COMPOSTING OF HIGH MOISTURE DAIRY MANURE USING SAWDUST OR MIXED PAPER AS AMENDMENTS AND WOOD CHIPS AS THE BULKING AGENT.

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COMPOSTING OF HIGH MOISTURE DAIRY MANURE USING SAWDUST OR MIXED PAPER AS AMENDMENTS AND WOOD CHIPS AS THE BULKING AGENT.

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ABSTRACT

The agricultural industry in New Zealand is a major source of waste generation and about 84% of the country's point source pollution comes from dairy sector alone. Dairy farm effluent in New Zealand is most commonly treated via waste stabilization ponds. Two-pond systems which are frequently used, are not sufficient to make the dairy shed effluent suitable for discharging to surface water, thus there is a need for investigation and development of treatment/disposal technologies, especially where land treatment is not a practical option. Composting is a process whereby the heat that is liberated from the decomposition of organics drives the evaporation of water. By reducing the large amount of water in the slurry, its mass, bulk weight & volume through composting, there is a large potential to reduce associated transportation and handling costs of disposal as well as minimising the area of land required for manure application. Composting can further reduce the risk of pollution from runoff, odour, and nitrate contamination of ground water.

A passively aerated composting system was used to treat high moisture (90%) dairy manure slurry. Both sawdust and mixed paper were investigated as amendments with wood chips as the bulking agent. Two identical piles (1.2m×1.2m×1.2m) for the sawdust investigation and another two for the mixed paper experiment were established. Passive aeration was achieved with three horizontal aeration pipes in the base of each pile. The piles were monitored for about 70 days for all the experiments.

During the active phase of composting, piles reached above 60°C and thermophilic temperatures were sustained for more than three weeks. The importance of pile cooling because of excessive wind flow was demonstrated suggesting the advisability of a wind barrier to protect piles.

Moisture content in the piles decreased over the period of study. Initial moisture content varied from 67% to 71% but diminished to between 47% and 58% by the

conclusions of the experiments. Results of these studies suggest that composting can remove water by virtue of the biologically produced heat.

The results of this study also suggest that the amount of heat energy generated from composting depends on the amount of volatile solids degraded. Energy rich feed materials were shown to be converted to energy poor materials due to reduced volatile solids degradation and energy poor feed materials emerged as energy rich due to the greater amount of volatile solids degradation. In this study from 47.2% to 76% of produced heat was lost as latent heat through convective (evaporative drying).

From the comparison of results using two different amendments, mixed paper was found better than sawdust as an amendment in terms of biodegradability, heat development, heat accumulation, evaporative drying, moisture removal, volume reduction and weight reduction.

The results of this study also indicated that the required extent of total coliforms destruction was not achieved within the period of composting using the materials and method undertaken. A longer maturation or curing phase may be helpful in achieving the recommended level of total coliform inactivation.

TECHNICAL ABBREVIATIONS

%	Percentile values unless otherwise stated will be expressed as weight per unit weight
Amb Air T	Ambient air temperature
ASH	Inert fraction after combustion (kg)
BVS	Biodegradable Volatile Solids
BW	Bulk Weight (kg / m^3)
C	Carbon
C:N	Carbon to Nitrogen ratio
D sa	Bulk Density (sawdust and manure) Or Combined bulk density of substrate and amendment.
DGASO	Dry exhaust gas from composting process
DM	Dry matter expressed as % (w/w)
Ds	Bulk Density (manure and sawdust or manure plus mixed paper)
Dw	Density of water at ambient conditions
E	Energy ratio (calories / g.water); also exponential symbol (Ratio of biological heat released from oxidation of organics to the weight of water present in the substrate.
EI	Experiment I
EII	Experiment II
FAS	Free air space (% v/v), The ratio of gas volume to total volume of material.
Fb	Free air space (FAS) within interstices of bulking agent
Fm	Free air space (FAS) within interstices of final mixture of substrate, amendment and bulking agent.
G sa	Specific Gravity (sawdust and manure) or Combined Sp. Gravity of substrate and amendment.
Gs	Specific gravity of substrate (manure).
HORG	Heat of combustion of substrates, kg/g. VS)
HSWVI	Sensible heat with water vapour (input air) (k cals)
L	Distance in mm from floor of compost pile; also used to indicate Litre.
Mbs	Volumetric mixing ratio
Mbs	Volumetric Mixing Ratio (manure and sawdust to wod chips or manure and mixed paper to wood chips).
MC	Moisture Content (% w/w). Also expressed as g/g
MIC	Microns (10^{-6} M)
Mmb	Factor for volume increase after mixing
MPN	Most Probable Number (index per g dry solids)
N	Nitrogen
N.paper	Un-used newsprint paper
NBVS	Non-biodegradable volatile solids
Off paper	Office Paper
P-1	Compost Pile number 1
P-2	Compost pile number 2
PAIR	Atmospheric pressure (m m Hg)
PAN	Particles < 250 microns collecting in fractionation pan
PV	Actual vapour pressure of water
PVS	Saturation vapour pressure
RHAIR	Relative humidity (air), a fraction of the saturated vapour pressure
S sa	Solid Contact (sawdust and manure) or Combined solid content of substrate and amendment.
Ss	Solids (total) Content of substrate (manure).
$S_{Sm(m)}$	Maximum total solids content achievable (manure and sawdust or manure and mixed paper)
Ta	Absolute Temperature (°K)
TC	Total Carbon (% DW)
TN	Total Nitrogen (% DW)
TS	Total Solids (kg)
VS	Volatile solids (kg). May also be expressed as % DM
W	Specific humidity of inlet and outlet gases, g-water/g-dry air. Also water ratio in Haug equation.
W	Water Ratio (g. water/ g. BVS)
WAT	Water content (g) in raw compost mixture
WATSO	Water component in final compost
WATVI	Water vapour associated with input air
WATVO	Water vapour associated with output air

AMENDMENTS

READER'S SHOULD NOTE THE FOLLOWING MINOR CORRECTIONS TO THE PAGES AS INDICATED.

PAGE 112: PARA 4: LAST LINE:- READ "AREAS UNDER CURVES" & NOT "AREAS".
PAGE 128: FIG. 5.17:- FOR "TOTAL WEIGHT" READ: 138.00; & 87.34.
PAGE 128: FIG 5. 18:- FOR "TOTAL WEIGHT" READ: 134.76 & 46.03.
PAGE 129: FIG. 5.19:- FOR "TOTAL WEIGHT" READ: 128.07 & 51.38.
PAGE 129: FIG 5. 20:- FOR "TOTAL WEIGHT" READ: 134.75 & 58.73.
PAGE 131: PARA 1: LINE 1:- READ "INITIAL TOTAL COLIFORM COUNTS" & LATER, " FINAL TOTAL COLIFORM COUNTS" AND NOT, "TOTAL INITIAL COLIFORM COUNTS" & " TOTAL FINAL COLIFORM COUNTS" RESPECTIVELY.
PAGE 141: SECTION 6.4: PARA 1: LINE 5:- READ "HEAT LOSSES" & NOT "HEAT LOSS".
PAGE 141: " PARA 4:-LINE 2:- READ "TABLES WERE DEVELOPED" NOT "TABLES WAS DEVELOPED".

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CHAPTER-1

GENERAL INTRODUCTION

1.1 DAIRY FARMING IN NEW ZEALAND

The rapid development of the dairy industry in New Zealand started in 1882 with the successful demonstration of refrigerated transportation to distant markets of perishable food products on ocean steamers. The remarkable development of the dairy industry in New Zealand is mainly due to a natural temperate climate with plenty of rainfall and sunshine, the application of science in the manufacture of dairy products and the progressive spirit of the dairy-farming community. Also, the pasture-growing period in New Zealand is from10 months to possibly 12 months (in the far north) whereas it is only 6 months in competing dairying countries in Europe and America (Duncan, 1933). These natural advantages have led to the development of a strong pastoral-based dairy industry.

The total stock of dairy cattle in 1962 was 3.1 million including 2.0 million cattle in milk production producing an average of 2,728 kg of milk per head (or 128 kg milkfat/head). By 1975, the number of cattle in milk production had risen to 2.1 million and an average yield was 6,071 litres of milk per head (135 kg milkfat/head). In 1983, although the number of cattle remained 2.1 million, the average milk yield was 3,240 kg per head (149 kg milkfat/head). Thus 28% more milk and 19% more yield per head obtained in 1983 than that of 1962 (Rae *et al.*,1985). This progressive trend in terms of milk production and average yield of milk fat per head has been observed up to the present time (Fig.1.1 and Table 1.1). Table 1.1 shows for the period from 1974 to 2000 that the total number of cattle, the total milk processed, average yield of milk fat per head have been showing an upward trend over the years.

Table 1.1 also shows that the increasing number of cattle is reflected in an increase in the stocking rate (number of cattle/ha) of grazing. The stocking rate is highest in the South Island at 3 cattle/hectare in South Canterbury, 2.9 cattle/hectare in North Canterbury and Otago. In the North Island, stocking rate is 2.8 cattle/hectare in South

Auckland, Bay of Plenty, Taranaki, Wellington and 2.9 cattle/hectare is for the East Coast. Although the Auckland region is the main milk production region (43% of the national total) and the next biggest milk-producing region is Taranaki and Wellington (26%); in recent years production in the South Island has grown at above the national average. In 1999-2000 the production in the South Island was 22% of the national total which is 72% more than production in 1994-95. In terms of milk production New Zealand is the 4th highest producing country in the world but in terms of milk product manufacturing New Zealand is the number one country in the world with 97% of total production being used in manufacturing by-products (Dairy statistics,1999-2000).

Table 1.1 Summary of dairy cattle, milk production, herd size, stocking rate.

Season	Total cattle	Herds	Herd size (av)	Milk Processed. (million litres)	Milksolids Processed (million kg)	Milk fat/ cattle(av) in kg	Effective hectares (av)	Cattle/ha. (av)
74/75	2,079,886	18,540	112	5,222	425	128	-	-
75/76	2,091,950	18,442	113	5,403	466	137	-	-
76/77	2,074,443	17,924	116	5,775	479	143	-	-
77/78	2,052,624	17,363	118	5,238	437	131	-	-
78/79	2,039,902	16,907	121	5,655	477	142	-	-
79/80	2,045,808	16,506	124	5,997	506	151	-	-
80/81	2,027,096	16,089	126	5,868	491	147	-	-
81/82	2,060,898	15,821	130	5,979	491	144	63	2.1
82/83	2,128,199	15,816	135	6,096	505	143	64	2.2
83/84	2,209,725	15,932	139	6,733	564	154	65	2.2
84/85	2,280,273	15,881	144	6,965	578	152	64	2.4
85/86	2,321,012	15,753	147	7,326	609	157	64	2.4
86/87	2,281,894	15,315	149	6,385	524	138	65	2.4
87/88	2,236,290	14,818	151	6,921	579	154	65	2.4
88/89	2,269,073	14,744	154	6,533	541	143	66	2.4
89/90	2,313,822	14,595	159	6,868	572	147	67	2.4
90/91	2,402,145	14,685	164	7,077	599	148	70	2.4
91/92	2,438,641	14,452	169	7,454	637	157	-	-
92/93	2,603,049	14,458	180	7,629	651	148	74	2.5
93/94	2,736,452	14,597	188	8,603	736	160	77	2.5
94/95	2,830,977	14,649	193	8,633	733	156	80	2.5
95/96	2,935,759	14,736	199	9,325	788	163	82	2.5
96/97	3,064,523	14,741	208	10,339	880	173	86	2.5
97/98	3,222,591	14,673	220	10,651	891	168	87	2.6
98/99	3,289,319	14,362	229	10,168	850	147	91	2.7
99/00	3,269,362	13,861	236	11,480	970	165	93	2.7

Source: Dairy statistics (1999-2000).

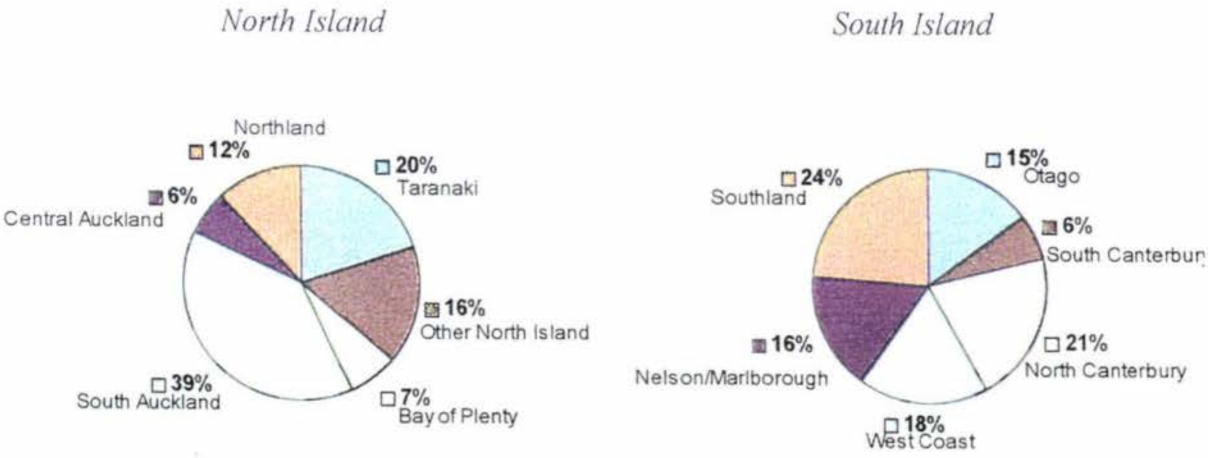

Fig. 1.1 Regional Distribution of Dairy Farms,1999-2000.
(Dairy Statistics, 1999-2000)

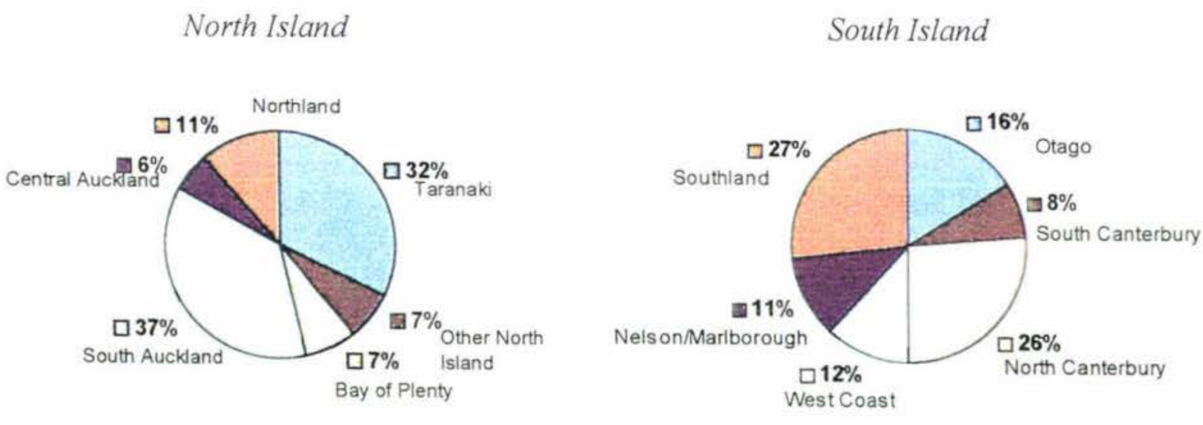

Fig. 1.2 Regional Distribution of Dairy Cattle in 1999-2000.
(Dairy Statistics,1999-2000)

The regional distribution of dairy farm and dairy cattle in the North Island and the South Island are shown in Figs.1.1 and 1.2 above. The distribution of dairy farms is highest (39%) in South Auckland (Auckland, Waikato and Bay of Plenty) and Taranaki (20%) is the next in the North Island. Southland (24%) and North Canterbury (21%) are the main dairy farm regions in the South Island. The population of dairy cattle is also highest in South Auckland (37%) and Taranaki (32%) in the North Island. Southland (27%) and North Canterbury (26%) are also the main regions of dairy cattle in the South Island. Thus, South Auckland, Taranaki, Southland and North Canterbury are the potential regions of greatest productivity in terms of dairy herd size. Table1.2. shows the trend in volume and value of New Zealand dairy exports in the last five years and it can be seen that the total volume and value of dairy exports are increasing annually.

Table 1.2 Total volume (000 tonnes) and value (NZ$Million) for dairy exports.

Season	Skimmilk power	Wholemilk powder	Cheese	Casein	Butter	AMF	Other	Total
Export volume (000 tonnes)								
95/96	127	278	173	72	193	44	120	1,007
96/97	183	347	236	83	250	64	190	1,353
97/98	166	359	232	94	232	82	181	1,346
98/99	174	362	240	103	188	89	202	1,358
99/00	172	393	249	106	249	87	191	1,447
Export value (NZ$ Millons)								
95/96	425.7	942.6	617.4	557.1	703.7	155.6	390.1	3,792.2
96/97	545.8	1,051.5	838.5	569.4	752.4	163.1	404.9	4,325.6
97/98	486.2	1,126.2	892.5	651.7	787.3	233.1	441.3	4,618.3
98/99	481.7	1,199.9	983.4	763.0	677.0	303.9	528.3	4,937.2
99/00	509.5	1,269.9	987.4	802.6	736.5	259.8	536.9	5,102.6

Source:Dairy Facts and Figures (1999-2000).

The average dairy farm cash revenue has increased from $159,750 in 1990-91 to $268,894 in 1999-2000 and during this time the number of cattle, effective hectares and variable expenses (81%) have also increased. Average farm profit before tax increased by 76% from $38,554 to $68,011 between 1998-99 and 1999-2000 (Economic Survey,1999-2000).

From the above information and discussion it has become evident that the dairy sector in New Zealand has been playing a vital role in foreign currency earnings (Table 1.2) and the economic development of the country. Therefore, for the betterment of people and to safeguard the life support capacity of air, water, soil and ecosystems, the dairy industry sector must be kept free from any environmental hazard and obstacle that may cause negative impacts on the natural and physical resources of the country.

1.2 LEGISLATION

In New Zealand, The Resource Management Act 1991 received its Royal Assent from the Governor General on 22 July 1991. The act brought together the laws governing New Zealand's land, air and water resources. The act established a common purpose and framework for dealing with the effects of disposal activities on the environment. The purpose of the Resources Management Act is sustainable management of New Zealand's natural and physical resources. The definition of sustainable management described in the Act reads as:

" Managing the use, development and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural wellbeing, and for their health and safety while-

(a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations;
(b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems;
(c) avoiding, remedying, or mitigating any adverse effects of activities on the environment."

One of the key changes the Act introduced, was to focus decisions on the effects of activities rather than the activities themselves. This was expected to lead to tighter and more effective targeting of regulatory controls. Regional councils are the consent authority for all activities involving discharges to water, land and air. Section 15 of the Act requires every person who discharges a contaminant into water to obtain a discharge permit from the regional council. However, provision was made that where, prior to 1 October 1991, any activity discharging contaminants into or onto land did not require any license or authorization to do so, those activities were exempted from the requirement to obtain a discharge permits to discharge contaminants to land for three years or sooner if a regional plan provided otherwise. Thus, from 1991 permits to discharge contaminated materials became universally applicable.

The type of activities related with discharge consent are divided into five categories permitted, controlled, discretionary, non-complying and prohibited. The permitted activities are allowed as of right, controlled activities are non-notified which are allowed by delegated staff with conditions, discretionary activities are notified/non-notified and are allowed/declined by delegated staff, non-complying activities are notified and granted/declined by the council and prohibited activities are never permitted. For example, if ponds are located and operated to avoid odour and spray drift and if their sealing permeability does not exceed 10^{-9}m/sec then land application (25mm/application) of dairy effluent at a loading rate 150kg-N/ha/yr is a permitted activity. But if the treatment systems do not comply with the above conditions or if the effluent is discharged to surface water then they will be categorized as discretionary activity. But that is not always automatically applicable because the notification requirements and decision on consent are determined on a case by case basis according to Part-VI of RMA (Environment Waikato, 1994). Every regional council in New Zealand has different guidelines based on scientific criteria about concentrations or numerical values of different parameters of various waste. Heatley (1996) prepared a summary of different regional council and unitary authority requirements for discharges of dairyshed and piggery wastewater.

It is expected that public concern about odour potential following land and surface water application of dairy waste would result in promoting waste disposal systems in an effective manner and that has been the case The Resource Management Act 1991 has been a turning point towards the implementation of new technologies for dealing with waste in New Zealand.

1.3 AGRICULTURAL WASTES AND IMPACTS IN NZ

"If you look at what you feed cattle, about one-third becomes meat or milk, the other two-thirds is manure."(Glenn,1998). The agricultural industry in New Zealand itself is a major source of waste generation and the bulk of it comes from animals. Waste produced from agricultural crops has not been considered in this discussion. Animal waste is a highly variable material with its properties dependent on animal age, species, type of ration, production practices and environment. Animal waste is commonly refered to as manure with added wash down water, bedding, soil, hair or spilled feed (Vanderholm,1984). A study was carried out for 10 days on 152 Friesian cattle during milking period in Palmerston North, New Zealand in January 1998. Undiluted dairy manure was collected and it was found that on average 2.0 kg manure/head/day is deposited in the holding area. This represented 3.7% of the average daily bovine manure production. The collected material comprised 60% faeces and 40% urine and the moisture content of that slurry was 92.6% (Mason & Reijnen, 1999).

This volume varied from 30-70 litres/head/day if wash water is included (Dakers,1979). For most dairies about 2 hrs/day and approximately 8% of the total manure (may vary & depends on holding time, amount of stress on the cattle) will be found in farm dairy wastes (Vanderholm,1984) but Drysdale (1977) suggested that 3.6% of total daily production of manure can be collected on cowshed yard, which is very close to the figure (3.7%) given by Mason & Reijnen (1999). Composition of the manure is neither liquid nor solid but a plastic slurry which is difficult to handle. Dickinson (1974) reported that "the amount excreta (dung and urine) produced per day by beef and dairy cattle is approximately 10% of their own weight and contain 85-90% water".

When cattle graze freely over pasture, their excretions are returned directly to the land and under normal conditions of good husbandry no particular problem either of waste disposal or of water pollution arises. However, problems develop when these animals are housed in a farm building or enclosure. During grazing, livestock deposit manure directly on the land where it is recycled naturally and does not cause significant pollution (Vanderholm, 1984). However, with increasing stock numbers the potential for pollution increases and subsequent environmental damage is of concern.

Currently, there are major concerns about the negative effects of nutrient losses (increased nutrients entering surface and ground water) due to non-point source of pollution from the manure of large dairy herds maintained on small acreages (Van Horn et al.,1994). "Sheep and cattle grazing can be a major cause of non-point source of pollution of ground and surface water in New Zealand. Contaminants can include sediment derived from erosion, nutrients such as N & P and pathogens. High levels of orthophosphate or dissolved reactive phosphorus and nitrate can cause eutrophication of warm, slow moving water" (Caruso & Jensen, 2000).

Much of the hill country on New Zealand's North Island is particularly sensitive because of deforestation, steep terrain and thin, unstable soils (Crozier et al.,1980; Merz & Mosley, 1998). Kruskal-Wallis tests showed that soil water had a significantly higher value for NO_3^--N concentrations than streams, surface runoff and subsurface water. This indicated that soil water is a reservoir and significant source of NO_3^--N entering streams (Caruso & Jensen, 2000).

Animal waste can also be a significant source of organic nitrogen and ammoniacal nitrogen both of which is toxic to many species of fish at very low concentration. Some organic-N is oxidized to NO_3^--N through nitrification. Transportation of N through a hillslope to stream water is predominantly as dissolved NO_3^--N. Transport mechanisms include overland flow during storms and nitrate saturated watersubsurface flow (Burt et al.,1993). Nitrogen concentrations in soil water are affected by these transport pathways and the residence time of water in contaminated soil (Cooper & Cooke,1984; Goulding et al.,1996).

Temporarily confined animals such as dairy cattle and such permanently confined livestock as pigs and chickens also generate significant quantities of wastes which may lead to disposal problems (Vanderholm,1984) of a point source and non-point nature. Dairy cattle are confined only during milking and controllable manure waste comes from this period. The manure produced comprises 6 to 12% of total daily manure production (MAF Agriculture policy, 1994)

The estimated contributions from dairy, pig & sheep sectors in terms of point and non-point source pollution are given in the Table 1.3 where it is indicated that only 2.88 percent of generated waste from these animals can cause point source of pollution and needs management by human intervention. Table 1.3 also shows that about 84% of the point source of pollution comes from dairy sector alone and remaining 16% from pigs. The dairy sector is the major source of both point and non-point source of pollution in New Zealand.

The animal population and associated waste generation in New Zealand during the period of 1952 to 1980 is given in Table 1.4. Also according to Statistics New Zealand, Agricultural Production Survey (1999-2000), an analysis of livestock populations of New Zealand and the respective animal waste generation is presented in Tables 1.3 and 1.5 respectively. From the data of Tables 1.4 and 1.5 it is evident that the total quantity and strength of animal wastes in New Zealand represents significant polluting potential , especially the quantity to be handled manually, i.e. these quantities of wastes coming from milking yards and feed pad.

Table 1.3 The estimated point and non-point pollution from dairy cows, pigs & sheep

Animal	Population (millions[1])	Waste generation (tonnes/day[2])	Pollution sources[3] (tonnes/day)		Point and non-point pollution (%)		Contribution to pollution (%)	
			Non-point	Point	Non-point	Point	Non-point	Point
Dairy cattle	3.26	176,040	169,527	6,513	65	84.3	97.12	2.88
Pigs	0.368	1,214	-	1,214	-	15.7		
Sheep	45.67	91,340	91,340	-	35	-		
Total	49.298	268,594	260,867	7,727	100	100		

Waste: Undiluted mixture of urine and faeces considered by Vanderholm (1984) for calculating waste generation of different livestock in New Zealand.

1. Statistics New Zealand, Agricultural Production Survey (1999-2000), where population of different animal in 1999-2000 is given.
2. Vanderholm (1984), where characteristics of different animal manure is presented.
3. Mason & Reijnen (1999) , where 3.7% of the average daily bovine manure production was found in the farm dairy waste.

The estimated dairy animal population for 1999-2000 was 3.26 millions (Dairy Statistics ,1999-2000). On a BOD_5 basis the farm dairy (dairyshed and milking parlour) produced waste, (based on 1999 numbers) equivalent to a human population of 1.97 million. The average herd size has increased steadily over the past 27 years from approximately 110 in 1974/75 to 236 in 1999-2000 and the number of farm dairies in 1999 was reported to be 13,861 (Dairy Facts and Figures, 1999-2000).

Some studies (Dakers,1979; Vanderholm,1984 and Mason & Reijnen,1999) have been carried out in New Zealand to investigate the basic characteristics of raw animal wastes. Table.1.6 has been prepared on the basis of data obtained from such investigations and shows some of these characteristics of freshly voided animal manure.

Table 1.4 National animal population equivalent and manually handled waste from 1952 – 1980

Farm Type [a]	Dairy	Beef	Pig	Sheep	Total P.E. (Millions)	Total [c] Manually handled
1952 Population (thousands)	2882	2282	566	35384		
P.E. [b] (millons)	36.6	29.0	0.74	14.9	81.2	2.6
1960 Population (thousands)	2933	30.2	660	32632		
P.E. (millons)	37.3	38.3	0.87	13.7	90	2.7
1970 Population (thousands)	3729	5048	578	60276		
P.E. (millons)	47.4	64.1	0.75	25.3	138	3.1
1980 Population (thousands)	2969	5162	68772			
P.E. (millons)	37.7	65.6	0.56	28.9	133	2.4

Source: Dakers & Painter (1983).

a. 75% of gross income is derived from this activity.

b. 1Population Equivalent (P.E.) = 0.077kg-BOD_5/Day.

c. Only pig waste and 5% of dairy waste considered.

Table 1.5 The quantity and strength of agricultural wastes in New Zealand

Animal	Population (millions)	Total Wastes		Collected Wastes	
		Daily BOD_5 [1] (tonne)	Population Equivalent [2] (millions)	Daily BOD (tonne)	Population Equivalent (millions)
Dairy cattle	3.26	2510	32.6	100.4	1.30
Sheep	45.67	1462	18.98	nil	nil
Pigs	0.368	51.52	0.67	51.52	0.67
Beef	4.64	3155	40.98	nil	nil
Total		7178.52	93.23	151.92	1.97

- Daily BOD_5 per capita, 0.077kg.
- 4% of total waste production is considered to be collected in yards (Drysdale,1977).
- All pigs and poultry are permanently housed and penned.

Table 1.6 Chracteristics of freshly voided animal wastes.

Animal	Raw			
	Dairy Cattle	Pig	Poultry	
			Layer	Broiler
Animal Weight (kg)	500	50	2	1
Raw Manure (kg/day)	54	3.3	0.11	0.071
Faeces, % RM	60	55	-	-
Total Solids (kg/day)	4.4	0.30	0.027	0.018
Volatile Solids (kg/day)	3.2	0.24	0.019	0.012
BOD_5 (kg/day)	0.77	0.14	0.007	-
COD (kg/day)	4.3	0.29	0.024	-
Total N (kg/day)	0.24	0.023	0.0014	0.0012
Total P (kg/day)	0.025	0.075	0.0056	0.0026
Total K (kg/day)	0.31	0.015	0.00062	0.00036
Solid content (%)	13	9.2	25.3	24.1

Source: Dakers (1979) & Vanderholm (1984).

There are eleven different types of pollutants referred to or implied in the standards of the RMA (1991) and of those eleven, nine pollutants (excluding heat, acids & bases) have been found in lagoon treated dairy and piggery effluents. These pollutants are: oxygen demanding substances, suspended solids, infectious microbiota, toxic materials, nutrients, odour-producing substances, tainting substances, light-attenuating materials, and unsightly (visually-degrading) materials among which faecal indicators, ammoniacal-N (toxic, oxygen-demanding and a nutrient), suspended solids and other light-attenuating materials in dairyshed lagoon effluents have been identified as priority pollutants (Davis-Colley, 1996). Therefore, these effluents represent a significant point source of pollution in New Zealand.

The characteristics of two-pond (anaerobic-aerobic) treated dairy effluent was investigated in New Zealand by Hickey et al.(1989) on 11 dairyshed oxidation ponds in two regions (Manawatu and Southland) which were designed according to national specifications. The results of that study have confirmed that the traditional two-pond systems are not sufficient to achieve the desirable level of treatment to protect the quality of receiving water and obviously these effluents need greater dilution. The results of that investigation of six priority pollutants and the relevant guideline values are given in the Table 1.7

Table 1.7 Characteristics of two- pond treated dairy effluent, stream guideline & dilution in New Zealand.

Variable	Stream Guideline	Effluent concentration		Dilution factor		Remarks
		Median	95%ile	Median	95%ile	
Faecal coliforms.	200 1000	70,000	540,000	350	2700	Health risk for bathing (DoH, 1992) stock watering, crop irrigation.
Nutrients						
DIN	0.040-0.1	75	216	750-1875	2160-5400	Promoting nuisance algal growths (MfE, 1992)
DRP	0.015-0.03	12	17	407-813	570-1140	Promoting nuisance algal growths (MfE, 1992)
NH_4^+-N (toxic)	0.22 0.77	75	191	341 97	868 248	Toxicity to NZ invertibrates, pH 8 (Hickey & Vickers,1994) Toxicity to salmonids, pH 8 (USEPA, 1985)
Visual clarity (light attenuation)	50%	0.03m	-	213	-	Visual water clarity impact (MfE, 1994) (for a stream with median visibility, 3.2m).
CBOD + NBOD (O_2 demand)	5	413	1068	83	214	O_2 stress on aquatic life (Hickey *et al*.,1989; Cooper,1986)
Suspended solids (organics)	4	198	804	50	201	Ecological impact (Quinn & Hickey, 1993).

Notes: Effluent data from Hickey *et al*.(1989), except for visibility data (from Sukias *et al*.,1995).

1. DIN = Dissolved Inorganic Nitrogen.
2. DRP = Dissolved Reactive Phosphorus.
3. CBOD = Carbonaceous BOD.
4. NBOD = Nitrogenous BOD.

1.4 ANIMAL WASTE TREATMENT OVERVIEW IN NEW ZEALAND

For the first century of livestock farming in New Zealand, the small proportion of total dairy waste concentrated in confined areas was usually discharged into streams and rivers. Before 1967, the farmers were generally reluctant to spend money for waste management. Beyond that, the simple and economic technology of animal waste management was also unknown (Dakers & Painter,1983). Due to the concern about natural environment particularly natural water, The Water and Soil Conservation Act,1976 through Regional Water Boards first imposed a "water right" to people-who desired to discharge wastewater into natural water or to land. But at that time there was a lack of technical expertise and understanding for planning, design, operation, monitoring and evaluation of treatment systems and what standards of effluent after treatment should be specified. Initially the land application of dairy shed wash down effluent by tanker or spray irrigation was considered satisfactory but pump and sprinkler blockages, seal and bearing failures in pumps, soil saturation and plugging in winter, the unpleasant and labour intensive task of sprinkler shifting, spread of weeds, and ground water pollution due to critical NO_3^- leaching induced farmers' disenchantment with these systems. The rate of sprinkler irrigation of waste was recommended by Ministry of Works and Development on the basis of hydraulic loading criteria rather than nutrient loading criteria. Hills (1975) noted that N was the critical for water pollution because of its higher mobility relative to P and K and recommended N loading rates on pasture based on 400 kg-N/ha/yr as given in the Table 1.8.

Table 1.8 Recommended area of land in hectares for land application based on N loading of 400kg-N/ha/yr.

Livestock	Fresh manure	Anaerobic winter storage	Anaerobic Lagoon	Aerobic treatment effluent.
100 cattle	0.64	0.88	0.44	0.22
500 pigs	3.7	5.1	2.6	1.3
10,000 poultry	10.1	14	7	3.5

Source: Dakers (1979).

Consequently, organic loading per hectare for land disposal became less meaningful than nutrient loading and due to this concept farmers and associated people looked for a satisfactory arrangement for economic disposal or management of the wastes. During the period between 1952 and 1980 the livestock population equivalent was increased about 60% with a corresponding 25% increase in grazing land area which indicates an increased intensity of animal population over a small area of land than previously used for waste disposal (Dakers,1979; Dakers & Painter,1983)

Before 1973-75, two stage anaerobic aerobic lagoon systems ware not considered viable alternatives. In 1972, Ministry of Works first specified lagoon systems which have received wide acceptance with regional water boards for permitting discharge from these lagoons into natural waters. Lagoon systems consist of two ponds in series, an anaerobic pond 3 to 4m deep with a design capacity of $42m^3$/kg BOD5, followed by a aerobic pond 1.2m deep with a surface area of 120 m^2/kg BOD5. A 70% BOD reduction occurred in the anaerobic pond and over-all 94% BOD reduction from the wastes ware measured (Dawn,1973).

There are some other systems such as trickling filters, sequencing batch reactors, anaerobic digester for biogas production and composting that have been tried in pilot scale by the New Zealand farmers and scientists but still none of them has been accepted for wide scale implementation. Although there are several anaerobic digester biogas plants installed in piggery and poultry farms they still need further technical development. Generally, the farmer is offered two alternatives; ponds or land disposal or a combination of these two (Dakers,1979) and even today these practices continuing to be used.

Dairy farm effluent in New Zealand is most commonly treated via waste stabilization ponds (two-pond system). The final effluent may then be released into streams or rivers or on to land. According to one estimate in 1985, half of the approximately 14000 dairy sheds in New Zealand were using pond systems (Hickey and Quinn,1992). In the Taranaki region, 1200 out of 2700 dairy sheds (44%) utilized pond systems in 1992 (Mason,1996).There were approximately 6000 dairy farms in Waikato region, 70% discharge their effluent to surface waters with 30% discharging to land (Environment Waikato,1994). The system is popular because of low operation and maintenance costs and the production of high quality effluents in terms of BOD and coliform level. However, their nutrient removal ability is not satisfactory (Mason,1996). The nutrient removal, particularly N by the two-pond system is proving insufficient to protect the quality of receiving waters. The effluent of two-pond oxidation systems offers additional benefit when it is applied to land, because much of its N is converted to NH_3 during the treatment process and this form of N is readily available for plant uptake (Taranaki Regional Council,2000).

Hickey *et al.*(1989) has reported that pond effluent has been found to vary widely in terms of Suspended Solids (52-804 g/m^3), BOD_5 (32-241 g/m^3), Nitrogen (7.2-216 g-N/m^3) and Phosphorus (4.6-17.1 g-DRP/m^3) and for the sake of water quality the effluents need 500-fold dilution for NH_3 criteria, >2700-fold dilution for faecal coliforms (bathing criterion), >67-fold dilution for coliforms (post-treatment drinking criterion) and >2700-fold dilution for nuisance control (algal proliferation). The organic matter, nutrients and Suspended Solids (SS) of effluent can cause river deoxygenation, nuisance growth of algae and macrophytes, depletion of Dissolved Oxygen (DO) levels. NH_3 are toxic to fish and invertebrates. Nitrification of NH_3 may also decrease DO levels. SS and dissolved organic matter reduce water clarity. Direct discharges of treated dairyshed effluent to surface water introduce contaminants such as NH_3, P, Faecal Coliform (FC), pathogenic bacteria and SS (Taranaki regional Council,1995).

Under the RMA 1991 regional councils are required to consider the Maori cultural concerns. Maori culture does not allow direct discharge of farm effluent to waterways but the purification of effluents through the land is much more acceptable to Maori and accordingly some Iwi and other Maori representatives favour pond, ditch or wetland systems which are land based treatment of effluent. That is why Waikato regional council has been encouraging the re-use of dairy effluent through land treatment systems as a permitted activity and providing financial incentives (Environment Waikato,1994).

For the above reasons most of the councils are moving towards managing effluent discharges in regard to NH_3, and pathogens. Land disposal of treated or untreated dairy effluent is encouraged by regional councils as a treatment/disposal/reuse option, where it is well managed (MAF policy,1994). From the above information it has become evident that two-pond systems are not sufficient to make the dairy shed effluent suitable for discharge to surface water and the existing systems need additional tertiary level of treatment to meet the criteria. There is a need for investigation and development of treatment/disposal technologies especially where land treatment is not a practical option. Technologies to consider are an additional maturation pond, use of zeolites, filtration, overland flow treatment bed, constructed wetland, rotating biological contactor and land application. One or more maturation ponds followed by a facultative pond can provide further polishing of effluent and especially they can remove coliforms significantly. Sukius *et al*.(1996) noted that four equal size ponds for treating domestic wastewater each having 2.5 day retention time achieved 3 decades reduction of faecal coliforms (0.1% remaining), whereas a single pond the same retention time (10 days) removed only 95% (5% remaining). Zeolites are crystalline hydrated alumino-silicates which are known to have an affinity for NH_4^+ and other cations (Nguyen,1996). Natural New Zealand zeolites (clinoptilolite and mordenite) can be used at the end of two-pond system or pond-constructed wetland sequence as a filtering bed to remove ammoniacal-N of dairy pond effluent, where clogging may not be a problem. Wetlands also commonly remove 70% SS of wastewater (Nguyen & Tanner,1998). The study carried out by Nguyen & Tanner (1998) suggested that although both clinoptilolite and mordenite are potential for NH_4^+ removal (87-98%), mordenite is more effective for NH_4^+ removal from dairy and piggery wastewater and this removal capacity was not influenced by the source of zeolite used and zeolite particle size.

Rock filters and back-flushable sand filters can remove a considerable proportion of SS and BOD_5 associated with algae in pond discharges, but to maintain through flow sand filters needs frequent back-flushing which is expensive and likely to provide insufficient benefit. In contrast, rock filters can be used with dairy effluent as biofilm can develop on the rock surfaces, nitrification and BOD conversion occur but these filters need periodic cleaning and rebuilding to remove clogging (Mason,1996). A by-product called ecoflow produced from the steel making process at BHP New Zealand Steel has been used to remove the nutrients in dairy pond effluent and an 80% reduction in SS and 90% removal of P was obtained. Removal through physical and chemical reaction processes has been proposed (Mason,1996).

Dairy effluent can be applied to soil for over land flow in the riparian zone before reaching a surface water body where a suitable slope of soil is available (2-10%). Effluent flows as a thin sheet, water saturates the upper soil layer than further effluent additions pass through the litter layer and grass sward. Suspended solids (SS) can be removed by settling and filtration. Nutrients are sorbed by the soil and microbial biofilm. Plants also assimilate nutrients. Aerobic degradation of organic matter and nitrification of NH_3 occurs. Denitrification of accumulated nitrate may also occur during flooding (Mason,1996). Results of laboratory-scale Rotating Biological Contactors (RBC) experiments carried out at National Institute of Water & Atmospheric Research Ltd, Hamilton, (NIWA) have shown that over 90% removal of ammoniacal-N is possible from dairy pond effluent with an initial concentration of 60 g/m3 at residence times of < 1 day (Mason,1996). Where land application is preferred, effluent may be passed through zeolite beds before land application.

Constructed wetlands can be used to reduce the organic pollutants from pond pre-treated dairy effluent through nutrient uptaking and storage by aquatic plants, sediments, detritus, microbes and fauna. Both surface and subsurface flow system can be used. Taranaki Regional Council prefers surface flow systems because they are simple to design, construct and operate and have the potential to produce a high quality effluent. However, subsurface flow wetlands require accurate and detailed engineering design and construction which may be difficult to achieve. For example, up-flow wetlands will often clog due to excessive algal inputs (Taranaki Regional Council,2000).

A study of dairy effluent treated through subsurface flow (SF) wetland (Tanner *et al*.,1995) concluded that planted wetlands are better than unplanted ones in terms of Total Nitrogen (TN) (0.15-1.4g/m2/d) and Total Phosphorus (TP) (0.13-0.32g/m2/d) removal. With gradually increasing mass loading rates the plants have the capacity to store N (3-20% of greater N removal) and P (3-60% of greater P removal). Final removal is achieved by harvesting the plants in the first year. Most studies of constructed wetlands performance have been carried out over limited time periods. Results from a 4 year long monitoring program of SF wetlands suggested that annual mean removal of Carbonaceous Biochemical Oxygen Demand (CBOD), SS, TP, and Total Kjeldahl Nitrogen (TKN) did not vary significantly over the years but soluble P removal declined markedly after second year and NH_4-N removal varied from year to year, ranging from 5-35% (P) and 31-51% (N) respectively (Tanner *et al*.,1998).

The gradual reduction of P removal in subsurface gravel bed constructed wetlands has been observed (Tanner *et al*.,1998). Tanner *et al*.,(1998) reported that the wetlands maintained their performance about CBOD, CNBOD, TN and Faecal Coliform (FC) removal over a period of five years but overall removal performance of TP and SS declined significantly over the years and the reasons could be the saturation of the key P removal processes (precipitation reactions and adsorption to detritus, humic materials, and soil minerals) and clogging. Since there are a finite numbers of P sorption sites in a wetland environment, these sites eventually saturated and when this happens, no further P removal will occur. If desorption of P occurs then the output could be greater than the input (Faulkner & Richardson,1989). Therefore, since the different regional councils are now looking for NH_3 and pathogen removal before discharging to a water body, constructed wetlands may offer an alternative tertiary treatment option because of their high pathogen removal capacity (92-99%) as observed by Tanner *et al*.(1998) and sustainable N removal through nitrification and denitrification processes. Maximum N removal in wetlands could be obtained when the NO_3-N concentration in the influent was high. However, the wetland was not efficient for removing ammoniacal-N.

Currently, land based systems are being actively promoted by various Regional Councils in New Zealand as the most preferred option for disposal of dairyshed effluents onto land (Taranaki Regional Council,1995). Land treatment of effluent after solid liquid separation is becoming more widespread. Irrigation of dairy-shed effluent on to pastures and cropping lands is being practiced increasingly by dairy farmers in New Zealand (Roygard,1999). The application of manure to land has been accepted because of its nutritive value as it offers a source of N,P,K and S fertilisers and trace elements which increase pasture and crop production and improves soil water holding capacity, soil aeration, drainage and soil tillage characteristics (Taranaki Regional Council,2000). One of the problems with this practice, however, is the potential for contaminants, such as pathogens and heavy metals in the effluent to enter the food chain (Di et al.,1998; Silva et al.,1999).

Fertilizer nutrients in manure can be recycled through land application but salt nutrients (Na and Cl) in manure are a potential limitation where the soils salt content is high especially in dry or low rainfall areas (Van Horn et al.,1994). Land application of effluent causes release of inorganic N in the form of NO_2^- & NO_3^-. Nitrite (NO_2^-) is usually transitory in soils as it is microbially converted to nitrate (NO_3^-) but it may accumulate in soil under certain conditions and it is toxic to higher plants even in very small quantities. Nitrate (NO_3^-) is a highly mobile anion, readily utilized by plants and microorganisms but it may readily be leached from the soil and thus contaminate ground water thus representing a potential human health hazard.

Nuisance problems in the vicinity of land application actually may occur. Its operation and maintenance cost is medium to high and extra attention has to be given to separated solids which need to be removed and hauled off the dairy farm. Also, control of K concentration during application is required in order to ensure edible crop production (Mason & Young,1999). This implies higher land areas, greater pipe systems and increased pumping costs. Sometimes, land application may not be possible due to weather conditions or mechanical failure. Extra costs subsequently are borne for storage facilities in high rainfall areas. Land application technology involves transportation of effluent and some sort of mechanical devices for irrigation which are also costly. In addition, both pond and land treatments produce some solids during solid-liquid separation in anaerobic pond or holding pond which has to be managed either by landfill or composting. Thus, neither of these systems is able to treat solid and liquid fractions in a single phase of treatment and pose therefore, medium to high management costs. One major limitation of land treatment is the lack of required acreage for disposing manure nutrients from large dairy farms. Here, nutrients cannot be applied in excess of crop requirements and off farm disposal of excess nutrients must be considered. Therefore, there is a great need to utilize technology that partitions fertilizer nutrients from manure and water so that surplus nutrients can be transported economically to other farms or regions where there are in deficits (Van Horn et al.,1994).

1.5 IS COMPOSTING AN ANSWER?

Rather than thinking of manure management as a burden, it can be viewed as an opportunity with which the dairy farmer must deal so as not to waste the nutrients in the manure. That's why composting makes so much sense. The economic viability of composting is predicted on the fact that the feed stock for the operation is generated on the farm. There are no hauling costs and no need to collect it (Glenn,1998). Dairy manure slurry contains a high water content (around 90%). Composting is a method of processing manure slurry whereby heat is liberated from the decomposition of organic substances and this released heat drives the evaporation of water, which is removed in exhaust gases (Patni & Kinsman,1997). Reducing the large amount of water in the slurry leads to a reduction in mass, bulk weight & volume. Thus, there is a large potential to reduce transportation and handling costs for disposal as well as the area of land required for manure application. Composting can also reduce the risk of pollution from runoff, odour, and nitrate contamination of ground water (Patni & Kinsman,1997). These ideas are reviewed in the next chapter of this work.