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Effect of Dairy Pond Sludge/Supernatant Application on Ryegrass Dry Matter Yield and Phosphorus Fractions in Soil

Dharmappa Hagare [1,*], Woo Taek Hong [1], Zuhaib Siddiqui [1], Sai Kiran Natarajan [2] and Julian Fyfe [3]

[1] School of Computing Engineering and Mathematics, Western Sydney University, Penrith, NSW 2751, Australia; wt.hong76@gmail.com (W.T.H.), z.siddiqui@westernsydney.edu.au (Z.S.)
[2] Liverpool City Council, Liverpool, NSW 2170, Australia, natarajans@liverpool.nsw.gov.au
[3] Wellington Water, Petone, Lower Hutt 5012, New Zealand, julianfyfe@gmail.com
* Correspondence: d.hagare@westernsydney.edu.au

Abstract: Pasture yield in dairy grazing systems is critical to supplying sufficient feed for milking cows and maintaining productivity. In the Australian dairy industry, ryegrass and clover are common grasses used in grazed pastures. Dairy shed effluent (DSE), the wastewater produced from washing down the dairy holding yards during and after milking, is generally managed through application to pasture as a fertilizer substitute/supplement following partial treatment in stabilization ponds. The aim of this study is to assess the benefits of applying sludge and supernatant collected from two-stage DSE pond systems to ryegrass pasture. A pot experiment was conducted which involved applying pond sludges and supernatant to soil seeded with ryegrass. The application rates of the pond by-products were set according to their labile (plant available) phosphorus content. Ryegrass yield and leachate generated from each of the pots were recorded, and samples were collected for analysis of nutrients and other parameters. The ryegrass grown in soil treated with pond sludge and supernatant yielded greater dry matter (DM) with higher nutrient content than untreated control pots. In addition, pots treated with pond sludge exhibited lower rates of phosphorus leaching from the soil compared with pots treated with supernatant. Thus, pond sludge retained more plant available phosphorus in soil than both the control and pond supernatant treatment. The potassium to calcium/magnesium ratios in the ryegrass in the pots treated with pond sludge and supernatant were below the recommended upper limit for grazing. Therefore, the application of pond sludges on the dairy paddocks was found to be superior to applying supernatant in terms of utilization and conservation of phosphorus within the dairy farm and presents low risks of groundwater pollution and grass tetany.

Keywords: dairy shed effluent; sludge; supernatant; plant available phosphorus; pasture yield; leachate phosphorus

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1. Introduction

In 2019–2020, it was estimated that there were about 5055 dairy farms in Australia with an average herd size of 279 [1]. Many Australian dairy farms use two-stage stabilization pond systems to hold and treat dairy shed effluent (DSE) prior to recycling back to the dairy and/or land application. These ponds accumulate nutrients in the sediments at the bottom of the pond, otherwise known as pond sludge. As the volume of sludge relative to supernatant grows, the water quality of treated pond effluent becomes compromised, which leads to problems with effluent pumping and recycling [2]. Pond systems are designed to enable sustainable management of nutrients, especially phosphorus (P), through the application of supernatant and sludge to grazing paddocks [3,4]. Land application of pond supernatant via irrigation is a routine seasonal activity that also helps to manage pond water levels and avoid overflows. Removal and land application of pond sludge is performed on a cycle of several years, the length of which depends on the loading and capacity of the pond system. It requires expensive machinery (vacuum tankers, agitators) and is logistically more challenging, but is essential to pond function in terms of maintaining treatment efficiency, avoiding surface crusting, enhancing storage volume and minimizing the risk of overflows.

Australian dairy farms typically sow pastures containing Italian, annual and perennial ryegrasses, and white and red clovers as they are well suited to Australian conditions and provide a nutritious diet for milking cows [5,6]. Other grasses, such as lucerne and tall fescue, might also be used to improve the productivity of dairy pastures and increase milk production. The combination of ryegrass and clover with plants such as plantain has also been reviewed [7]. McDowell and Cosgrove [8] conducted P studies with ten different plants/grasses and reported that white clover showed low P loss from a shoot and had high dry matter (DM) yield. However, it was noted that different environmental conditions could produce different results. Broughman (1959) cited in [9] found the DM yield varied with weather conditions in ryegrass and white clover combinations with white clover and Italian ryegrass known to have higher uptakes of nitrogen (N) and P than tall fescue.

Land application of organic manure, such as raw manure and compost, is known to increase the DM yield of plants [1,10–13] and improve the soil environment [14]. Waldrip et al. [13] compared the effects of conventional and organic dairy manures with N fertiliser and noted no significant difference in growth of sorghum sudan grass with N-based applications. Waldrip et al. [12] also demonstrated that poultry manure application increased soil plant available P (labile P) and in turn, this increased the utility of P for perennial ryegrass. Dougherty and Chan [11] reported that soil physical properties improved by land application of compost. Coad et al. [15] reported that maintaining the optimum agronomical P level reduced supplementary P and P loss, while Espana et al. [16] found that an overdose of pig manure application may negatively affect the growth of perennial ryegrass (*Lolium perenne*) due to the P toxicity. Earlier studies confirm that the land application of DSE pond sludge and supernatant increases plant productivity [17–19]. Cameron et al. [19] researched different application methods of DSE pond sludge and found that both injection and surface application were less likely to contaminate groundwater due to N loss.

This study aimed to determine the effects of DSE pond sludge and supernatant application on soil properties and grass yield. In particular, the focus was on assessing the impacts on P fractions in the soil, plant material and leachate, which have not been fully investigated in the literature that is currently available. The approach adopted for the study was a pot experiment using soil, sludge and supernatant samples collected from a working dairy farm.

2. Materials and Methods

2.1. Experimental Setup

The pot experiment was installed at Werrington South campus of Western Sydney University. Figure 1 shows the pot arrangement and design. The soil used in the pot experiment was taken from a unfertilized paddock within a working dairy farm in the Southern Highland dairy region, New South Wales, Australia (Figure 2). This paddock, located adjacent to the dairy shed, had no organic or commercial fertilizer applied as explained in [20]. The soil was air dried and sieved using 2 mm screen before being packed into the pots at a density of 1130–1140 kg/m^3. The total volume of soil placed in each pot was 3.5 L.

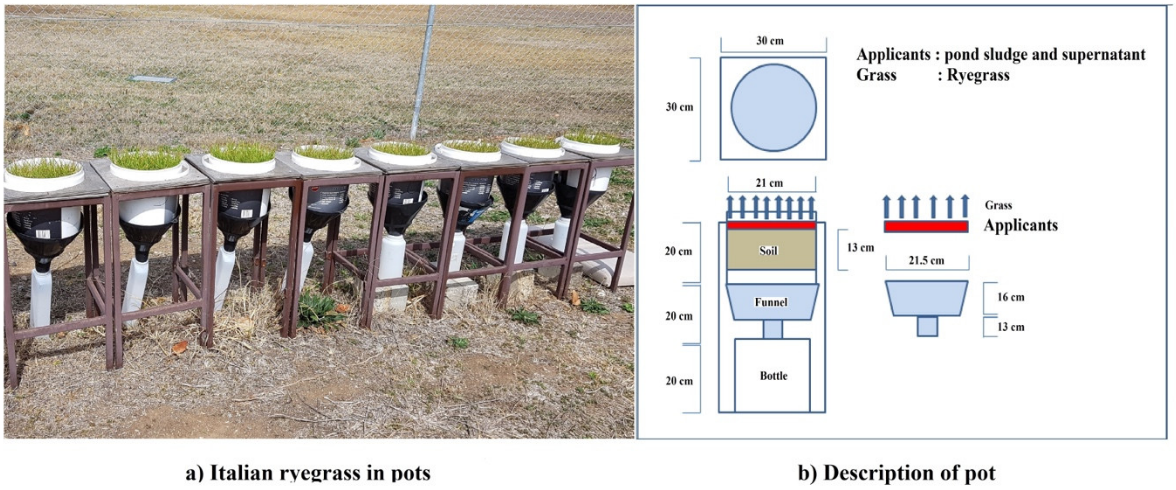

Figure 1. Italian ryegrass in pot experimental set up at Werrington South campus, Western Sydney University.

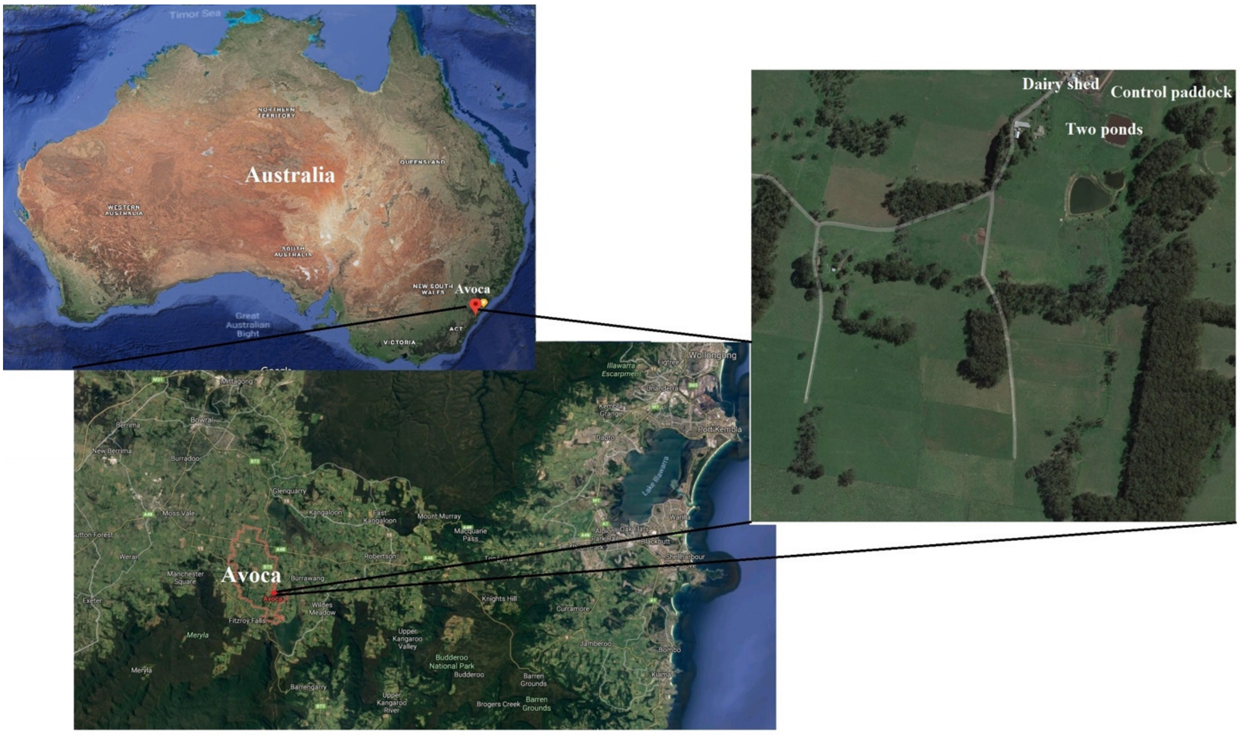

Figure 2. Study area showing the location of soil collection from a unfertilized paddock and two ponds.

A HACH 2194300 sludge judge sampling kit [20] was used to collect primary anaerobic pond sludge (PP_{sludge}) and secondary facultative pond sludge (SP_{sludge}) from the locations shown in Figure 3. Secondary pond supernatant ($SP_{supernatant}$) was collected from secondary pond from each corner about 20 cm below the surface. Each sample was thoroughly mixed before being decanted into 1 L sampling containers for transport to the Western Sydney University Environmental Engineering laboratory. In the laboratory, samples were mixed using a homogenizer in preparation for nutrient analysis. Figure 4 shows the pictures of primary and secondary ponds. Relative location of the two ponds is shown in Figure 2.

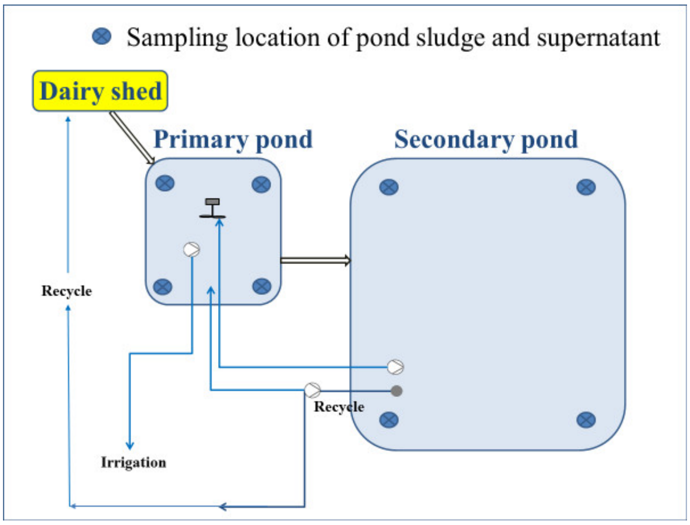

Figure 3. Pond sludge and supernatant collection points.

(a) Primary pond (b) Secondary pond

Figure 4. Pond system at the dairy farm.

2.2. Soil, Sludge and Supernatant Characteristics

Quantitative analysis of TP and total cations of soil and pond sludge were carried out with 0.5 g of dried and sieved pond sludge and soil samples using reverse aqua-regia digestion method followed by ICP-OES analysis. Detailed analysis procedures including P fractionation are given in [20,21].

The chemical properties of the soil are summarized in Table 1. The texture of the soil used for the experiment was sandy loam (76% of sand and 13% of clay). Soil $pH_{1:5}$ was near neutral at 6.6 (6.25–6.85) and $EC_{1:5}$ was 63 µS/cm. Among soil P fractions, NaOH-P was the highest [21]. Organic phosphorus (OP) was mostly present as $NaHCO_3$-P and NaOH-P. Labile P, the summation of H_2O-P and $NaHCO_3$-P, is classified as P available for plant uptake [20] and made up 49% of total soil P. The soil is rich with cationic nutrients such as, K, Ca and Mg. On the other hand, Na concentration is low which is good for the plant growth.

Table 1. Characteristics of soil used for pot studies.

Parameter	Units	Values
$pH_{1:5}$		6.6
$EC_{1:5}$	µS/cm	63
K	mg/kg	2475
Na	mg/kg	280
Mg	mg/kg	1469
Ca	mg/kg	6369
TN	mg/kg	3979
TP	mg/kg	502
H_2O-P	mg/kg	11
H_2O-P_i	mg/kg	6
$NaHCO_3$-P	mg/kg	235
$NaHCO_3$-P_i	mg/kg	27
NaOH-P	mg/kg	339
NaOH-P_i	mg/kg	34
HCl-P	mg/kg	4

Note: P_i indicates inorganic portion of phosphorus. P includes both organic and inorganic portions.

Table 2 presents the nutrient concentrations in the pond by-products. Comparing TP and TN between secondary and primary pond sludges, it can be said that TP in SP_{sludge} is significantly higher than PP_{sludge}, this may be attributed to the higher solids concentration in SP_{sludge} and TP mostly in particulate form. On the other hand, TN for SP_{sludge} is much lower presumably due to mineralization of organic N through anaerobic digestion, and volatilization and nitrification-denitrification of ammonia-N. The concentration of Labile P in both the PP_{sludge} and the SP_{sludge} accounted for 44% of total P, which accords with previous analyses [20]. In total, 16% $SP_{supernatant}$ P was in dissolved inorganic (plant available) form.

Table 2. Pond by-product nitrogen and phosphorus content.

Parameter	Units	$SP_{supernatant}$	SP_{sludge}	PP_{sludge}	Tap Water
Solids	%	0.5	57	14	0
TN	mg/L	387	627	3243	0.15
TP	mg/L	97	4302	972	0.08
Labile P[a]	mg/L	NA	1908	442	NA
Soluble P[b]	mg/L	16	458	138	0.003

[a]Sum of H_2O-P and $NaHCO_3$-P in sludge samples.
[b]Filterable reactive phosphorus in liquid samples, H_2O-P in sludge samples.

2.3. Preparation and Maintenance of Pots

The experiment was conducted in eight pots incorporating two replicates of each of three treatments and two replicate control pots. The treatment pots received applications of $SP_{supernatant}$, SP_{sludge} and PP_{sludge} and were irrigated with tap water. The two control pots received just tap water.

Each pot was sown with 1.256 g of ryegrass seed to give a rate of 318 kg/ha. The first green sprout came out a week after seeding. Pond sludge and supernatant treatments were applied to each pot 21 days after the seeds were sown to prevent plant burn. The three treatments were based on a labile P application rate of 100 kg/ha, which equated to a loading of 78.5 mg labile P to each pot. In total, 5059, 41 and 178 mL of $SP_{supernatant}$, SP_{sludge}

and PP_{sludge} were applied to the pots, respectively (Table 1). These volumes were calculated based on the labile P concentrations of each by-product given in Table 2.

The Italian ryegrass seeds (*Lolium multiflorum*; Feast II, Tetra variety) were purchased from a commercial outlet. Ryegrass has a life cycle of four leaves, with the fourth leaf appearing as the 'residual' leaf dies off. The ryegrass was harvested for analysis at the three-leaf stage as recommended to maintain optimal ryegrass productivity [6,22]. After the initial harvest, the ryegrass was harvested again when it reached 10 cm height, maintaining a minimum a cropped grass height of at least 3 cm [6,22].

Meteorological data including rainfall and reference evapotranspiration (ET_o) were collected using a weather station installed in the experimental field. The moisture content of the soil was maintained by irrigating water according to the measured volumetric water content (VWC), measured using a TDR-100 moisture meter, Spectrum Technologies, Aurora, IL, USA [23]. The TDR-100 moisture meter was checked using gravimetric analysis and was found to give reliable VWC values. Water to plants was supplied via precipitation and irrigation, and water loss occurred by evapotranspiration and leaching. Leachate was collected and analyzed as soon as it was observed. To mimic best practice in regards to minimizing runoff losses of P, N and E. coli from by-products applied to land [24], the applications were timed to allow 10 days (at least 2 days) before forecast rainfall was expected.

2.4. Nutrient Analysis

Harvesting was conducted 9 times over the course of the experiment. The ryegrass collected from each harvest was transferred to the laboratory and dried at room temperature. The dried sample was pulverized, homogenized and monitored for DM yields. The DM was determined by weight differences before and after drying. The grass samples were then analyzed to determine total nitrogen (TN), total phosphorus (TP) and total cations (K, Na, Mg and Ca) concentrations. The pulverized and homogenized grass was transferred in an aluminum tray and then dried in an oven at 70 °C for 48 hours until it reached a constant weight. TN and TP in the grass samples were determined using a discrete analyzer (Gallery; Thermo Scientific, USA) after Kjeldahl digestion in a block digestion system (BD50; Seal Analytical). Total cations were determined by inductively coupled plasma optical emission spectrometer (700 series, ICP-OES; Agilent Technologies, USA) after a reverse aqua-regia digestion with block digestion system [25].

Leachate was collected in a sampling bottle. After measuring its volume, it was transported to the laboratory for nutrient and the other parameters analysis. TN, TP and cations in leachate were analyzed in accordance with standard methods [26]. TN and TP were analyzed by discrete analyzer after persulfate digestion and cations were analyzed as ionic nutrients after filtering. Cations were determined by ICP-OES analysis.

The K to (Mg + Ca) ratio in the plant was determined to gauge the risk of grass tetany to grazing cattle as per equation 1 (units milliequivalents per kg of dry matter) [27]. An elevated proportion of K in plants can interfere with the uptake of Mg and Ca by grazing animals. It is recommended that the grass tetany ratio is maintained below 2.2 [27,28].

$$\text{Grass tetany ratio} = \frac{K^{+}}{Ca^{2+} + Mg^{2+}} \quad (1)$$

3. Results and Discussion

3.1. Ryegrass Yield

As shown in Table 3 and Figure 5, pots which were applied with pond by-products produced 30 to 80% higher yields compared to the control pots. Total DM yields for $SP_{supernatant}$, SP_{sludge} and PP_{sludge} treatments were 58%, 24% and 32% higher than the total control yield, respectively. Differences between treatment and control yields over the period between the 1st harvest and the 7th harvest were found to be statistically significant ($p<0.05$). The DM yield differences between pots treated with pond supernatant and sludge decreased gradually over time. Towards the end of the experiment, the DM yield for both PP_{sludge} and SP_{sludge} started to overtake the DM yield for $SP_{supernatant}$. This could be attributed to the fact that the pots which received sludges managed to retain more phosphorus in the soil (Table 3). At the end of the experiment (9th harvest), it was found that pond sludge and supernatant application pots had significantly higher cumulative DM yield than the control ($p<0.001$). DM yield between PP_{sludge} and SP_{sludge} were found to be significantly similar ($p<0.001$). These results suggest that pond sludges and supernatant can enhance the growth of ryegrass, significantly.

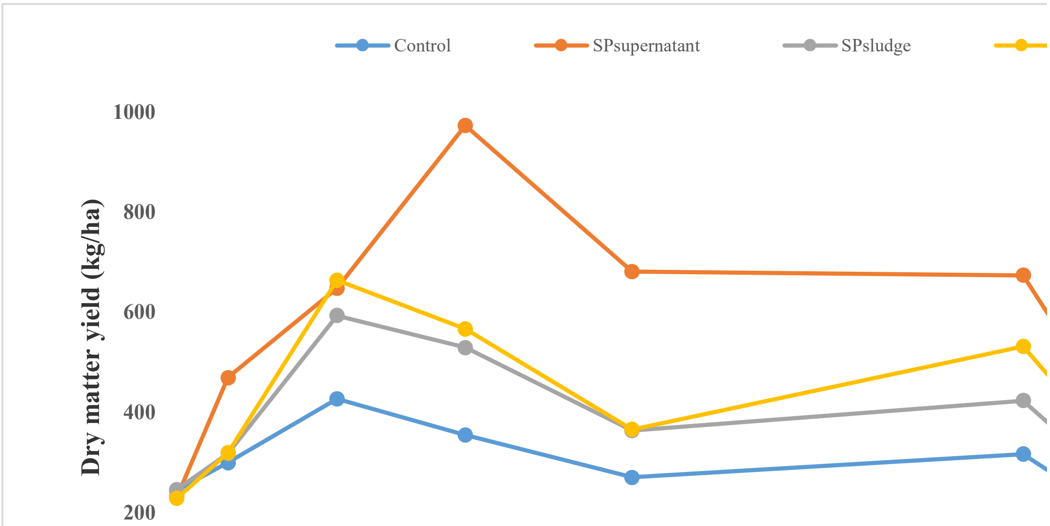

Figure 5. Dry matter yield of Italian ryegrass in soil treated with pond sludge and supernatant.

Table 3. Phosphorus usage by ryegrass and accumulated in soils and proportion of phosphorus in ryegrass, soil and leachate.

Phosphorus Fraction	$SP_{supernatant}$	SP_{sludge}	PP_{sludge}	Tap Water
		mg		
TP in soil, initial	2978 ± 9	2975 ± 19	2974 ± 22	3007 ± 13
TP added via pond by-products	492	177	173	0
Labile P added via pond by-products	78.5	78.5	78.5	0
TP in soil, (residual -after final harvesting)	1409 ± 11	1618 ± 21	1628 ± 7	1634 ± 4
TP in ryegrass leaves, residual	28 ± 9	28 ± 9	32 ± 10	26 ± 8
TP in ryegrass roots, residual	9 ± 3	13 ± 4	23 ± 7	6 ± 2
TP in ryegrass leaves, harvested	51 ± 1	37 ± 2	41 ± 3	27 ± 1
TP in ryegrass, total	88	78	96	59
TP lost in leachate	1973	1456	1423	1314
DM yield, mg	14073 ± 193	9916 ± 177	10777 ± 246	7694 ± 111

Note: Standard deviation values are indicated by ±.

3.2. Water Balance and Phosphorus Usage in Pots

Table 4 shows the water balance for all eight pots used in the experiment. Water lost due to leachate in the $SP_{supernatant}$, SP_{sludge}, PP_{sludge} and control pots amounted to 31%, 24%, 23% and 27%, respectively. The water loss in SP_{sludge} and PP_{sludge} was less than in the control. The total water loss of $SP_{supernatant}$ was higher than in the control and other pots as the pot was applied with more water. Water loss was highly affected by soil physicochemical properties such as organic matter and water holding capacity. Soil texture and pH also have a significant relationship with P leaching [29,30]. However, this study indicates that applying sludges instead of supernatant on paddocks may help to hold water in the soil. This can be attributed to the higher organic content in the sludges which in turn helps to retain more water within the soil structure.

Table 4. Overall water balance for the pots.

Parameter	$SP_{supernatant}$	SP_{sludge}	PP_{sludge}	Control
Total water in, mL	22,706	21,620	21,790	21,962
Inputs				
Irrigation (town) water, mL (%)	11,785 ± 135 (52)	15,717 ± 50 (73)	15,750 ± 0 (72)	16,100 ± 100 (73)
Pond sludge and supernatant applied, mL (%)	5059 (22.3)	41 (0.2)	178 (0.8)	0 (0)
Rainfall, mL (%)	5862 (26)	5862 (27)	5862 (27)	5862 (27)
Outputs				
Leachate, mL (%)	7005 ± 3 (31)	5171 ± 102 (24)	5097 ± 288 (23)	5925 ± 445 (27)
Moisture content in soil, mL (%)	631 ± 7 (2.8)	646 ± 9 (3)	631 ± 8 (2.9)	645 ± 5 (2.9)
ET_c, mL (%)	14,790 ± 688 (65)	15,588 ± 494 (72)	15,776 ± 229 (72)	15,104 ± 566 (69)
Grass, mL %	272 (1.2)	216 (1.0)	283 (1.3)	286 (1.3)

Note: ET_c is evapotranspiration (calculated from mass balance analysis); standard deviation values are indicated by ±; values in parentheses are percentages. Values in parenthesis indicate the distribution of water in percentages.

As shown in Table 5, pots treated with pond sludges had lower P loss through leachate compared to supernatant-treated pots, but slightly higher than the control pots. The ryegrass harvested from the treated pots had higher TP content than the ryegrass from the control pots. At the end of the experiment, more P (about 15%) remained in the soil treated with PP_{sludge} and SP_{sludge} compared to the soil treated with $SP_{supernatant}$. Lower P in the soil applied with supernatant can be attributed to the higher leachate losses. During this study, on some occasions, intensive rain after treatment applications caused labile P to be transported downward through the soil profile, resulting in significant P losses via leachate. Hart et al. [31] found that 70–80% of annual P losses resulted from the rainfall soon after application of fertilizer.

Table 5. Overall phosphorus balance for the pots.

Phosphorus Fraction	TP Balance After Harvesting, %			
	$SP_{supernatant}$	SP_{sludge}	PP_{sludge}	Control
TP in soil, residual after harvesting	40.6	51.3	51.7	54.3
Total TP in Ryegrass	2.6	2.5	3.0	2.0
TP in ryegrass leaves, residual	0.8	0.9	1.0	0.9
TP in ryegrass root, residual	0.3	0.4	0.7	0.2
TP in ryegrass, harvested	1.5	1.2	1.3	0.9
TP lost in leachate	56.8	46.2	45.3	43.7

Note: Loss of P due to leachate was calculated using mass balance approach.

3.3. Phosphorus and Nutrients in Ryegrass after Pond Sludge Application

Uptake of TP by ryegrass in the $SP_{supernatant}$, SP_{sludge} and PP_{sludge} pots was higher than the control pots by 100%, 17% and 33%, respectively. Similarly, TN uptake was higher by 168%, 43% and 62%, respectively. In the short-term, the application of $SP_{supernatant}$, which contained the highest TP load (492 mg), appeared to have caused the most rapid increase in ryegrass nutrient use and DM yield (Figure 4). The observed findings corroborated with previous studies that reported ryegrass and lucerne DM yields were significantly affected by P application rate [17,32]. In contrast, clover was not significantly affected by the P application rate [33]. As shown in Table 6, the amount of cations (K, Na, Mg and Ca) in the ryegrass in the pots treated with $SP_{supernatant}$ and pond sludges increased by 93–150% and 17–65%, respectively, compared to the control. Significantly higher amounts of the cations in the ryegrass applied with supernatant could be due to the higher applied loads.

The tetany ratios of the ryegrass in $SP_{supernatant}$, SP_{sludge}, PP_{sludge} and control pots were 1.7, 1.8, 1.9 and 2.0, respectively, all less than the recommended value of 2.2. These are positive results considering the pond sludge and supernatant used in this study contained higher concentrations of K than the other ponds studied in Australia. This indicates that the risk of animal metabolic problems due to Mg deficiency can be considered to be low when pond sludge and supernatant are applied to land. Similar conclusions were made by previous studies [34]. The TP contents of 3.0–3.3 g/kg in ryegrass were sufficient to meet the minimum cattle dietary requirements with the recommended P range in the grass being above 2.2 g/kg. The Mg concentrations in harvested ryegrass were 3.7, 2.6, 2.8 and 2.6 g/kg in $SP_{supernatant}$, SP_{sludge}, PP_{sludge} and control, respectively, which compares favorably with the recommended level of 2.5 g/kg or higher [35]. The ryegrass Ca content was 7.5, 5.9, 6.0 and 5.3 g/kg in $SP_{supernatant}$, SP_{sludge}, PP_{sludge}, and control, respectively. The recommended safe level of Ca is between 2.7 and 20 g/kg [36], so again the potential risk of animal metabolic problems was negligible.

Table 6 shows losses of cations via leachate. Losses were highest from the $SP_{supernatant}$ pots for most cations. With relatively low amounts of solids, $SP_{supernatant}$ can readily infiltrate through the soil and carry nutrients with it. Indeed most potassium and sodium in raw manure is present in the ionic state, resulting in the notably higher losses. This also indicates that the presence of organic solids in the applied sludge can minimize the loss of cations through leachate to deeper depths of the soil.

Table 6. Dissolved cations in the leachate and ryegrass DM.

	$SP_{supernatant}$		**SP_{sludge}**		**PP_{sludge}**		**Control**	
	Leachate	**Ryegrass DM**	**Leachate**	**Ryegrass DM**	**Leachate**	**Ryegrass DM**	**Leachate**	**Ryegrass DM**
K^+, mg	114 ± 2	485 ± 18	63 ± 12	306 ± 7	32 ± 4	365 ± 19	64 ± 23	255 ± 18
Na^+, mg	236 ± 5	15 ± 0	199 ± 21	8 ± 0	138 ± 1	9 ± 0	173 ± 8	6 ± 0
Mg^{2+}, mg	26 ± 1	47 ± 2	21 ± 2	29 ± 1	12 ± 1	34 ± 0	15 ± 1	24 ± 2
Ca^{2+}, mg	74 ± 5	91 ± 6	83 ± 3	57 ± 6	56 ± 4	64 ± 1	61 ± 7	41 ± 1

Note: Standard deviation values are indicated by ±.

3.4. Phosphorus Fractions and Nitrogen in Ryegrass and Soil after Dismantling of the Pots

Nutrients applied to soil are taken up by plants. During rainfall events nutrients are lost due to surface runoff or as leachate. In this study, TP loss in $SP_{supernatant}$ pots via leachate was about 48% higher than that observed in control pots as shown in Table 5. On the other hand, P loss via leachate for SP_{sludge} and PP_{sludge} pots were only 11% and 8% higher than the control pots, respectively. In their study, Caretta et al. [37] have suggested that the loss of P is often dependent on the amount of P applied. In this case, the total P load of $SP_{supernatant}$ was much higher than for the sludges on account of its very high ratio of TP to available P. Further, as shown in Table 3, P uptake was similar between the three treatments and higher than the control. This shows that the use of SP_{sludge} and PP_{sludge} for land application on dairy paddocks is superior to $SP_{supernatant}$ in terms of P utilization and loss.

All of the P fractions in soil treated with pond sludges were higher than those in the control pots, which was also noted in a previous study [20]. As shown in Table 7, TP left in the soil at the completion of the experiment was 10 – 15% higher for SP_{sludge} and PP_{sludge} pots as compared $SP_{supernatant}$ pots. This is despite the fact that higher TP (almost 180% - Table 5) was applied for $SP_{supernatant}$ pots than SP_{sludge} and PP_{sludge} pots. Also, the pond sludge applied pots had 15-25% more residual labile P than the supernatant applied pots (Table 7). As shown in Table 6, the residual total inorganic P which is readily available was once again higher for the pots which were treated with pond sludges. The same trend can be seen in the case of total organic P and stable P. These results show that the application of pond sludge is also superior to secondary pond supernatant in terms of soil P retention and potential future utilization.

Table 7. Phosphorus and nitrogen in soil, ryegrass leaves and roots after dismantling pots.

		Parameter	$SP_{supernatant}$	SP_{sludge}	PP_{sludge}	Control
Ryegrass leaves		TN, mg/kg	6356 ± 946	8921 ± 778	9119 ± 150	7350 ± 177
		TP, mg/kg	3000 ± 177	4042 ± 88	4000 ± 354	3750 ± 177
Ryegrass roots		TN, mg/kg	2313 ± 1573	4379 ± 415	6475 ± 583	1656 ± 521
		TP, mg/kg	500 ± 177	917 ± 88	1188 ± 88	375 ± 177
Soil		TN, mg/kg	2526 ± 526	2615 ± 24	2649 ± 237	2571 ± 66
		TP, mg/kg	490 ± 12	564 ± 43	540 ± 5	462 ± 3
		Total P_i, mg/kg	114 ± 2	126 ± 0	125 ± 3	110 ± 0
		Total P_o, mg/kg	376 ± 10	438 ± 42	415 ± 2	352 ± 3
	Labile P	H_2O-P, mg/kg	13 ± 1	16 ± 1	13 ± 0	10 ± 0
		$NaHCO_3$-P_i, mg/kg	17 ± 0	20 ± 1	30 ± 0	13 ± 2
		$NaHCO_3$-P, mg/kg	171 ± 7	215 ± 19	199 ± 3	180 ± 23
		Total labile P, mg/kg	184 ± 0	231 ± 1	212 ± 0	190 ± 2
	Stable P	NaOH-P_i, mg/kg	83 ± 2	90 ± 1	82 ± 3	87 ± 2
		NaOH-P, mg/kg	305 ± 4	332 ± 22	329 ± 2	273 ± 20
		HCl-P, mg/kg	0	0	0	0
		Total stable P, mg/kg	305 ± 4	332 ± 22	329 ± 2	273 ± 20

Note: Standard deviation values are indicated by ±; Pi is inorganic P; Po is organic P, P includes both inorganic and organic P.

4. Conclusions

The aim of this study was to examine the effects of application of pond sludge and supernatant from a dairy effluent management system on ryegrass yield and soil properties. The experimental study included the construction of eight pots and study the growth of ryegrass under different conditions. At the end of the experiment, the pots were dismantled, then the soil and root system were carefully separated and analyzed for various nutrients and cations. The dairy effluent by-products used in this study were primary pond sludge, and secondary pond sludge and supernatant. To compare the results a set of control pots was used. Two pots were used for each experiment.

The pot experiments carried out in this study found that both the pond sludges and the supernatant were effective fertilizers for ryegrass; the pots which were fed with pond sludges and supernatants resulted in about 30 to 80% higher yield in terms of ryegrass dry matter (DM) compared to control. Due to the high concentration of total P in secondary pond (SP) supernatant (and possibly, total N), the DM yield of ryegrass was the highest for the pots treated with the supernatant. Additionally, it was found that land application of pond sludge resulted in lower losses of nutrients and minerals compared to the pots treated with pond supernatant. At the end of the experiment, it was observed that more plant available (labile) P, organic P and stable P remained in the soil treated with pond sludge compared to the soil treated with pond supernatant. The losses of P and cations via leachate was the highest for the pots which were applied with secondary pond (SP) supernatant. These results indicate that the organic solids present in the sludge help to retain the nutrients within the root depth of the soil and prevent the loss of these nutrients into deeper layers of soil and possibly polluting the groundwater.

Results showed that the pond sludge application is not likely to induce grass tetany when applied to soil, despite the high potassium (K) level in pond sludge of the dairy farm considered in this study. Hence, grass produced by the use of pond sludges is safe for cattle consumption.

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