species [9, 25].

Crops	Biomass yield Mg/ha	Nutrient uptake kg/ha		
		N	P	K
Napier	10–40	150	30–70	375–450
Giant reed	45	528	22	664
Sunflower	10	200	35	450
Lucerne	25	150–450	15–45	554
Maize silage	10–25	220–550	30–75	200–500
Fodder sorghum	15	200–400	35–75	332
Cereal	2–6	59–239	9–20	–
Dryland pasture	1–4	20–80	3–12	15–60
Irrigated pasture	8–20	16–400	24–60	120–300
Grain sorghum	2–8	40–160	6–24	–
Cotton	2–5	40–100	8–20	16–40
Chick pea	0.5–2	20–80	2–8	2–8
Cow pea	0.5–2	15–60	2–8	10–40

6 Conclusion

Wastewater reuse after removing the pollutants, nutrients and pathogens is an important component in the sustainable management of water resources and ensuring water security. Phytoremediation of abattoir wastewater treated soils can emerge as a sustainable measure towards water resources management. Phytoremediation is energy efficient, aesthetically pleasing method of remediating sites with low to moderate levels of contamination and it can be used in combination with other more traditional methods such as multiple ponds, wetlands. The remediation of wastewater irrigated soil using specific plant species such as *Pennisetum purpureum* and *Arundo donax* as remediators, which also has the potential to uptake high amount of nutrients and heavy metals, can serve as a cost effective technology. Consequently, the plants used not only act as remediators, but also provide biomass that can also be used for energy generation, paper production and as a feed for animals.

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