AGRICULTURAL ODOURS
-AN IRISH PERSPECTIVE OF THE NUISANCE

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Degree of Master in Science in Environmental Protection

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Dedication

I would like to dedicate this document to a wonderful person who has touched my heart since we first became acquainted nineteen years ago. She was a great source of inspiration to everybody who knew her and demonstrated the real value of a background driving force. We all hope you continue to inspire us in the same manner in the future from God's home in heaven.

To Mrs Esther McMorrow. I thank you.

AGRICULTURAL ODOURS
AN IRISH PERSPECTIVE OF THE NUISANCE

Padraig Doherty

Summary.

Animal numbers have continued to increase over the past decade. Associated with this is an increase in the amount of animal manures to disposed of. The odours associated with this manure are perceived to be a problem. The extent of the problem in Ireland has not been quantified. Therefore a survey of Local Authorities to assess the number of odour complaints received, was undertaken. Only four Local Authorities were deemed suitable for follow-up contact.

The level of odour complaints is small in comparison to the total number of agricultural complaints received. Odour pollution is short-lived compared with water pollution. The public are more likely to complain about pollution that is more persistent. They appear to be more "tolerant" of odours from agriculture. Improvement in the recording system within Local Authorities and better follow-up action would improve the confidence in the odour complaints procedure.

Land spreading of slurry was identified as the commonest source of odour complaint. It represented 81% of all the agricultural odour complaints received by the four Local Authorities. Land spreading of slurry in accordance with the Teagasc Code of Good Practice to reduce odour emissions will reduce nuisance. Communication with neighbours who are sensitive to odours, can reduce potential annoyance. Buffer zones can reduce odour nuisance but further research is required regarding the sizing of these zones. The majority of slurry is applies using a conventional vacuum tanker with a splash plate. Pig slurry spreading in comparison to other slurry results in a higher level of complaints. The use of bandspreading of pig slurry is recommended where odour is giving rise to complaints.

The various treatment options of slurry were reviewed. Technologies such as aerobic and anaerobic digestion are effective odour control strategies. However, they are expensive. Other odour control methods including mechanical separation, incorporation into soil, composting, additives, dietary control, bioscrubbers and biofilters are considered.

Chapter1

Introduction

1.1 Introduction

The 1996 livestock population in Ireland is 6.76 million cattle, 1.67million pigs and 13.4 million poultry (CSO 1997), which is an average increase of 5% on the previous twelve month period. It represents a continuing increase in animal numbers over the last decade (Teagasc 1994). The decrease in the farming population has led to the intensification of agriculture, more urbanised societies and a change in public attitude to farming practices. Associated with this intensification of agriculture has been an increase in the management challenges created by the manures. Carton and Majette (1996) estimate that approximately 40 million tons of manure are produced annually by housed animals. The odours associated with the management of this manure are perceived to be a problem. The 1987 Air pollution Act makes it an offence to create an odour nuisance. However, the extent of this problem in Ireland has not been quantified. Codes of Good Practice to reduce odour emissions have been formulated by various Government Agencies. It appears that these are based on common sense rather than research. Research has been conducted on strategies and technologies to control odour emissions from agriculture. There are systems with the potential for odour reduction but they are costly. The objectives of this thesis are as follows;

To review the relevant literature pertaining to odours from agriculture and their control;

To quantify the extent of the problem in Ireland by means of a practical survey;

To suggest possible strategies regarding the issues raised in relation to the best practical means of reducing the nuisance they cause.

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Chapter 2

Literature Review

2.1 Introduction

Most research, advice and education have revolved around the impact of agriculture on water resources. Considerable funds, both national and E.U. have been expended in addressing the problem. The economical and environmental effect of ammonia loss from livestock production has been extensively researched, particularly in Europe, over the last decade. A number of strategies and technologies to minimise this loss were identified. However, research on odour emissions from agriculture, particularly in Ireland, is relatively new.

This literature review attempts to summarise recent research and development on odour emissions from agriculture. The identification of the numerous odour causing compounds and various agricultural odour sources are investigated. Measurement of odour is discussed together with a number of control methods.

2.2. Definition/Perception/Nuisance/Annoyance

Odours from livestock farms, are not usually harmful to the environment or to human health. However, offensive odours from agricultural activities can interfere with people's enjoyment of their home and countryside. Odour has been defined as the subjective interpretation and response to what people detect in their breathing air through their sense of smell (Person *et al*, 1995). Odours are most likely generated by agricultural activities which involve housed livestock, storing of manure or spreading of livestock manure (MAFF, 1992). Some of these odours may be considered tolerable or pleasant if they are consistent with the individual's perception of the rural environment (Lohr, 1995). An example of this is the odour from freshly cut hay. Odour is viewed as subjective because people react differently depending on a variety of factors (Thu and Durrenberger, 1995). The basis for varying responses may not be odour *per se*, but rather a series of social concerns and conditions. However, the odours associated with livestock production systems can be perceived by the public as a nuisance and a source of annoyance if they are at odds with expectations about rural air quality. Nuisance is often defined as that which unlawfully annoys or does damage to another or that which annoys or disturbs the others free use or enjoyment of their property (Patterson, 1995). Nuisance liability arises regardless of fault. Annoyance is a general feeling of displeasure or aversion towards a source. It can involve mild anger or fear (de Boer *et al*, 1987; Evans and Tafalla, 1987). Since smell is the most sensitive of the human senses, it is not surprising that nearby residents are the first to detect a change in rural air quality (Lowe, 1995).

2.3. Odorous compounds in animal manure.

A complex mixture of a large number of volatile compounds is responsible for the mal-odours associated with animal manure, particularly slurries or liquid manure. These are produced through a series of physical and biochemical processes (Hobbs *et al*, 1995) associated with the incomplete anaerobic breakdown of a mixture of faeces and urine and the accumulation of the intermediate compounds of the breakdown process (Fig. 2.1). Parameters such as airflow, temperature of the air and slurry, slurry stirring rate (Hobbs *et al*, 1995) and various other factors which are unfavourable to complete anaerobic breakdown of the manure cause unpleasant odours to be produced.

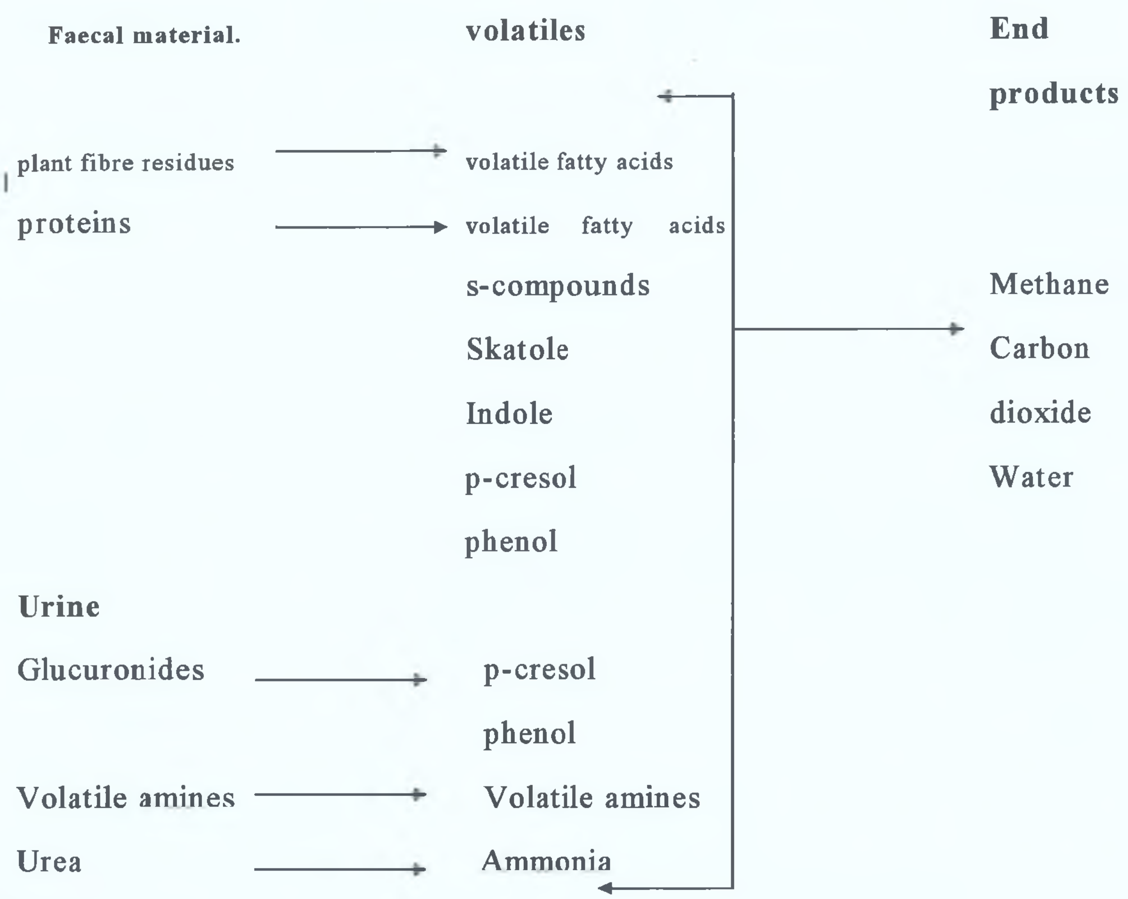

Figure 2.1. Summary of the microbial breakdown of animal manure(Adopted from Pain and Bonazzi,1994)

Anaerobic breakdown during storage produces fatty acids and other substances that are intensely malodorous. These are released at the point of storage, when the manure is disturbed, and in particular when the material is spread on the land (Working Party Report, 1974). Up to 168 compounds have been identified. The main groups include volatile fatty acids, aldehydes, alcohol's, esters, phenols, indoles, sulphur containing compounds and volatile amines. Many have very low detection thresholds. Schaefer (1977) has identified indole, skatole, phenol, and p-cresol as being the most important odorous compounds in pig slurry.

Many studies have been conducted which attempt to classify odour on the basis of its chemical composition. Most of these have been concerned with pig rather than cattle or poultry manure. For example, Hobbs (1995) identified and classified a number of compounds commonly found in the odour emissions from pig slurry. An odour emission's chamber was used to study the emissions. The compounds identified in the headspace are shown in Table 2.1. It also identifies diluted slurry to be much less odorous than undiluted slurry. This list is not exhaustive. Considerable variation can be found in published data. These may arise from differences in analytical techniques and variations in the slurries analysed. The diet, age of the animal length of storage as well as dilution all influence the composition. Odam *et al*, (1985) has identified a number of sulphur containing compounds in undigested cow and pig slurry. All of these compounds are highly odorous.

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Table 2.1 Odorants and their concentrations in the headspace above pig slurry. (Hobbs, 1995).

Odorant	undiluted slurry (gm^{-3})	diluted slurry(gm^{-3})
hydrogen sulphide	15	3
methanethlol	36	n.d.
dimethyl sulphide	14	n.d.
dimethyl disulphide	12	n.d.
dimethyltrisulphide	5	n.d.
acetic acid	47	18
propanoic acid	2.5	0.02
2-mehhyl propanoic acid	0.2	n.d.
butanoic acid	1.1	n.d.
3-methyl butanoic acid	1..1	n.d.
pentanoic acid	0.2	n.d.
phenol	4.8	4.3
4-methyl phenol	7.0	4.6
4-ethyl phenol	4.9	0.48
indole	0.12	0.26
3-metyl indole	0.13	0.36
	odour units m^{-3}	odour units m^{-3}
odour concentration	5 million	0.5 million

2.4: Measurement of odours.

Measurement of odours can be achieved using either chemical, organoleptic or olfactometric techniques. The use of instrumental techniques to quantify total perceived odour sensation presents a number of difficulties. These include the correlation of concentrations of odorous compounds with odour perception and annoyance (Schamp and Langenhove, 1985). Where a relatively small number of odorants can be identified as contributing to a smell, chemical analysis can provide a means of evaluating odour abatement strategies. Many attempts have been made to relate various chemical parameters of slurry to odour concentration, intensity or offensiveness and to find indicator compounds (Kowalewsky, 1980; Spoelstrs, 1980; Williams and Evans, 1981; Barth *et al,* 1974 and William, 1984). However, to date, no satisfactory indicator compound has been identified which could be used to predict odour offensiveness, intensity or emissions in all cases.

Organoleptic techniques, *i.e.* those which involve the use of the human nose, are more appropriate where the odour results from a complex mixture of compounds. Various scaling techniques have been used with observers sniffing the headspace gases from odorous liquids held in flasks (Barth *et al,* 1974; Williams, 1984). These are cheap and relatively easy to do but provide limited useful quantitative data compared with the olfactometric methods.

Olfactometry remains the most widely used technique in the measurement of odour concentration, intensity and offensiveness. It is based on the assessments of a group of trained people, (selected to be representative of the population), called a "panel", under controlled laboratory conditions. Some variations exist in the methods and instruments used but certain factors are common. Static and dynamic sampling procedures are used for olfactometric

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measurements (Hartung, 1985). The type of sampling procedure used will determine the type of olfactometer to be used or *vice versa*. Static measurements involve the collection of odourous air samples in a vessel/bag for subsequent introduction to the olfactometer. This method is best for the accurate measurement of threshold concentrations of single odorants or as a reference for other olfactometric measurements. It allows measurement of odour at sources that are not readily accessible. However, this method is slow. Dynamic measurement is faster. It requires a partial flow of the odorous gas to be continuously extracted from the source and subsequently directed to the olfactometer. This instrument mixes known quantities of the odour sample with known quantities of odour-free air to give a known concentration of the odorant at the sniffing port. The odour panel assesses the odour stimuli, at the sniffing port. The odour concentration is the number of dilutions required to reach the detection threshold of the sample for 50% of the odour panel members. It is expressed as odour units m^{-3}. Background odour concentrations measured in rural areas are typically 30 odour units m^{-3}. There are few situations where farm odour concentrations at source are more than 5000 odour units m^{-3} of air, where as industrial odours may have to be diluted over a million times to reach the odour threshold (MAFF, 1992). Odour intensity is a subjective measure of the relationship between odour concentration and perceived sensation as ranked on a scale by the odour panellists (Thacker and Evans, 1985). This is an important measure in assessing nuisance because they provide useful data on the relationship between odour concentration and sensation. It is noteworthy that major changes in the odour concentration are required to affect a change in odour intensity. This means that odour abatement strategies must be very effective to make perceivable changes in odour intensity. Odour offensiveness is a measure of the acceptability of an odour as ranked on a scale by the odour panellists

(Thacker and Evans,1985). It is more properly called hedonic tone because odours can range from being extremely pleasant to extremely offensive. Odour emission rate is the product of odour concentration and the volumetric flow rate. The unit is OUs^{-1} and is a measure of the mass flow rate of odour from a source. It is an important measure in assessing odour nuisance.

2.5: Sources of odour emissions.

Sources of odour emissions from agriculture can be classified into four broad categories namely landspreading, livestock buildings, manure storage and silage.

2.5.1: Landspreading emissions.

The odours from landspreading of manures can be divided into two phases - during landspreading and following spreading from the manure on the land surface.

2.5.1.1. During landspreading

High rates of odour emissions occur during the spreading of animal slurries using the conventional splashplate tanker. This method results in slurry droplets or aerosols in the air and is a common cause of complaint of nuisance from the public. Such aerosols have been detected eight kilometres down wind during spreading operations. Where the liquid waste is spread in reasonable quantities, *e.g.* up to $33m^3ha^{-1}$, the odour will not travel more than 400m (Working Party Report, 1975). Odour emissions immediately after spreading increase in line with increasing application rates (Phillips *et al*, 1991). However, this increase is not linear. An even application rate of $22m^3ha^{-1}$ results in a 2mm layer of slurry on the ground surface. Tankers equipped with multi-tube applicators or with dribble-bars are the most cost affective for surface spreading slurry with reduced odour (Phillips and Shroud, 1984). Hall (1995) identified the features of equipment design that influence the risk of odour problems arising from surface spreading. The measured odour concentration during the spreading of pig and cattle slurry was measured at 2020 and 1059 odour units m^{-3} respectively (Pain and Klarenbeek, 1988). The rates of odour emission for these concentrations, although dependant on wind speed, was 100 to 400 odour units s^{-1}. However, odour emissions of up to 954 $x10^3$ odour units s^{-1} have been measured during the spreading of pig slurry.

2.5.1.2 Following land spreading.

Fields on which manure is spread for utilisation by crops have a large, but short-lived potential for odour production, depending on the nature of the manure's and the weather (Barth *et al*, 1984). The highest odour concentrations are recorded during the first hour after the slurry has been applied to the ground surface (Fig 2.2). These high concentrations decline rapidly to much lower values that persist for 36 to 60 hours (Pain *et al*, 1991). Odour emissions follow a similar temporal pattern but are subject to influence from a range of factors including wind speed and air temperature.

High application rates (> $55m^3ha^{-1}$) may result in anaerobic conditions developing in the field and high emission rates of odour (Working Party Report 1974).The rates of emission during land spreading are higher compared with following land spreading but they account for only about 1% of the total emission after spreading. If the manure is properly applied to the land, the

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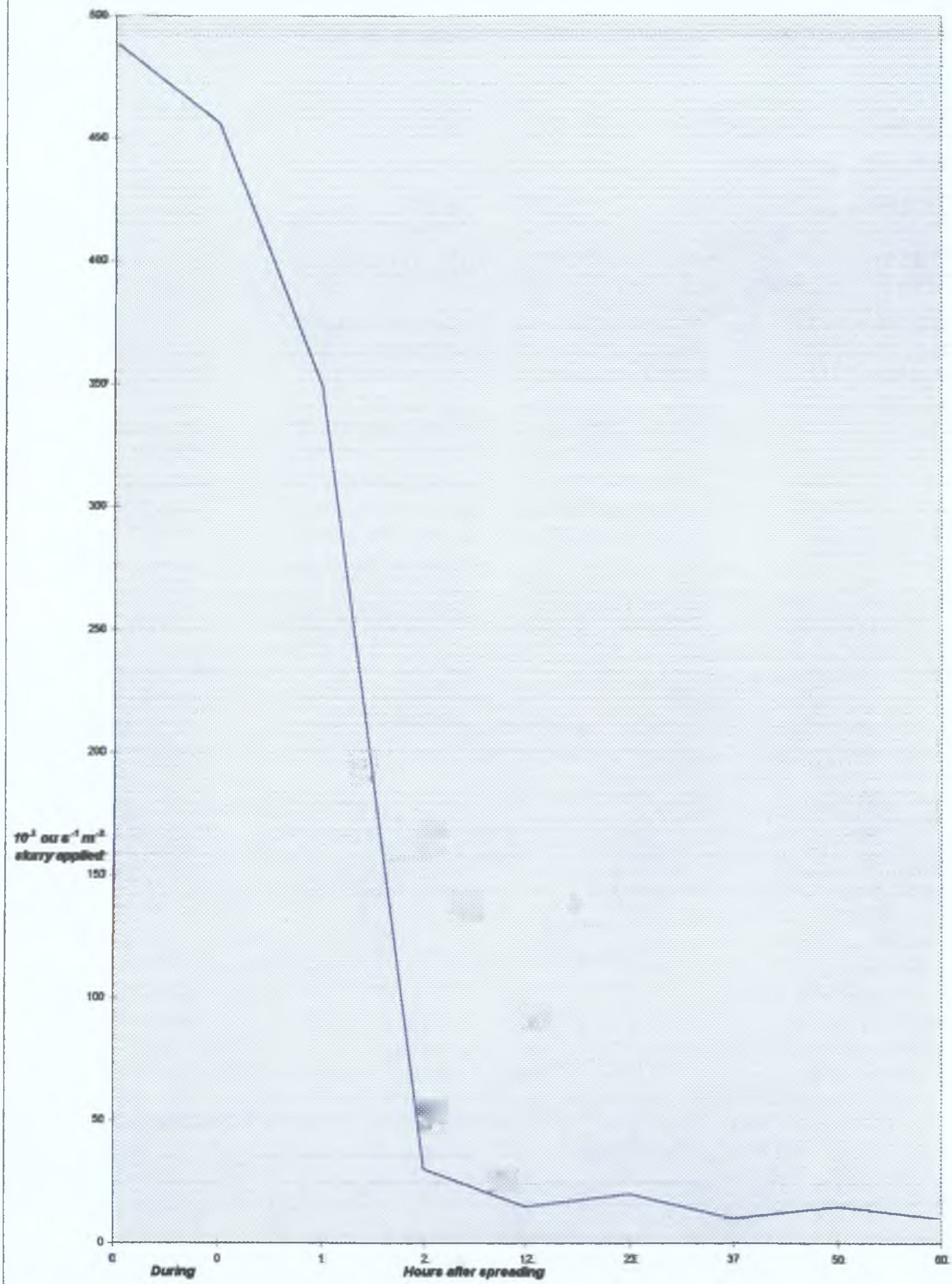

Figure 2.2 Odour emission during and following application (adopted from Pain, 1995).

normal aerobic soil processes will remove most of the odour and the residual odour on the spreading area can then pass quickly.

Initially, odour emissions are higher following the spreading of pig compared with cattle slurry (Pain *et al,* 1991). Withdrawing slurry from the top or bottom of the tank or mixing prior to spreading also effects odour emissions. The accumulation of volatile fatty acids in the bottom layers appeared to account for these differences.

Table 2.2: Odour emissions over 24 hours after spreading stored pig slurry and some slurry properties.

	Odour emissions (odour units x 10^3 m^{-2})	Volatile fatty acids mg l^{-1}	Total solids (%)
slurry from top of store	1588	1197	0.82
slurry from bottom of store	6370	8707	8.1
mixed slurry	3356	5864	3.7

There is some evidence that odour from spreading cattle or poultry slurry persists for a longer period than that from pig slurry. Peak emissions from the landspreading of drier poultry manure are not reached until about 24 hours after spreading unlike semi-liquid slurries.

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2.5.2 Animal confinement areas

Odours from livestock buildings derive primarily from the anaerobic breakdown of proteinaceous materials including faeces, urine, skin, hair, feed and bedding materials. Odour concentrations in buildings will be influenced by stock type and numbers, building design and the manure management practices. Holding pens and yards, soiled with manure, are a major source of odour (Barth *et al*, 1983).

Different manure management systems have been shown to influence odour in buildings. Prompt removal of manure from piggeries (Braun, 1983; Klarenbeek *et al*, 1982) and poultry houses (Raabe *et al*, 1984) is a certain way of avoiding production of the very offensive odours associated with anaerobic decomposition. Odour concentration in pig and poultry housing air with different waste management systems is shown in Table 2.3.

Table 2.3 Odour concentration in pig and poultry housing with different waste management systems (van Geelan and van der Hock, 1982).

	Pig housing				Poultry (layers) housing			
	slurry storage		Dry manure storage		Belt manure system		slurry storage	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Odour conc. (odour units/m^3)	97	20-280	39	11-76	59	11-169	258	94-412

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Drier poultry manure is less offensive than manure diluted with water and frequent removal of manure using scraping reduces the offensiveness of odour emissions in the ventilation air (Sobel, 1972). The design of the floor influences emissions from pig units (Klarenbeek *et al,* 1982). The quantity of bedding material used influences the extent and nature of manure decomposition. The two properties of bedding likely to exert the greatest influence on odour production is the quantity it can absorb and its physical structure. When using straw the resulting manure is reported to be less odorous than slurry (Williams and Evans, 1981). However, there is little published information on the odour abatement potential of different bedding materials.

Ventilation can influence odour emissions directly by affecting the extent and rate of manure drying and indirectly by influencing the dunging behaviour of the animals. Poor ventilation can result in humid conditions that give rise to the production of unpleasant odours, high levels of ammonia and poor animal health.. The system design should ensure that the ventilation air does not pass directly over the stored manure. The type of ventilation system may influence odour within the building and emissions from the building but there is little data available. The height and number of outlets, for the ventilation air, also influence the odour concentration outside the building.

Odorous compounds may be absorbed and transmitted on dust. Dust within animal houses originates mainly from the feed (80% - 90%), the bedding material, the manure (2% -8%) and the animals themselves (2% - 12%)

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(Hartung, 1985). The factors determining the amount of dust in confinements includes animal activity, temperature, relative humidity, ventilation rate, stocking density and volumetric air-space per animal, feeding method and the nature of the feed. The odour from it arises from the material itself and any absorbed volatile compounds. Volatile fatty acids and phenolic compounds contribute mostly to the strong, typical odour of animal houses. Investigations of dust from piggeries (Hartung, 1985) show that both volatile fatty acids and phenols / indoles are present in considerable amounts. A number of studies (Geelan, 1982; Eby and Wilson, 1969) have shown that reducing dust in the air reduces the odour concentration in poultry houses as well as improving the general conditions within the house. However, the results are not conclusive as there are some reports (Batel, 1975; Williams, 1989) which show that filtering the dust had no significant effect on odour concentration.

Manure storage systems range from solid manure to slurry based to liquid handling systems. Adequately sized, properly constructed, lead-proof storage facilities are a fundamental requirement for on-farm management of manures. Under the climate conditions prevailing in this country, it will generally be necessary to store concentrated organic fertilisers (comprising all animal excreta, dungstead and farmyard manures) produced on farms for most if not all of the housing period (Department of the Environment/Department of Agriculture, Food and Forestry, 1996). Data on odour emissions from manure storage facilities is relatively scarce. Generally, the maximum odours occur from manure storage systems when manure is being agitated and removed for land application.

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Measured emissions from slurry stores were higher for pig slurry compared with cattle slurry. Similarly, they were higher in summer than in winter (Copelli *et al*, 1986). Carney and Dodd, (1989) found higher emissions from slurry stores during agitation with emissions increasingly higher for cattle, pig and poultry slurry stores, respectively. Odours are reduced by covering slurry stores (Mannebeek, 1986 and de Bode, 1991).

2.5.3 Silage and soiled water odours.

The production of silage involves a fermentation process that means all silage will have a smell. A good fermentation process produces little odour. However, an unstable fermentation with decomposition can produce obnoxious smells (Working Party Report, 1974). Good ensiling techniques will therefore ensure odour emissions will be minimised. The liquid effluent that drains from the silage, as well as being a serious water pollutant, can be a major source of odour if allowed to stand and not carefully collected.

Soiled water consists of washing from milking parlours and dairies, run-off from open cattle yards, silos, *etc* (Department of the Environment/Department of Agriculture, Food and Forestry, 1996). It can be a major source of odour if anaerobic activity takes place. This occurs where land spreading is not possible for long periods.

2.6. Methods for reducing odour.

Control in farm situations is rarely simple and straight forward because within agriculture there exists a wide interplay of factors including the weather, types of animals, labour requirements, storage periods, housing design, manure handling systems, other husbandry methods and population movement. Common-sense approaches and good hygienic management of both buildings and manure can avoid creating a public odour nuisance. These are summarised in the Teagasc Code of Practice to reduce odour emissions. They include checking wind direction in relation to neighbours' houses before spreading manure, not spreading close to houses or buildings or at weekends or public holidays when people are likely to be at home.

It must be recognised that it is impossible to eliminate all odours from livestock production because either the technology does not exist or is too expensive. This is recognised in legislation in many countries. The concept is to minimise odour emissions by good management practices and allow for the diluting effect of air movement and dilution by distance to remove odour. Minimum distances for the siting of livestock buildings, house's *etc* have been set. In the Netherlands the minimum distance is 50m from dwelling houses while in Germany the minimum distance is 100m for piggeries and 200m for poultry houses. However, it must be recognised that there is very limited data available on which to base these. Current recommendations are generally based partly on experimental work and the experience of research workers and advisors concerned about the problem. For example, in a re-evaluation of

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distance graphs as a technique for odour abatement in the Netherlands it concluded that the existing distance graph's to control odour from livestock housing are successful (Klarenbeek, 1995). These were originally developed in the nineteen sixties.

The use of shelter belts can assist in the dispersal of odours. However, these must be well planned and the trees spaced to allow for 40 to 50% wind permeability. Dense groups of conifers should be avoided and preference given to planting irregular shaped trees of various species (Nielsen, 1986).

2.6.1 Improved management

High standards of management, hygiene, cleanliness and maintenance are required to minimise odour emissions from livestock production systems. These will include regular removal of manure to storage areas where possible; avoid the accumulation of manure around and within empty buildings, holding pens and yards, removal and disposal of dead stock and foetal remains immediately; avoid ponding of effluents due to poor drainage; maintain and replace leaking drinking systems which result in wet floor areas. Clean buildings regularly; remove thick deposits of dust; avoid over stocking; and avoid badly designed floors.

It is worthwhile getting specialist advice in the design of ventilation systems for livestock buildings. It will not only reduce odours but also ensure a healthy environment for man and beast. Well designed and maintained systems

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ensure the lying area remains clean and the dung is deposited on the slats (Randall *et al*, 1983). Release of odour may be reduced as most of the manure goes directly into the storage pit.

2.6.2 Bioscrubbers and Biofilters.

The odorous chemical compound in the air discharged from livestock buildings will dissolve in water. These dissolved compounds can be used by micro-organisms as a substrate for growth. Two types of systems have evolved for the reduction of these compounds in the exhaust air - bioscrubbers and biofilters. Both are biologically based and therefore require higher levels of management compared with chemical or physical processes. The associated costs are often high.

Bioscrubbers involve passing the air through a film or mist of water to achieve contact. The water then passes to a treatment chamber in which the odorous compounds are used by aerobic micro-organisms and thus removed from the water. Another technique involves the use of a medium with a large surface area to volume, on which the micro-organisms develop and degrade the odorous compounds. Removal of excess biomass and dissolved ammonia are carefully controlled to maintain the pH and to reduce the volume of liquid drained off. Adequate storage for this liquid is required ($1m^3pig^{-1}year^{-1}$) and it must be managed properly to ensure it does not cause water pollution. Up to 80% reductions in odour emissions with bioscrubbers can be achieved (Schirz,1990). Similar investigations by Klarenbeek showed that odour

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abatement efficiency of well-maintained bioscrubbers in a piggery varies between 77 and 94% (Klarenbeek, 1993a,1993b,1995a , 1995b).

Biofilters are based on impeding the air flow through a damp porous medium such as soil, peat or woodchippings. They consist of a plenum chamber below the filter medium. Air is blown into the chamber and filters up through the biolfilter medium which can be up to 1m thick. The medium must be kept moist to operate efficiently and this may require an irrigation system. Reductions of 75 and 85% in odour and ammonia emissions are possible providing appropriate design principles (Zeisig, 1987) and regular maintenance are followed.

2.7. Treatment of manure

Treatment of livestock manure and of odour emissions from buildings is a step beyond currently accepted good agricultural practice. Treatment systems to reduce odour should only be considered when good practice has failed. They are expensive both in terms of installation and running costs.

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2.7.1 Separation

Mechanical separation can be useful as an aid to improved manure management. The faeces, urine and water can be separated in the building using a combined separation and manure removal system. This is achieved by the use of a filter bed fitted beneath the slats in the floor of piggeries (Kroodsma, 1986). About 35% of the total faeces and urine is separated into a stackable solid while the remaining liquid is taken from the building for storage in a tank. The removal of both streams on a daily basis results in 49 to 59% lower odour emissions from the ventilators of building's compared with conventional under slat storage systems.

Mechanical separation of slurries based on screens, presses and centrifuges are used to improve the handling and storage of slurries. It is generally a pre-requisite for the aerobic treatment of slurries to reduce odours. The solid fraction can be stacked and stored while the liquid fraction is more easily applied to land with low emission spreaders such as band spreaders or injectors. Raw slurries with a dry matter between 3 and 9% are most suitable for separation. The liquid fraction generally represents 80 to 85%, of the original volume with a dry matter content in the range of 3 to 6%, and consists of fine solids and dissolved salts. The solid fraction represents 15 to 20% of the original volume and has a dry matter in the range 12 to 32%. The solid fraction removes hairs, grit, bedding materials and the larger undigested residues in the faeces. A reduction in odour concentration following land spreading has been reported (Table 2.4). This effect is probably due to better infiltration of land spread slurry in the soil.

Table 2.4 Effect of separation on the temporal trends in odour concentration (odour units m^{-3} air) following land spreading (Pain and Bonazzi, 1994)

	Odour Concentration (odour units m^{-3} air)			
Hours after spreading	0	4	28	52
Slurry treatment				
Untreated	201	173	71	99
Treated	147	121		34

2.7.2. Aerobic treatment

The primary objective of aerobic treatment of slurry is odour control. Up to 90% reduction in the amount of odour emitted during and after land spreading can be achieved by aerobic biological treatment systems that are correctly designed and used. The odour concentrations following the land application of aerobically treated slurry are shown in Table 2.5 (Pain and Bonazzi, 1994). During the process oxygen is pumped into the slurry mass and facilitates the aerobic breakdown of the odour causing compounds. The energy costs required for aeration is a major factor that has prevented aerobic treatment from being used widely for manure treatment. For the most economical operation, aerators should supply a minimum of 1 kg of dissolved oxygen for each kilowatt of energy demand. There are a range of systems available from the more efficient sub surface and venturi type systems to the compressed air type sparge systems often used in deep storage tanks (Sneath *et al,* 1990; Svoboda *et al*, 1990; Skjelhaugen, 1990).

Table 2.5. Effect of aerobic slurry treatment on the temporal trends in odour concentration (odour units m^{-3} air) following landspreading (Pain and Bonazzi, 1994).

	Odour concentration (odour units m^{-3} air)			
Hours after spreading	0	4	28	52
Slurry treatment				
Untreated	201	173	71	99
Aerobic treatment	106	30	66	43

A number of studies on aerobic treatment (Sneath *et al,* 1992; Copelli *et al,* 1985; Williams *et al* 1985) concluded that the level of odour reduction was dependant on the operational parameters of the treatment system. These include the selection of the most appropriate aeration time, reaction temperatures and dissolved oxygen level to be maintained in the aerated mixed liquor. A clear definition of the treatment objectives for each particular farm enterprise is also necessary. Up to two days aeration is required for control of odour at land spreading while closer to four to five days is required for odour control during storage. The more oxygen supplied to the slurry the greater the odour control. However, this generally requires more energy. The stabilised manure after aerobic treatment can be stored for at least a month before the odour returns. Aeration systems must be operated at maximum efficiency to ensure cost effectiveness.

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2.7.3. Anaerobic treatment

Significant reduction in odour is possible in animal manure using anaerobic treatment. This system is used with higher dry matter slurries. It consists of a series of reactions during which the organic matter is converted to methane and carbon dioxide. The slurry in the reactor is heated to either 30 to 35^{o}C or 55 to 77^{o}C under anaerobic conditions. It is maintained at this temperature for between 10 and 30 days depending on slurry type. The microbial reactions are complex and have been described by Pffeffer (1979) and Hobson *et al* (1981). The reduction of the typical smell of slurry by anaerobic digestion is a result of the breakdown of the known odour causing compounds in the slurry. Volatile fatty acids may be reduced by up to 93% (Summers and Bousfield, 1980) and phenol and p-cresol virtually eliminated (Velsen, 1979). Odour emissions following land spreading of anaerobically digested pig slurries are reduced compared with untreated slurry (Table 2.6).

Table 2.6 Effect of anaerobic slurry treatment on the temporal trends in odour concentration (odour units m^{-3} air) following land spreading (Pain and Bonazzi, 1994). Pig slurries from digesters on two commercial pig farms was used.

	Odour concentration (odour units m^{-3} air)	
Hours after spreading	0	6
Slurry treatment		
Farm A Untreated	611	15
Farm A Anaerobic Treatment	143	31
Farm B Untreated	1101	23
Farm B Anaerobic Treatment	223	5

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Demuynch *et al* (1984) compared the design of many anaerobic systems. Newer, cheaper and more reliable systems have been developed. In addition, anaerobic digestion has other benefits such as waste stabilisation and liquefaction and production of biogas an alternate fuel that can be used as an energy source. However, to ensure viable gas yields are achieved there is a need to include other high carbon containing biosolids with the manure. Following digestion the slurry is often separated and the solid fraction is composted. The fertiliser value of the raw manure is conserved in the digested effluent (Field *et al,* 1984; Dahlberg *et al*, 1988). There is also a considerable reduction in the number of pathogens (Demuynck *et al*, 1985).The digested slurry can be stored for several months after it has been treated before offensive odours return.

2.7.4 Composting

Composting is a process in which solid manures or separated solids undergo an aerobic degradation to produce a stable odour free product that can be used as a source of organic matter. An important criterion in composting is to achieve a carbon / nitrogen ratio of 30:1. In the case of some solid manures such as poultry manure this may require the addition of straw. Ammonia emissions from the process are often high (Bonazzi *et al*, 1988). The material should have a dry matter content 30 to 60%. Where the dry matter is too low there may be difficulty in having sufficient oxygen in the pore spaces of the compost heap. The control of airflow is important for even composting. This is achieved by forcing air through the composting material or regular turning of material. Temperature control is also important with the optimum range being 55 to 60^{o}C. The control of air supply or turning is used to control temperatures (Finstein et al, 1985; Biddlestone and Gray, 1985). Composting

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generally takes three to four weeks to complete with a further two to three to cool and stabilise.

2.8 Land spreading machinery

Odours from spreading manure's and slurries can be detected at various distances from the field of application (Carney and Dodd 1989). This depends on the weather, type of waste and method of spreading. The rate and total odour emissions from the land spreading of slurry is determined by the type of spreading equipment used. Injectors and low trajectory spreaders reduce odour emissions compared with vacuum tankers and irrigators (Phillips *et at*, 1990). Deep injection (150mm), shallow injection (60mm) and bandspreading reduce odour emissions by 83, 70 and 38%, respectively, compared with the conventional splashplate. The higher emission rates occur when the jet of slurry shatters into very small droplets upon contact with the splashplate or similar devices and encourages the loss of the volatile odour causing compounds into the air. Although deep injection does reduce odour emissions it has a high power requirement and may not be suitable when the soil is heavy, dry, frozen or stony and where there are steep slopes. The sward damage caused by the tines can reduce herbage yields by between 10 to 15%. The use of shallow injection systems addresses some of these problems but it is not suitable either for all soil types.

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Table 2.7 Odour emission rate and total odour emission from land spreading of pig slurry to grassland using a range of spreading systems (Philips *et al*, 1990).

System	Odour emission rate (k odour units s^{-1})	Total odour emission (k odour units m^{-3} slurry applied)
Splashplate	7.9	349
Trailing pipe	1.1	35
Deep injection	2.7	182
Shallow injection	3.3	133
Irrigator	31.0	6520

2.8.1 Incorporation into soil.

Manure's applied to tillage have the potential to be incorporated into the soil as part of the cultivation process. Pain *et al*, (1991) demonstrated that the immediate incorporation, by ploughing only, gave the only worthwhile reduction in odour emissions. Immediate ploughing gave 52% compared with the conventional system. No reduction in odour emission was obtained if incorporation by any method was delayed for three to six hours after spreading.

2.9 Effect of weather on odour dispersion

The prevailing weather affects the dispersion of odour after it is released into the air. There is very little data available concerning odour dispersion and different meteorological conditions. However, Williams and Thompson,(1985) studied the effects of weather on odour dispersion from livestock buildings and from fields using dispersion modelling. The land spreading of manure is the major source of complaint about odour, therefore, the weather conditions at the time of application is important. The most suitable conditions for spreading manures are where the air mixes to a great height above the ground. These are typically sunny, windy days followed by cloudy, windy nights. The least suitably conditions are high humidities and light winds or clear still nights (MAFF,1992). The direction and strength of the wind and distances from houses are extremely important in dilution and dispersal of odour. The codes of practice advise the use of a weather forecast when planning manure spreading operations.

2.10 Chemical and biological additives and masking agents.

The control of odours from agriculture using chemical and/or biological additives or masking agents has been attempted for a long number of years. There is well in excess of a hundred products that are promoted to accomplish odour reduction, commercially available for use in manure storage systems. There is little supporting data to document the success of these materials (Pain *et al,* 1987). In practice the chemicals must be cheap, easy and safe to handle, readily miscible with large quantities of slurry and without adverse effects upon the structure of the soil, plant nutrients and soil microflora (Working Party Report, 1974). In studies conducted on odour control by additives including biological supplements, masking agents and odour suppressants, the results indicated that none of the products tested was effective in reducing odour (Warbukton et al, 1981; Potni and Jui, 1993).

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Generally there are five main categories to control odour.

- Oxidising agents such as permanganate, hypochlorite and ozone that oxidise the odour causing compounds. Large quantities will be required because of the large quantities of oxidisable organic matter in manures.
- Deodorants are chemicals that react with the odorous compounds, inhibiting their release or neutralising them.
- Masking agents with concentrated pleasant smells, *e.g.* pine
- Digestive agents are generally bacterial cultures, mixtures of bacteria and enzymes that are claimed to break down the odorous compounds during storage.
- A range of chemicals including bactericides, disinfectants and plant extracts, which claim to either destroy the micro-organisms in the slurry or inhibit enzyme activity thus preventing the development of the odorous compounds. Some products with plant extracts appear to give good results but there is no objective odour data available.

Clay products (*e.g.* bentonite, kaolinite, zeolite) are claimed to have odour reducing properties. The effect is based largely in their large absorptive capacity. Large quantities are required so costs will be high.
The costs of the additives are usually high and while some success is claimed by farmers with these products their general use is not recommended.

2.11 Dietary Control

Dietary control has a potential for controlling odours. The majority of research in this field of development has been very recent. The advantages are that no additional machinery is required as the odour is controlled at source and the cost to the producer maybe reduced as there is potential to reduce the crude protein of the diet (Hobbs, 1995). Some products such as zeolite, when added to the feed at a rate of 5% can improve growth rate of domestic animals and reduce manure odour (Bartke *et al*, 1993). Reducing the crude protein level of pig diets and supplementing with essential amino acids significantly reduces the nitrogen excretion, ammonia concentration and concentrations and ratio's of selected volatile fatty acids and other odorants in fresh manure and anaerobically stored manure (Sutton *et al*, 1995; Hobbs and Pain, 1995). However, further research is necessary to determine a dietary formulation that is of benefit and cost effective.

2.12 Economics of odour control.

Economical studies of odour control technologies for all aspects of odour control in animal production systems are high. It is important to note that many of the technologies only reduce odours from one of the sources. Therefore, it is important to identify the cause of the odour problem and ensure that the basic management principles are being applied. Where the problem persists it is important to carefully review the technical requirements and effectiveness of the potential solutions and their cost.

2.13 Odour problems from agriculture.

There is very little historic data available, in this country, regarding odour emissions from agriculture. However, since we have similar farming practices to Great Britain, an analysis of a survey (Table 2.8) conducted in the early seventies(Working Party Report, 1974) would allow us some insight into the

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scale of the problem. It involved a survey of Local Authorities similar to the survey carried out for this thesis regarding odour complaints received. A total of 660 replies related to farming problems. The majority of these were concerned with animal excreta, its storage and spreading. A wide range of activities were covered in the 660 cases. Poultry and pig production were the largest groups involved, accounting for 63% of the total. Only 2% related to cattle while silage operations accounted for 5%. Part of the survey involved an assessment of any control measures being used and the degree of success of the various methods. There were four different methods identified.

- Use of deodorants:
- Improved management: Measures taken which do not require extra equipment or a change in basic methods, *e.g.* better housekeeping, frequent waste removal.
- Modification to plant: control measures requiring extra equipment, *e.g.* treatment of ventilated air, change of premises.
- Change of method: control measures involving a fundamental change of approach, *e.g.* changeover from slurry to solid manure handling, prohibition of types of sprays or rain guns.

Ten percent of cases involving the use of some control measure were successful; 40% were partly successful. The use of deodorants was rarely successful, although about half the cases showed some improvement

Significantly "Improved management" gave the greatest response, *i.e.* of the total of 326 successful or partially successful cases 125 or 30% were in this group. In contrast, the "No Control method" group showed only 5% improvement.

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Table 2.8 Summary of Local Authority survey into sources of odour and control methods being used in England and Wales in 1972 (Working Party Report, 1974)

	Source of odour complaint					
Control measure used	Poultry	Pigs	Cattle	Silage	Others	Total
Deodorization	56	49	1	2	49	157
Improved management	66	44	2	10	31	153
Modification to plant	13	6	1	3	39	62
Change of method	18	17	1	0	12	48
No control used	43	31	5	11	22	112
Method not described	33	39	3	7	46	128
Total	229	186	13	33	199	660

All of this data leads to the suggestion that Local Authority officials were having fruitful contact with some farmers and that many farmers had been willing to co-operate. However, it must be remembered that the 660 cases only represented 0.3% of all the agricultural holdings. This agrees with an 1982 survey (Table 2.9) into the sources of odour complaint in England and Wales (Hardwick, 1985).

Table 2.9: Number and source of justifiable odour complaints in England and Wales in 1982 (Hardwick, 1985).

Odour source	Pigs		Cattle		Poultry		Total	
	No.	%	No.	%	No.	%	No.	%
Buildings	224	22	65	18	163	36	452	35
Slurry Storage	169	17	98	28	78	17	345	19
Slurry Spreading	525	52	122	34	190	42	838	46
Animal Feed Production	84	8	4	1	11	3	99	5
Silage Clamps	10	1	68	19	8	2	86	5
Total	1013	100	357	100	450	100	1820	
%	56		20		24			100

A similar trend existed in this survey where pigs, poultry and cattle accounted for 50, 24 and 16% respectively of the 1820 justifiable complaints assessed. Furthermore, slurry spreading accounted for 46% of all the complaints while buildings and slurry storage accounted for 35 and 19%, respectively. There is nothing in the literature to suggest that this situation has changed in recent years. The intensification of animal enterprises has led to a higher level of complaint but the trend regarding the sources of these complaints still remains similar to the survey's cited above.

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2.14 Legislation

The Air Pollution Act (1987) correlates both National and EC law into a progressive, comprehensive form in relation to odour pollution. Prior to this odour pollution was controlled indirectly by conditions attached to planning permissions but in many cases Local Authorities neglected to attach conditions relating especially to odour. Odour's are covered by definition in Section 4 subsection (1.1.1) which defines air pollutant " as a condition of the atmosphere in which a pollutant is present in such a quantity as to be liable to impair or interfere with amenities or with the environment" (Air Pollution Act, 1987).

Under section 24 of this act the occupier of any premises is under obligation to prevent air pollution. He shall use the best practicable means to limit or prevent an emission in such a quantity or in such a manner as to be a nuisance. Where it can be proven that the best practicable means was used with regard to nuisance prevention , this shall act as a good defence. Under section 59 of the Common Law Nuisance Action, an action can be taken for nuisance where proof of a defendants insufficient preventative methods are not required. In this case best practicable means may not necessary be a good defence. How exactly best practicable means is defined in relation to odour pollution has not been ruled upon by the courts so far.

2.15 Codes of Practice

Two codes of practice were developed by Teagasc to be followed when spreading slurry. One deals specifically with the reduction of odour while the other was designed for the prevention of water pollution. There was also a Code of Good Agricultural practice released by the Ministry of Agriculture,

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Fisheries and Food in the UK, in 1992, for the Protection of Air. These codes are not statutory and would not provide a defence such as "best practicable means" if you cause air pollution. Similarly it does not protect you from legal action although it may lessen the chance of this happening. The following are the main points of each code.

2.15.1 Code of Good Practice to reduce slurry smells. (Irish Farmers Journal, 1997)

Odour impact can be minimised if a sensible approach, good farm management and consideration for close-by residents, is taken when handling and spreading slurry. This infers the adherence to the following practices.

- Direct slurry downwards towards the soil using a low trajectory splashplate.
- Switch off the vacuum pump immediately the tanker empties to minimise mist production.
- Never use tanker rain guns to spread slurry.
- Avoid spreading slurry at times when risk of causing odour nuisance to the public is greatest, *e.g.* weekends and bank holidays.
- Spreading in light rain or damp conditions will minimise smell drift.
- Where slurry is spread on tilled soil or land that is to be ploughed it should be incorporated into soil as quickly as possible following application.
- Spread early in the day when air is rising to increase dispersion.
- Take account of wind direction and do not spread if wind is towards populated centres.
- Use a band spreader in areas sensitive to odour emissions.

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2.15.2 Code of Good Practice for spreading Farm Wastes. (Bell, 1997)

The following Code includes some points already cited in the previous code. It is contained in the conditions for farm waste spreading in the Rural Environmental Protection Scheme (R. E. P.S.).

The code is as follows:-

- Do not apply manures when heavy rain is forecast in the next 48 hours. Check the weather forecast.
- Apply the manure at rates that meet crop needs. Spread earlier rather than later in the growing season so that crop growth utilises the nutrients.
- Do not apply manures to.

---Wet or waterlogged land.

---Frozen or snow covered soils.

---Land steeply sloping towards watercourses.

---Bare ground.

---Exposed bedrock.

- Take account of wind speed and direction to avoid spray and odour drift.
- Maintain spreading equipment in good condition.
- Do not apply within 1.5m of hedge grows.
- Do not apply on bird nesting sites in the breeding season.

2.15.3 M.A.F.F. Code of Good Agricultural Practice for the Protection of Air.

This code is a very comprehensive document, which also includes practices for the prevention of smoke pollution and emission of greenhouse gases from agricultural sources. In addition to the spreading of manures and slurries and other farmyard wastes, this document address other areas of potential odour

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and ammonia emissions such as housed livestock systems, storing slurry and manure, producing compost for mushrooms, landspreading of livestock wastes, treatment of livestock wastes and siting of livestock building's, manure and slurry stores. Recommended land spreading machinery together with various treatment options for manures and ventilation air are highlighted. In comparison, the Teagasc code of good practice is only concerned with the spreading of manures.

2.16 Rural Environmental Protection Scheme (R.E.P.S.)

The REPS is an EU funded scheme that provides farmers with a financial incentive to farm in a manner that protects our countryside and water supplies from pollution and further deterioration (Bell,1997). One of its objectives is the establishment of farming practices and controlled production methods that reflect the increasing concern regarding conservation, landscape protection and other environmental problems. Odour emissions are only highlighted in the Teagasc code of practice for the spreading of farm manures in the farm waste management measure. The emphasis throughout all seventeen measures is the prevention of water pollution and improvement of watercourses.

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Chapter 3

Materials and Methods

3.1 Introduction

A survey of Local Authorities was undertaken to assess the number of agricultural related odour complaints in recent years. Media reports and growing public awareness have often given a high public profile to this issue. There is no information available to quantify the extent of the problem in Ireland. In order to make recommendations and possible improvements in the control of odour emissions it is important to identify the sources of agricultural odour emissions which cause complaints and to identify the priority areas for control and to suggest possible amelioration strategies. It is clearly recognised that all complaints of odour from agriculture are not reported to the Local Authorities for various reasons. These are considered to be outside the scope of this study. However, analysis of complaints received provides us with the only reliable data source.

3.2 Survey of Local Authorities

A letter was circulated to some Local Authorities requesting information regarding their filing system of odour complaints received. (Appendix 1). A total of twenty-seven Local Authorities were circularised and a 100% response was received (Table 3.1).

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Table 3.1: Summary of responses from Local Authorities concerning records of odour complaints.

Name of local Authority	Register of odour complaints		Comments
	Yes	No	
Cavan		*	Some complaints on different files
Carlow		*	
Cork	*		
Clare	*		
Donegal		*	
DunLaoghaire Rathdown		*	
Galway		*	Some landspreading/planning received
Kildare		*	
Kilkenny		*	
Kerry	*		All complaints in a diary
Laois	*		All complaints in a book
Leitrim		*	
Limerick		*	
Longford		*	
Louth		*	
Mayo		*	Some land spreading complaints received
Meath		*	
Monaghan		*	
Offaly		*	
Sligo	*	*	Register opened in 1997/ some complaints in other
Tipperary S.	*		
Tipperary N.		*	
Roscommon		*	Some complaints received re landspreading.
Waterford	*		
Westmeath		*	
Wicklow		*	Some complaints received re; land spreading
Wexford	*		
Total	7	20	

Follow up contact was made to those with records to determine the extent of their database. Cork had some records erased due to computer failure but indicated that a number of complaints were received regarding pig slurry spreading (O'Scanaill Pers Comm). Cavan has the highest density of sows at 1 for every 4 hectares farmed (Irish Farmers Journal 1997) but they indicated that only a limited number of odour complaints were received. These again were primarily in relation to manure spreading. Similar situations existed in Waterford, Roscommon, Mayo, Galway and Sligo where only a limited number of odour complaints were received. On this basis it was decided that only four Local Authorities had sufficient information to justify further investigation. The response received from some Local Authorities suggested that it would be difficult to co-ordinate and extract the relevant information. Some of the reasons were; refusal of access to the information, no register but some action taken based on verbal complaints and some complaints were filed in different places based on the person investigating same. Only four Local Authorities were considered to have sufficient records to provide reliable data for the study. These were Wexford, Laois, Tipperary South and Clare.

3.2.1 Wexford

A register of all complaints received by the Local Authority was available for the period July 1990 to August 1996. The data recorded included date, time, location, types of complaint, who received the complaint and what action was taken. Copies of the register were obtained from the Local Authority and the relevant information extracted.

3.2.2 Laois

A record of complaints in book form was viewed at the Local Authority offices for the period 1989 to March 1997. The data recorded included date, time, cause of complaints, name of complainant and what action was taken. A

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number of odour complaints referred to the landspreading of blood and are not included in the present analysis.

3.2.3 Tipperary South

Information regarding agricultural odour complaints from 1991-1997 was compiled and forwarded by the Tipperary South Environmental Office. The information included file reference No. , nature of complaint, cause of complaint, region, location and date. A number of complaints were in connection with non-agricultural sources, *e.g.* paunch waste, offal storage and rendering plant effluent. Consequently they are not included in the present study.

3.2.4 Clare

Preliminary reports from this Local Authority suggested that not much information was available regarding odour from agriculture. However, it was decided to investigate the available records to increase the scope of the survey. All complaints were filed separately in a large file. Reliable information was deemed to be from 1995 onwards. Complaints previous to that were not recorded in any one file which meant that great difficulty would have been encountered in establishing a reliable dataset. Each recorded complaint included date, time, cause, name of complainant, name of person suspected of causing odour, action taken, and all correspondence.

3.2.5 Information Compiled.

A file was compiled for each of the four Local Authorities by extracting the following information:

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- Total number of agricultural complaints received.
- Total number of odour complaints received.
- Date and day on which complaint was made.
- Number of odour complaints due to an agriculture source.
- Cause of odour complaints from agriculture.
- In the case of slurry spreading; the type of slurry causing the complaint.

Note: The total number of odour complaints received was only quantified from the Wexford register. It provided the most comprehensive record.

It was not always possible to clearly identify the source of the agricultural odour from the records available. For example, some complaints received were filed under type as "smell" or "odour" and on inspection it was found that the cause was a farmer spreading slurry. No indication of the type of slurry was reported. Similarly, some complaints were filed as emanating from a particular farm with the cause being smell / odour. It was not clear whether these complaints were due to odour from the production units or from an activity taking place on the farm.

Three major odour sources were identified from the survey.

- Slurry Spreading
- Solid manure
- Farmyard

For the purposes of this survey the classification of a complaint under farmyard includes manure storage, silage, production units, yards, holding pens and complaints that specifically mention smells from farmyards. Slurry spreading refers to the land application of liquid manure, applied with a vacuum tanker. The classification of solid manure refers to solid manure applied with a muckspreader. In such cases the register clearly indicated that the source of odour complaints was solid manure, farmyard manure or manure heap. The quantification of the type of slurry causing the complaint was difficult to assess as many were filed under slurry spreading with no indication of the slurry type e.g. cattle or pig. Unless it was clearly stated to have originated from pigs it was classified under "other slurry". Similarly, where the cause was filed as "pig slurry" or "slurry" it was assumed that this referred to the land spreading of same.

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Chapter 4

Results

4.1 **Introduction.**

The available data from the selected Local Authorities was grouped together under the following headings.

- Total number of complaints.
- Total number of odour complaints.
- Number of Odour Complaints pertaining to all sources in Wexford Local Authority area.
- Sources of Agricultural odour.
- Classification of Slurry.
- Daily and Monthly Variation in odour complaints.

The following is a presentation of these results.

4.2 **Total number of agricultural complaints**.

The total number of complaints received by the four Local Authorities, emanating from an agricultural source with the data available are summarised in Table 4.1.

In the period covered (1989-1997) a total of 712 complaints about agriculture were received by the four Local Authorities. There is considerable between year variation in the number of complaints received. For example, Laois received a total of 13 complaints in 1991 compared with 42 in 1993 and 1994. The yearly average, based on full year analysis, showed that Wexford and Clare had more complaints than Laois and Tipperary South. The highest level of complaints from agriculture in Wexford and Tipperary South occurred in 1995 while 1996 and 1993/94 were highest in Clare and Laois, respectively. It is important to note that some of the results did not refer to a full year analysis due to incomplete databases. For example, the 8 complaints received in Wexford in 1990 refers to the period June to December of that year. Similarly, Wexford 1996 and Laois 1989 are not full year analysis.

Table 4.1: Total number of agricultural complaints received by the Local Authorities including water and odour.

Year/C.C.	Wexford	Laois	Tipp. South	Clare	Total
1989	N/A	5*	N/A	N/A	5
1990	8*	26	N/A	N/A	34
1991	54	13	N/A	N/A	67
1992	51	15	20	N/A	86
1993	41	42	17	N/A	100
1994	52	42	10	N/A	104
1995	75	23	44	30	172
1996	30*	15	33	47	126
1997	N/A	11*	N/A	8*	19*
Total	311	192	124	85	712
Yearly Av. Full years only	55	25	25	39	106

* Not full years data.

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4.3. **Total number of agricultural odour complaints**.

The total number of agricultural odour complaints received by each Local Authority are summarised in Table 4.2

Table 4.2: Trends in the total number of agricultural odour complaints received by the Local Authorities in Wexford, Laois, Tipperary South, and Clare

Year/C.C	Wexford	Laois	Tipp. S	Clare	Total
1989	N/A	0*	N/A	N/A	0
1990	2*	1	N/A	N/A	3
1991	5	0	N/A	N/A	5
1992	8	0	1	N/A	9
1993	21	4	0	N/A	25
1994	14	3	2	N/A	19
1995	26	1	6	5	38
1996	10*	2	8	3	23
1997	N/A	2*	0	3*	5
Total	86	13	17	11	127
Yearly Avg. full year only	15	2	3	4	19

* not full years data.

A total of 127 agricultural odour complaints were received by the four Local Authorities. There is considerable between County variability with the largest average number recorded in Wexford at 15 and the lowest recorded in Laois at 2. Considerable between year variability in the number of complaints was also recorded within counties. For instance in Wexford this varied from 5 in 1991 to 26 in 1995.

4.4 Number of Odour Complaints pertaining to all sources in Wexford Local Authority.

Only Wexford had reliable data on odour complaints from sources other than agriculture. Agricultural odour complaints were 56% of the total received within a range of 37 to 100% between 1990 and 1996 (Table 4.3).

Table 4.3: Distribution of odour complaints pertaining to agriculture and all other sources.

Year	Agriculture	Other	Total	% Agricultural complaints
1990	2	0	2	100
1991	5	1	6	83
1992	8	7	15	53
1993	21	12	33	64
1994	14	14	28	50
1995	26	17	43	60
1996	10	17	27	37
Total	86	68	154	56

In five of the seven year's studied the level of complaints from agricultural sources was greater than from other sources. In 1994, the same number was received for both. Only in 1996 did complaints about odour from non-agricultural sources exceed those from agriculture.

4.5 Sources of agricultural odour.

The sources of odour complaints received by the four Local Authorities are summarised in Table 4.4 .

Table 4.4 Sources of agriculture odour.

	Slurry Spreading	Solid Manure	Farmyard
Total no.	103	7	17

Slurry spreading was responsible for 81% of odour complaints. This agrees very consistently with the literature (Pain and Misselbrook 1995), where application of livestock manure to land is cited as the most common source of odour complaints from agriculture. Only 7 complaints were received regarding the land spreading of solid manure. This included a complaint about solid manure that had been heaped in the field awaiting spreading. It represents only 5% of the total odour complaints received. The category "farmyard" where 17 complaints or 13% of the total were received, included manure storage and animal housing.

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4.6 Classification of Slurry.

Within the category of slurry spreading most complaints originated from the spreading of pig slurry (Table 4.5).

Table 4.5: Type of slurry causing odour complaints.

	Pig slurry	Other slurry		
Local Authority	No.	No.	% Pig slurry	Total.
Wexford	37	43	44	80
Laois	1	6	14	7
Tipp. South	7	3	70	10
Clare	1	5	17	6
Total	46	57	45	103

Pig slurry accounted for 45% of all the complaints received regarding the spreading of slurry (Table 4.5). Other slurry includes only the complaints that specifically referred to slurry. Solid manure spreading is not included. Within County variability was again evident with Tipperary South having the highest proportion of complaints from pigs with 70% while Laois had the lowest with 14%

4.7 Daily and Monthly Variations in odour complaints.

The distribution of odour complaints on a daily basis is shown in Figure 4.1.

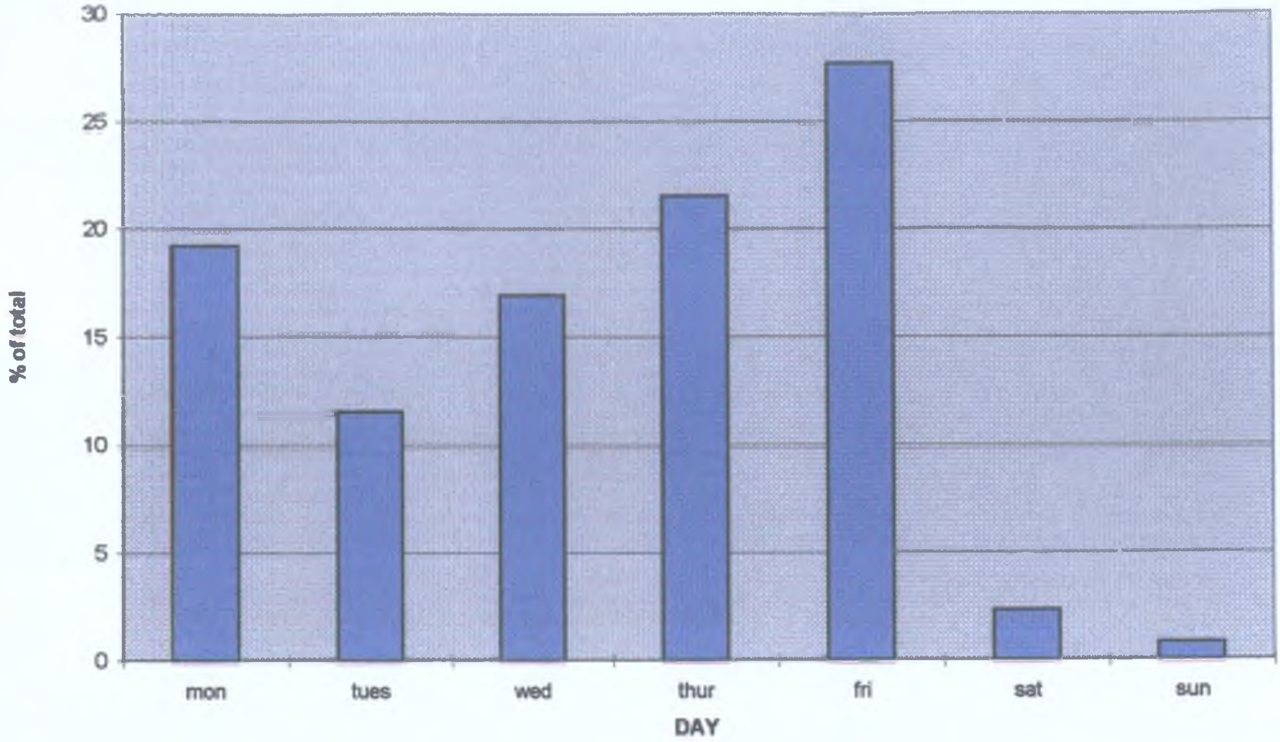

Fig. 4.1 Daily variation in odour complaints from agriculture received by the four Local Authorities in the period 1989 to 1997.

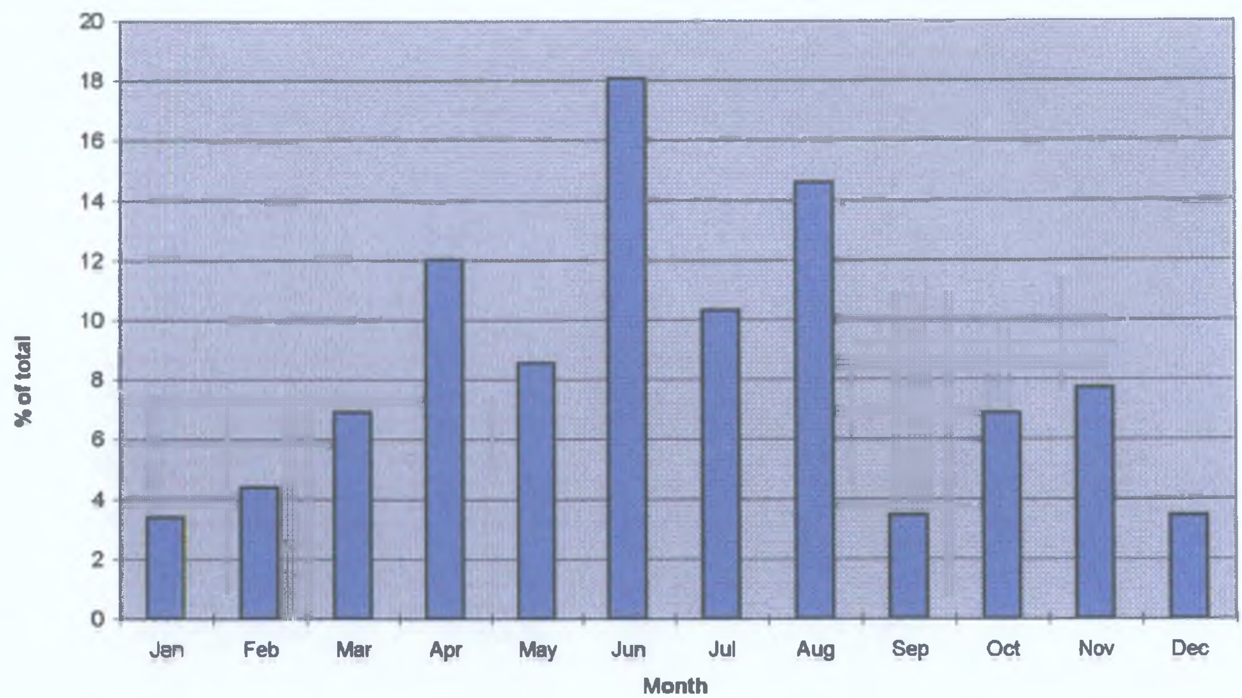

Fig. 4.2 Monthly variation in odour complaints from agriculture received by the four Local Authorities in the period 1989 to 1997

Most complaints were received on a Friday with the least being received on a Tuesday. Very few complaints were received at the weekend possibly due to Local Authorities offices being closed. A similar distribution was tabulated having regard to the month of complaint. (Fig. 4.2) This shows that from April to August is the most sensitive time for the public to complain about odour as 64% of the complaints were received in this period. June and August had the highest with 18% and 15%, respectively, of the total annual number of odour complaints received, while January, September and December were the lowest with 3% each.

Chapter 5

DISCUSSION

Nationally, there is very little recorded data available on odour nuisance from Local Authorities. Only four data-sets were deemed suitable for inclusion in this study. There was considerable variation in the standard of data recording even within the four Local Authorities whose records was examined for this study. This is reflected in the fact that more data regarding complaints was available for the latter years of the survey (Table 4.1). There is a need for a more standardised recording system if available data on the impact of odours on the public is to be generated.

It is important to note in any interpretation of these results that not all complaints received were recorded or that all odour nuisance incidences resulted in a complaint to the Local Authority. However, this limited data provides the only objective assessment as to the extent of the problem. It is suggested, therefore, that the data, despite its obvious limitations, will provide an indication of sources of odour complaint from agriculture.

There was a trend in the data for an increase in the total number of agricultural pollution complaints received by the four Local Authorities (Fig 5.1). These complaints were primarily related to water and odour (Fig. 5.2) pollution. However, detailed examination of trends in the data is difficult because of the missing data for particular years or within years for the four areas included. However, the increase is not surprising because of the greater public awareness of the environment.

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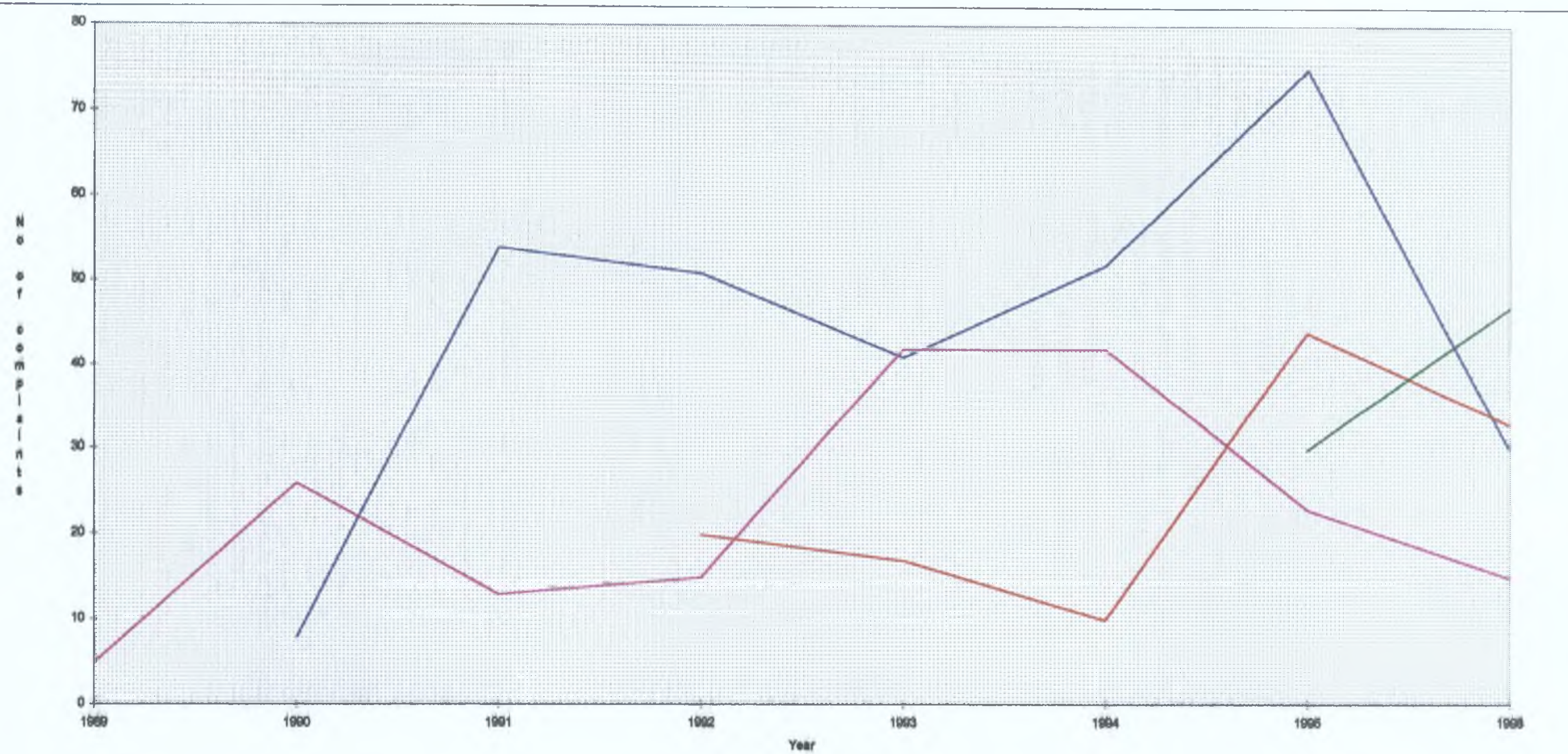

Figure 5.1 Temporal trends in the number of complaints pertaining to agriculture received by Wexford, Laois, Tipp. South and Clare Local Authorities in the period 1989 to1996

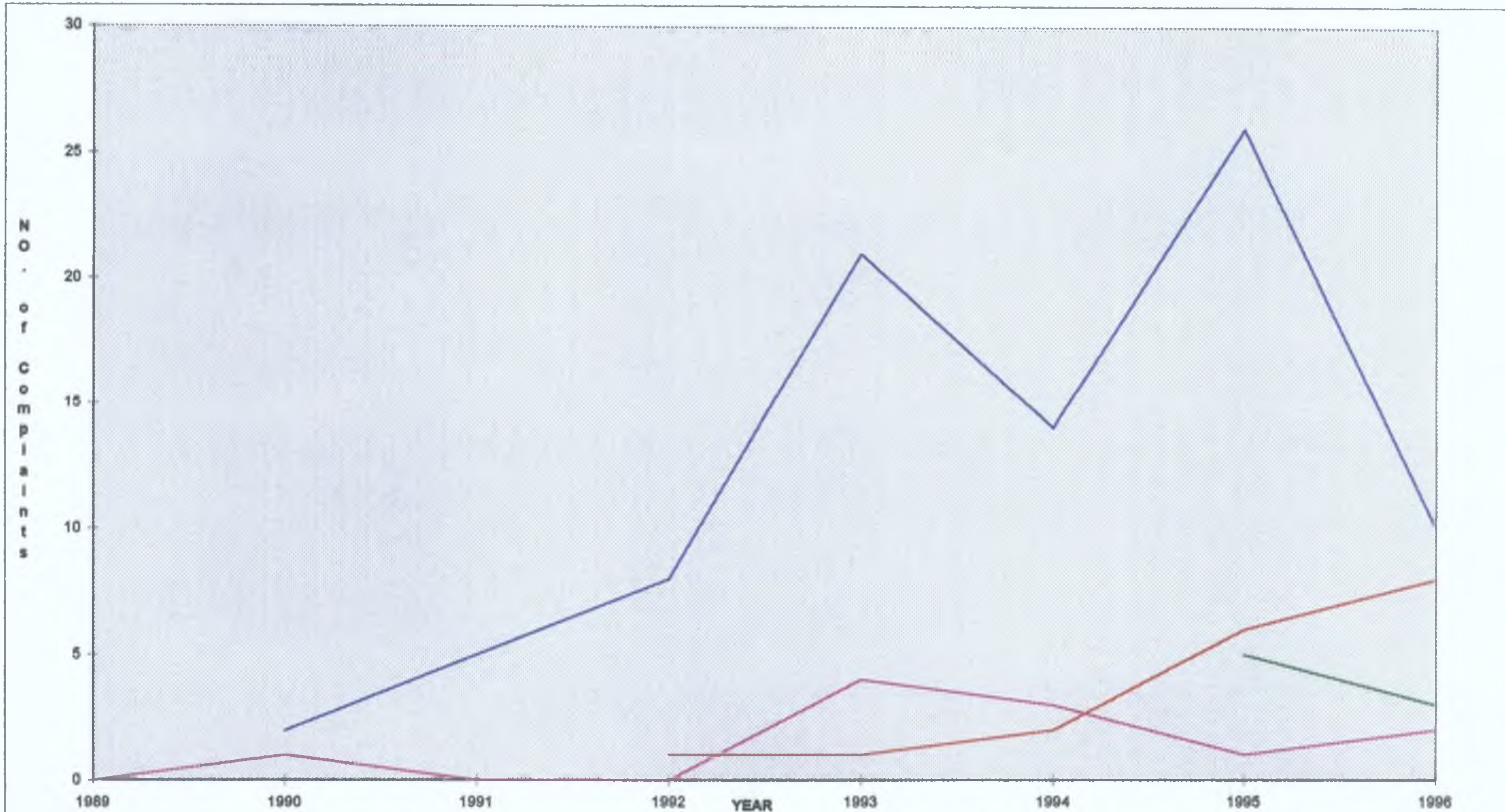

Fig. 5.2 Temporal trends in the number of odour complaints pertaining to agriculture recieved by Wexford, Laois,Tipperary South and Clare Local Authorities in the period 1989 to1996.

It is noteworthy that there was a higher yearly average number of complaints in Wexford and Clare compared with Laois and Tipperary South (Fig. 5.3). This may reflect the greater emphasis on tourism within these counties so that any pollution including that from agricultural activities has a greater public impact. Odour represented only 18% of the total agricultural complaints received (Table 4.1 and 4.2). This is surprisingly small considering the apparent public awareness of the problem. There are a number of possible explanations. The impact of odour pollution on the environment is more short-lived compared with water pollution. Therefore, the public are more likely to complain about pollution that is persistent. Odour from slurry spreading is short lived and will have disappeared within a relatively short period of time. The public may also be aware of the difficulty in prosecuting for odour. This is highlighted in the small number of actions brought under Section 25 of the Air Pollution Act (1987).

The higher level of complaint in counties that have a greater emphasis on tourism is again evident when odour complaints alone are considered, (Fig. 5.4). This could also reflect a greater emphasis by the Local Authority on the recording of complaints. If good follow-up action is taken then more confidence in the complaint procedure could mean a higher level of complaints.

Not all odour complaints received were from agriculture (Fig. 5.5) In Wexford agriculture accounted for 56% of the total odour complaints received (Fig.5.6). This may not be a good indication of the national trend because many of the non-agricultural odour sources related to a single plant. The survey also identified a significant number of complaints relating to the land spreading of factory wastes, such as blood and paunch wastes, in Laois and South Tipperary. It maybe suggested, based on this data, that the public to date appear to be more “tolerant” of odours from agriculture.

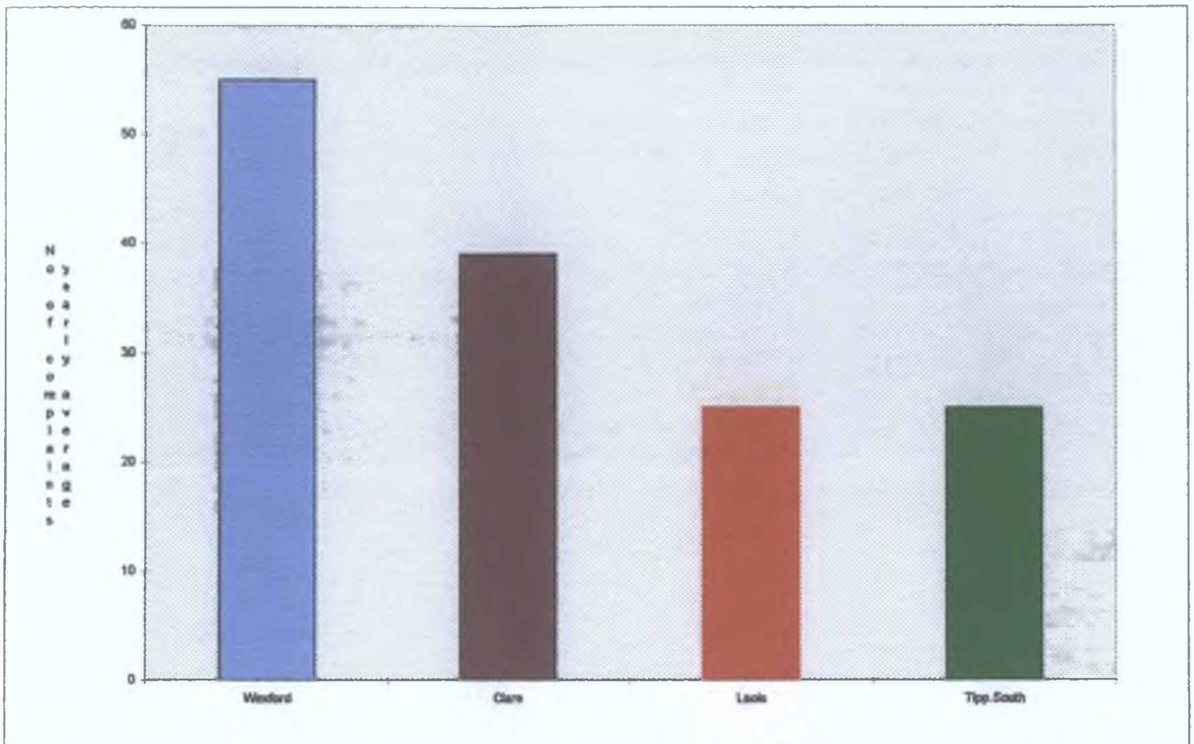

Fig. 5.3 Average number of agricultural complaints recieved by the four Local Authorities each year

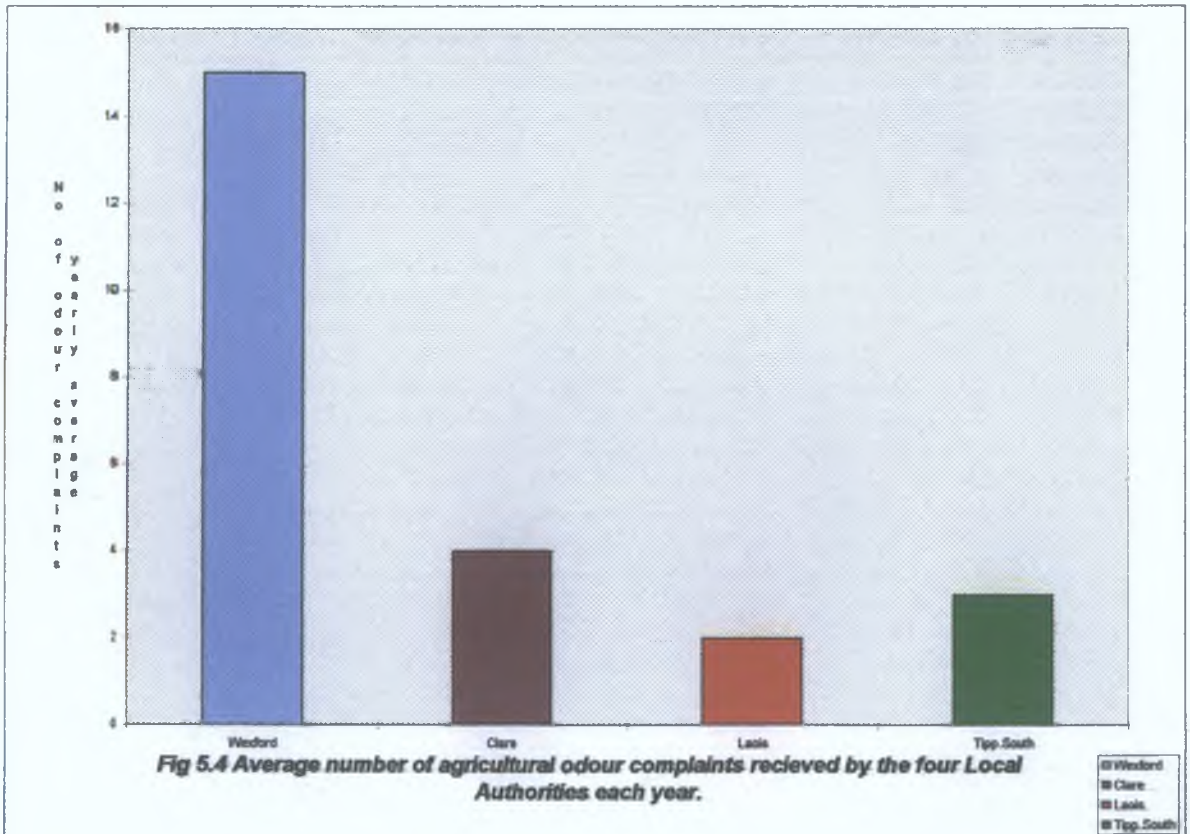

Fig 5.4 Average number of agricultural odour complaints recieved by the four Local Authorities each year.

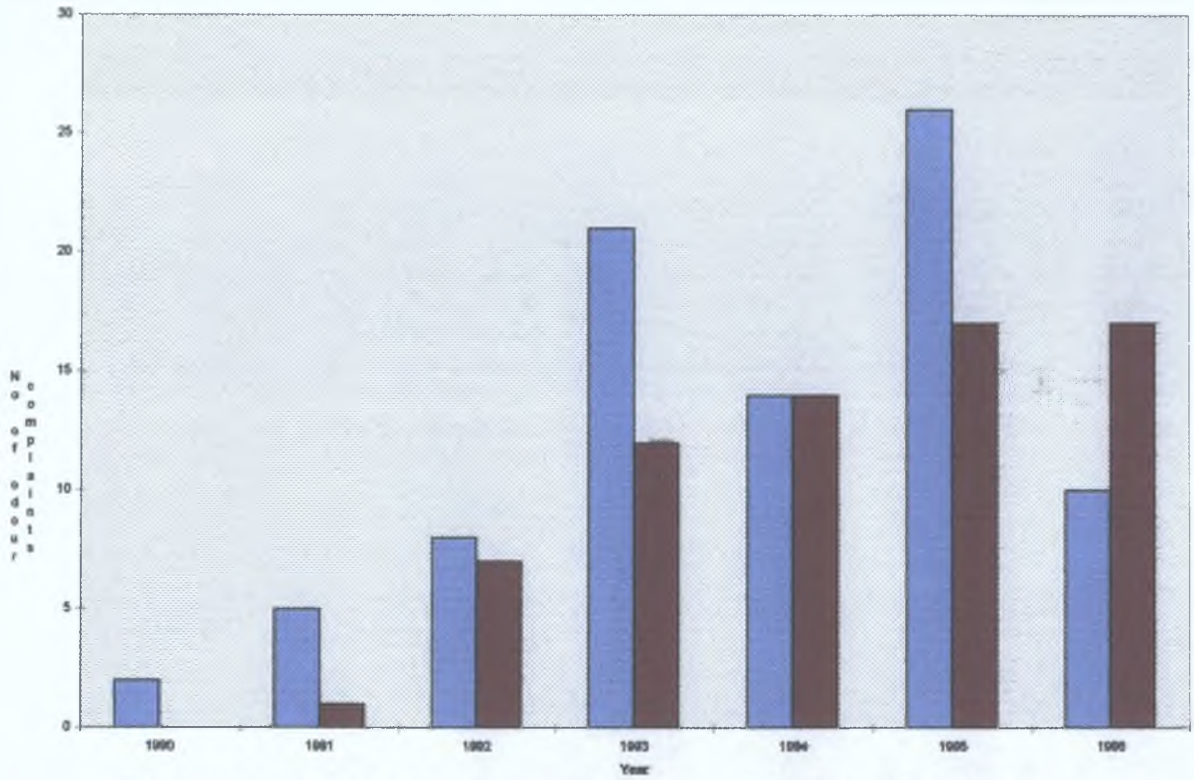

Fig 5.5 Comparison of odour complaints pertaining to agriculture and all other sources in Wexford Local Authority area

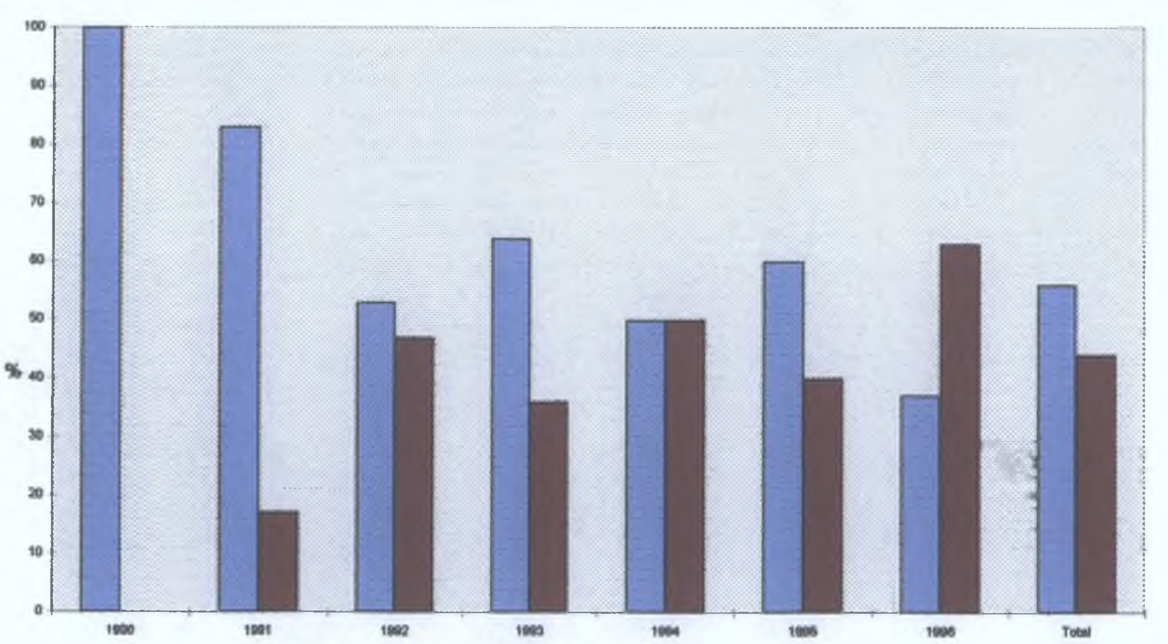

fig 5.6 Percent of total odour complaints pertaining to agriculture and all other sources in Wexford Local Authority area

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The land spreading of manure is the biggest problem (Table 4.4). This is similar to the UK data [Working Party Report 1975, Pain and Misselbrook 1995, Hardwick 1982, (Table 2.9)]. In the survey conducted for this thesis, land spreading represented 81% of the agricultural odour complaints received by the Local Authorities reviewed (Fig. 5.7). This indicates that research into odour control in this country should be directed towards reducing odour emissions from slurry spreading.

In the files reviewed the action taken on agricultural odour complaints, in the majority of cases, consisted of the Local Authority contacting the offender and making them aware of the existence of the Code of Good Practice to reduce odour emissions when land spreading slurry. The application of this code provides a common-sense approach to reduce the number of complaints. A greater education and awareness of this code is necessary within the farming community. It would also inform farmers of the potential annoyance that can be created among nearby residents by agricultural odours. Communication with neighbours, particularly those known to be sensitive to the odours, that the slurry is to be spread in the next few days will demonstrate that the farmer is aware of the nuisance. Equally important is the provision of a buffer zone between the spreadlands and neighbouring houses and buildings. Mawms (1994) suggested a 100m buffer zone. This is similar to buffer zones recommended in Netherlands and Germany. Clearly further research is required to provide a rational basis for the sizing of the buffer zone. The MAFF Code of Good Agricultural Practice for the Protection of Air (1992) suggests that, the weather, type of waste and method of spreading all influence the distance at which odours can be smelt from the spreadlands following the application of slurries and manure. This demonstrates how difficult it would be to set a definite buffer zone outside of which no odour annoyance would occur.

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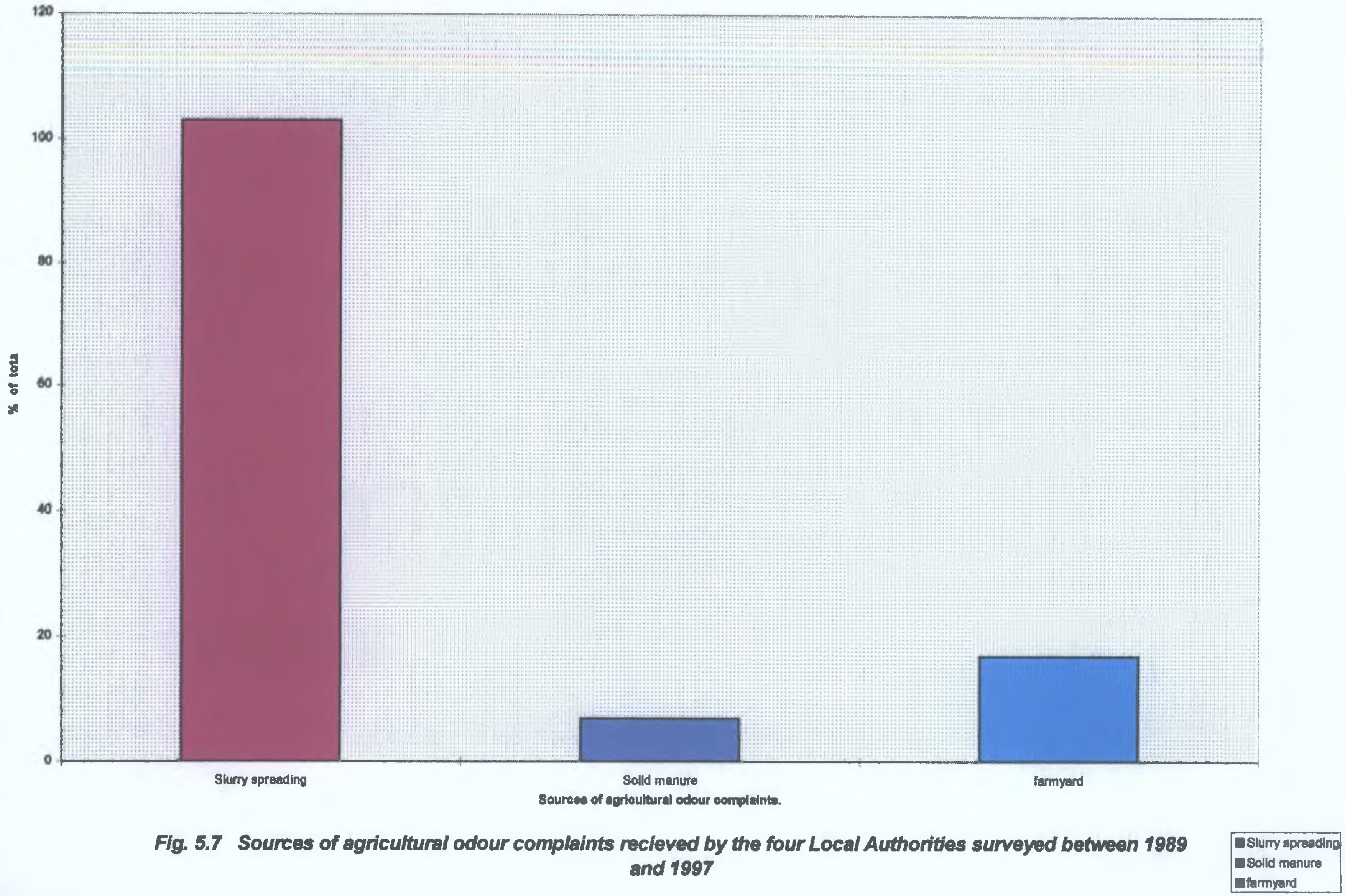

Fig. 5.7 Sources of agricultural odour complaints recieved by the four Local Authorities surveyed between 1989 and 1997

Odour emissions from the spreading of pig slurry compared with other slurry gives rise to a greater number of complaints (Table 4.5). Although the results of the survey show only 45% of the complaints are attributable to pig slurry (Fig.5.8), it must be remembered that, of the total quantity of slurry requiring management annually, (approximately 40 million t), only 2 million t is from pigs. Taking in to consideration the difficulties encountered when classifying the type of slurry from the files reviewed, it is suggested that this percentage may be higher. This again is similar to the UK data (Working Party Report 1975). MAFF (1988) presented data which showed that the odour threshold (i.e. the mean number of dilutions required to dilute odorous air so that panellists could not detect an odour) was greater for pig compared with cattle slurry (Table 5.1).

Table 5.1 Temporal trends on the odour threshold for pig and cattle slurry (MAFF, 1988)

Time after application	Pig slurry	Cattle slurry
1	905	299
6	97	145
12	98	177
24	95	126
36	66	214
48	62	
60	33	

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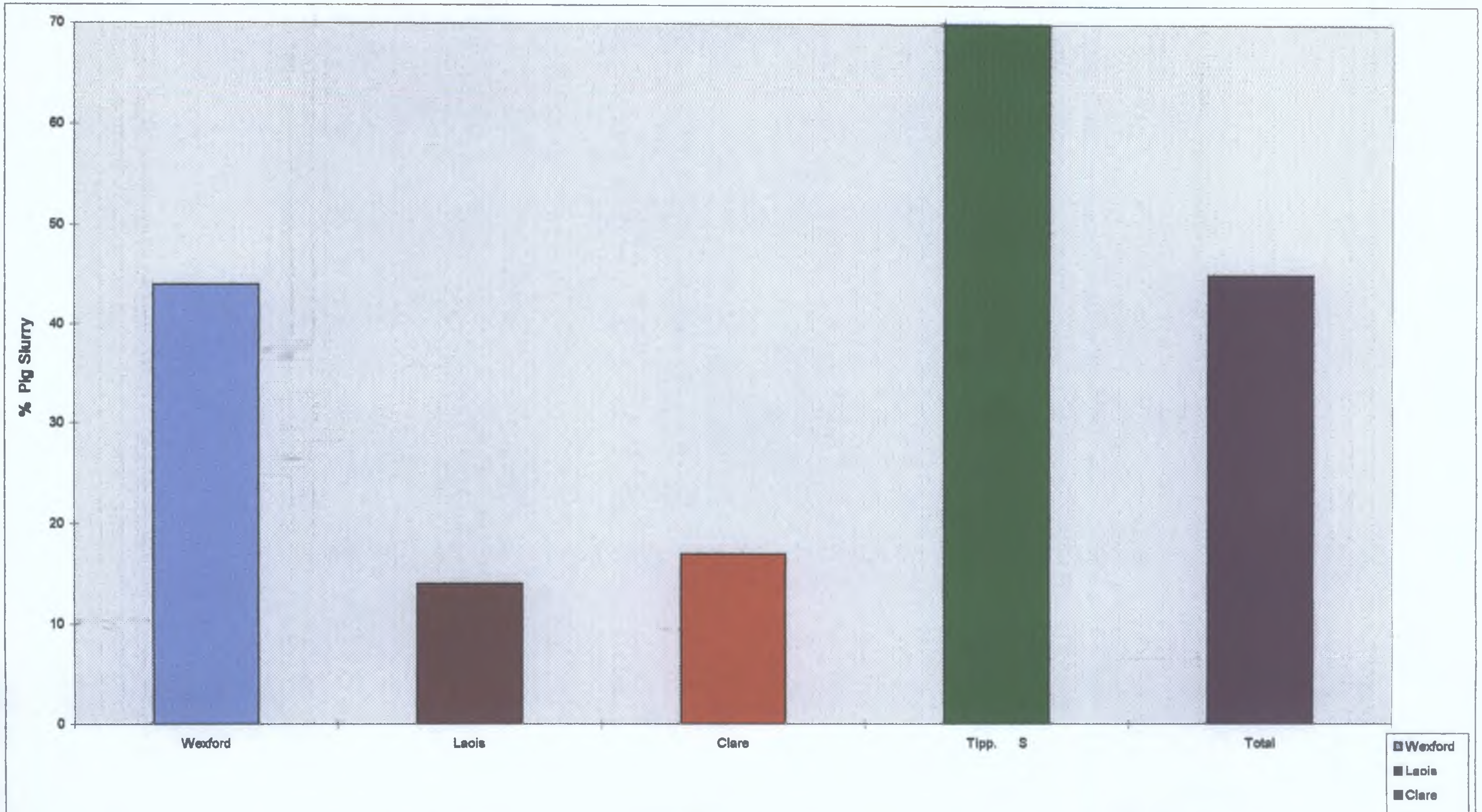

Fig. 5.8 Percent of slurry spreading odour complaints pertaining to pig slurry.

Other possible reasons can be put forward for this higher level of complaints from pig slurry. The fact that only a small number of opportunities exist for the application of cattle slurry each year compared with pig slurry, which can be spread more frequently, may be a factor. Cattle slurry is generally applied to silage ground only, which limits the number of spreading opportunities to four i.e. early spring, after first silage, after second cut silage and in the autumn. Pig slurry, on the other hand, can be applied to grazing ground with a reduced risk of grass rejection or of disease transfer to the grazing animals compared with cattle slurry. Therefore, these are more spreading opportunities for pig slurry. The confinement period for pigs is normally twelve months compared with three to six months for cattle. Pig units in Ireland tend to be large and concentrated in certain areas. This is reflected in a bi-annual survey carried out by Teagasc in January 1977 (Irish Farmers Journal 1997). It shows that over three quarters of all pigs are found in eleven counties. Commercial pig units have increased by 9% over the 1995 figure. Therefore, the volume of manure for land spreading is increasing. It is noteworthy that Wexford and Tipperary are included in the above eleven counties. It is significant that these two Local Authorities identified pig slurry as been the cause of agricultural odour complaint more often than Laois or Clare.

Pig manure is generally applied over a wider area than cattle slurry to ensure nutrient application levels, particularly phosphorous, do not exceed crop requirements. Therefore, the number of people exposed to odour will be greater. Phillips *et al,* 1991 has shown that the use of shallow injection and bandspreading can reduce odour emissions significantly compared with the conventional splashplate. Teagasc recommends bandspreading of pig slurry where odour is giving rise to public complaints. This is the preferred option because bandspreading is cheaper (30%) and is suitable for all soil types. There are many Irish soils upon which injection is not suitable.

The use of technologies such as aerobic and anaerobic digestion, while providing an effective odour control strategy are expensive. Greater pathogen control in livestock manures is likely to be required in the future therefore pre-treatment of the wastes before land spreading maybe necessary. Current research on aerobic treatment has revolved around determining the minimal aeration requirement for odour control (Westerman and Zhang 1995). A precedent does exist whereby aerobic treatment was specified, by the Courts, as the method of odour control in a nuisance action in Meath in 1988.

Although some research has been conducted into the use of biological/chemical/feed additives to control odour emissions, to date they have offered no real solution to the problem. However, the potential exists for the development of a cost effective additive that will control odour and improve slurry handling.

The increased sensitivity of the public at the weekends is demonstrated by the fact that Fridays was the day when most odour complaints were received (Fig. 4.1). The small number received on Saturday and Sunday is due to the Local Authority offices been closed. This supports the Code of Good Practice which recommends to avoid slurry spreading at weekends and Public holidays. Odour from slurry spread on Fridays will be perceived by the public to last over the weekend and to interfere with their leisure time. A large number of people move to the countryside for weekends during the summer months. This could account for Friday having the highest number of odour complaints recorded. Their sensitivity would be higher than residents of the country therefore more complaints could be encountered. This could also account for

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the fact that 64% of the odour complaints, received by the Local Authorities surveyed, occurred between April and August inclusive (Fig.4.2). Furthermore farming activity is at its highest during this period.

Presently, under the Rural Environmental Protection Scheme it is necessary to prepare a waste management plan. This should be extended to all farms where slurry is being stored for later disposal. The reduction of odour emissions would be an integral part of this plan and recommendations already cited would be included. The success of this plan would also require more vigilance on the part of the Local Authority in the area of inspections. Part of this responsibility would also rest with the Environmental Protection Agency under the Integrated Pollution Control licensing system which is in existence for new pig production units. At present three applications have been made but no draft licence has yet been issued (Nolan, *Pers. Comm*). Furthermore licensing will commence for existing intensive poultry rearing activities and pig rearing activities, on a phased basis in 1998, under an order made by the Minister on 27 of March 1997 (Department of the Environment, 1997). This licensing system can have a major role in the control of odours from Irish agriculture.

CHAPTER 6

CONCLUSIONS

1. Approximately 18% of agricultural complaints being received by Local Authorities relate to odour nuisance. More than three quarters of agriculture odour complaints originate from the application of slurry to land.
2. The recording systems by some Local Authorities are such that it limits the database available on odour nuisance and public complaints.
3. There is an increasing awareness within Local Authorities regarding odour emissions. However the prevention of water pollution still remains a higher priority for Local Authorities than the reduction in public annoyance due to agriculture odour
4. Only a limited number of nuisance actions have been taken through the Courts. Proof of a nuisance is difficult.
5. The quantification of odour is a complex and expensive process.
6. The level of complaint to Local Authorities does not reflect the true level of annoyance experienced by the public. This annoyance could be much higher.
7. The land spreading of pig slurry is the biggest source of odour complaint.
8. Adherence to the Code of Good Practice should reduce odour annoyance.
9. The majority of slurry is applied using conventional vacuum tanker with splash plate.
10. Other methods of land spreading slurry are available but they may not always be economically viable.
11. Treatment of slurry is expensive but some options are very effective in reducing odour emissions.

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12. The most sensitive period regarding complaints from agricultural odour is between the months of April and August.

13. Elimination of agricultural odours is not a realistic target but substantial reduction in emissions is possible.

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APPENDIX 1

NAME OF LOCAL AUTHORITY

NAME OF APPROPRIATE CONTACT PERSON

Tel. No.

1. DO YOU KEEP A REGISTER OF COMPLAINTS REGARDING ODOUR.

   YES. NO.

2. IF "YES" WHEN WAS THIS REGISTER FIRST BROUGHT INTO EXISTENCE.

3. ARE AGRICULTURE ODOURS INCLUDED IN THIS REGISTER.

   YES. NO.

4. IF SUCH A REGISTER EXISTS WOULD IT BE POSSIBLE FOR ME TO REVIEW IT AT A LATER STAGE OF MY RESEARCH.

   YES. NO.

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REFERENCES

Barth, C. L., Elliott, L. F., Melvin S. W. (1984). Using odour control technology to support animal agriculture. In: 1984 American Society of Agricultural Engineers. pp 859-864.

Barth, C. L., Hill, D. T., Polkowski, L.B. (1974) Correlating odour intensity index and odorous components in stored dairy manure. *Transactions of the ASAE* 17, 4, 724-744, 747.

Batel, W. (1975) Messungen zur Staub-, Larm, und Geruchsbelastung an Arbeitsplatzen im der landwirtschaftlichen Produktion und Wege zur Entlastung-erster Bericht. *Grundl. Landtech.* 25,135-157.

Biddlestone, A. J. and Gray, K. R. (1985) Practical Experience with Farm Scale Systems. In: Composing of Agricultural and Other Wastes. Gasser, J.K. R. (ed). Elsevier Applied Science Publishers, London. 111-134.

Carton, O. T.

C.S.O. (Pers Comm.). Central Statistics Office, Dublin.

de Bode, M. (1991) Odour and ammonia emissions from manure storage. In: *Ammonia and odour emissions from livestock production.* Proceedings of COST 681 Workshop, silsoe 1990 (in press).

Bonazzi, G., Valli, l., Piccinini, S. (1988) Controlling ammonia emission from poultry manure composting plants. In: *Volatile emissions from livestock farming and sewage operations.* Nielsen, V. C., Voorburg, J. H. and L'Hermite, P. (eds). Elsevier Applied Science Publishers, London. 183-195.

Braun, A. (1983) Stallklima und Geruchbelastigung. Tell 111. KTBL. Schrift 280, Darmstadt.

Carney, P.G., Dodd, V. A. (1989) A Comparison between predicted and measured values for the dispersion of malodours from slurry. *Journal of Agricultural Engineering Research* 44, 67-76.

Carton, O. T., Majette, (1996) Manure-Waste or Resource in proceedings of the Institute of Engineers of Ireland, 1996. Annual Conference Athlone.

Copeill, M., Angelis, de S. and Bonazzi, G. (1986) Aeration of pig slurry to control odours and to reduce nitrogen levels. In: *'Odour prevention and control of organic sludge and livestock farming'.* Nielsen, V. C., Voorburg, J. H. and L'Hermite, P. (eds). Elsevier, London. pp 251-257.

Dahlberg, S. P., Lindley, J. A., Giles, J. F. (1988) Effect of anaerobic digestion on nutrient availability from dairy manure. Trans. ASAE 31: 1211-1216.

Denuynck, M., Nyris, E J., Palz, W. (1984) Biogas Plants in Europe. In: *Solar Energy R&D in the European Community.* Series E6. Reidel Publishing Company.

Department of the Environment/Department of Agriculture, Food and Forestry, (1996) Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates. Department of Environment / Department of Agriculture, Food and Forestry.

Department of the Environment, (1997) Major extension of EPA Licensing announced. In: Department of the Environment, *environment bulletin, issue 34, May 1997.*

Eby, H. J., Willson, G.B. (1969) Poultry house dust, odor and their mechanical removal. In: *Animal Waste Management*. Coference Proceedings. Cornell University, Ithaca. 303-309.

Field, J.A., Caldwell, J.S., Jeyanayagam, S., Reneau, R.B. Jr., Kroontje, W., Collins, E. R. Jr. (1984). Fertilizer recovery from anaerobic digesters. Trans. ASAE 27: 1871-1876, 1881.

Finstein, M. S., Miller, F. C. (1985) Principles of composting leading to maximization of decomposition rate, odour control and cost effectiveness. In: *Composting of Agricultural and other wastes*. Gasser, J. K. R. (ed). Elsevier Applied Science Publishers, London. 3-13.

Geelen, van M. (1983) Dust filters to reduce the odour of a broiler house. Report no 8371. IMAG, Wageningen.

Geelan, van M., Hoek, van der K.W.(1982)Stankbestrijdingstechnieken voor stallen in de intensieve veehouderij. IMAG Publikatie 167, Wageningen.("Odour abatement techniques for intensive livestock units" AFRC Engineering Translation No. 535,December 1985)

IT Sligo

Hall, J.E. (1985) Machinery spreading: soil injection as a barrier to odour dispersion. In: Odour Prevention and Control of Organic Sludge and Livestock Farming. (Eds) V. C. Nielsen, J. H. Voorburg and P. L'Hermite. Elsevier Applied Science Publishers, London.

Hartung, J. (1986). Dust in livestock buildings as a carrier of odours. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming.* (Eds) V. C. Nielsen, J. H. Voorburg and P. L'Hermite. Elsevier Applied Science Publishers, London.

Hartung, J. (1986) Sampling of odours air for olfactometric measurement. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming.* (Eds) V. C. Neilsen, J. H. Voorburg and P. L'Hermite. Elsevier Applied Science Publishers, London.

Hardwick, D. C. (1982) Agricultural problems related to odour prevention and control. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming.* (Eds) V. C. Neilsen, J. H. Voorburg and P. L'Hermite. Elsevier Applied Science Publishers, London. pp 21-26.

Hobbs, P., Pain, B. F., Misselbrook, T.H. (1995). Odorous compounds and their emission rates from livestock wastes. In: International Livestock Odour Conference Proceedings, 1995. pp 11-13.

Geelen, van M. (1982) Dust filters to reduce the odour of a broiler house. Report no 8371. IMAG, Wageningen.

Hall, J. E. (1985) Machinery spreading: soil injection as a barrier to odour dispersion. In: Odour Prevention and Control of Organic Sludge and Livestock Farming. (Eds) V.

Irish Farmers Journal (1997) Irish Farmers Journal, March 8 1997.

Irish Farmers Journal (1997) Irish Farmers Journal, June 7, 1997.

C. Nielsen, J. H. Voorburg and P. L'Hermite. Elsevier Applied Science Publishers, London.

Hartung, J. (1986). Dust in livestock buildings as a carrier of odours. In: Odour Prevention and Control of Organic Sludge and Livestock Farming. (Eds) V. C. Nielsen, J. H. Voorburg and P. L'Hermite. Elsevier Applied Science Publishers, London.

Hartung, J. (1986) Sampling of odorous air for olfactometric measurement. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming.* (Eds) V. C. Nielsen, J. H. Voorburg and P. L'Hermite. Elsevier Applied Science Publishers, London.

Hobson, P. N., Bousfield, S., Summers, R. (1981) *Methane production from agricultural and domestic wastes.* Applied Science Publishers. 10-48.

Klarenbeek, J. V. Jongebreur, A. A., Benmer, S. C. C. (1982) Odour emission in pig fattening sheds. Report no. 48. IMAG, Wageningen.

Kowalewsky, H. H., Scheu, R., Vetter, H. (1980) Measurement of odour emissions and immissions. In: Effluents from Livestock - Proceedings of a CEC seminar, Bad Zwischenahn, October 1979. Ed. Gasser J.K.R. Applied Science Publishers, London.

Kroodsma, W. (1986) Separation as a method of manure handling and odours reduction in pig buildings. In: *Odour prevention and control of organic sludge and livestock farming.* Nielsen, V. C., Voorburg, J. H. and L'Hermite, P. Elsevier, London. 213-221.

MAFF (1992). Code of Good Agricultural Practice for the Protection of Air. Published by Ministry of Agriculture, Fisheries and Food, London.

Mannebeck, H. (1985) Covering manure storage tanks to control odour. In: *Odour prevention and control of organic sludge and livestock farming.* Nielsen, V. C.; Voorburg, J. H.; L'Hermite, P. (eds). Elsevier Applied Science Publishers, London. pp 183-193.

MAWM'S (1993). MAWM'S Working and Technical Report. Monaghan County Council.

Mortensen, B., Kai, P. (1995) Odour problems in relation to pig production in Denmark. In: International Livestock Odour Conference Proceedings 1995. pp 121-124.

Nielsen, V. C. (1986) Treatment processes for farm wastes. In: *Processing and use of organic sludge and liquid agricultural wastes.* D. Reidel Publishing Company, Lanchester. 25-38.

IT Sligo

Nolan, P. (Pers. Comm.) Environmental Protection Agency.

O'Scanaill, T. R., (Pers. Comm.) Cork County Council.

Pain B. F., Bonazzi, D. G. (1993) Environment, agriculture and stock farming in Europe, European Conference, 1990-1993, Mantua, Italy.

Pain B. F., Clarkson, C. R. Philips, V. R., Klarenbeek, J. V., Misselbrook, T.H. and Bruins, M.A. (1991) Odour emissions arising form application of livestock slurries on land: measurements following spreading using a micrometeorological technique and olfactometry. *Journal of Agriculture Engineering Research* 48, 101-110.

Pain, B. F., Klarenbeek, J. V. (1988) Anglo-Dutch experiments on odour and ammonia emissions from landspreading wastes. Research Report 88-2 IMAG, Wageningen, The Netherlands.

Pain, B. F. and Misselbrook, T.H. (1995). Quantification and Control of Odours following Application of Manures to Land. In: *New knowledge in livestock odour, Proceedings of international livestock odour conference,* 1995. 40-43.

Pfeffer, J. T. (1979) Anaerobic digestion processs. In: *Anaerobic Digestion.* Stafford, D.A., Wheatley, B.I. and Hughes, D. E. (eds). Applied Science Publishers, London 15-33.

Phillips, V. R., Pain, B. F., Clarkson, C. R., Klarenbeek, J. V. (1990) Studies on reducing the odour and ammonia emissions during and after the landspreading of animal slurries. *Farm Buildings and Engineering* 7, 17-23.

Phillips, V. R., Stroud, D. A. (1985). A preliminary assessment of machines for surface spreading of sludges and slurries with minimum odour. In: *Volatile emissions from livestock farming and sewage operations.* Edited by Neilsen, Voorburg and L'Hermite. Elsevier Applied Science.

Raabe, S. J. (1984) Evaluation of manure flush systems at caged layer operations. *Transactions of the American Society of Agricultural Engineers* 1984, 852-858.

Randall, J. M., Armsby, A. W., Sharp, J. R. (1983) Cooling gradients across pens in a finishing piggery. 11 Effects on excretory behaviour. *Journal of Agricultural Engineering Research* **29**, 295-303.

Schaefer, J. (1977) Sampling, characterisation and analysis of malodours. *Ag. & Environment* **3**,121-127.

Schamp, N., van Langenhove, H. (1985). Comparison of olfactometric odour measurement and chemical odour measurement. In: *Odour prevention and control of organic sludge and livestock farming.* Nielsen, V. C.; Voorburg, J. H.; L'Hermite, P. (eds). Elsevier Applied Science Publishers, London.

Schirz, S. (1991) Practical application of bioscrubbing technique to reduce odour and ammonia. In: *Ammonia and odour emissions from livestock production.* Proceedings of COST workshop, Silsoe 1990 (in press).

IT Sligo

Skjelhaugen, O. J. (1990) Aerobic treatment of cattle slurry in farms plants. In: Recent developments in animal waste utilisation. REUR Technical Series 17. Hall, J. (ed) FAO/CRPA. 73-80.

Sneath, R. W., Burton, C. H., Williams, A. G. The performance of a farm scale aerobic treatment plant for reducing odour from piggery slurry. In: *Agricultural and Food Processing Wastes.* Proceeding of 6th International Symposium on Ag and Food Processing Wastes, Chicago, USA 17-18 December 1990. 460-469. St Joseph Michigan USA ASAE. ISBN 0-929355-10-5.

Sobel, A. T., (1972) Olfactory measurement of animal manure odor. *Transactions of the American Society of Agricultural Engineers* **15**, 696-699.

Spoelstra, S. F. (1980) Origin of objectionable odorous components in piggery wastes and the possibility of applying indicator components for studying odour development. *Agriculture & Environment* **5**, 241-260.

Summers, R., Bousfield, S. (1980) A detailed study of piggery waste anaerobic digestion. *Agricultural Wastes* **2**, 61-78.

Svobda, I. F., Deans, E. A., Fallowfield, H. J. (1990) Integrated system for aeration of whole piggery slurry with heat recovery and algae treatment. In: *Recent developments in animal waste utilisation. REUR Technical Series 17.* Hall, J. (ed) FAO/CRPA. 64-72.

Teagasc, (1993) Irish agriculture and figures 3rd Edition, Published by Teagasc, 19, Sandymount avenue, Dublin 4. 22 pages .

IT Sligo

Thacker, F. E., Evans, M. R. (1986) BOD, TOA and odour offensiveness. In: *Odour prevention and control of sludge and livestock farming.* Nielsen, V. C., Voorburg, H.H. and L'Hermite, P. Elsevier, London. 307-320.

Velsen, van A. F. M. (1979) Anaerobic digestion of wet piggery wastes. In: *Engineering problems with effluents from livestock.* Hawkins, J. C. (ed). CEC, Luxembourg.

Westerman, P.W., Zang, R. (1995) Aerobic treatment of animal waste for odour control. In: *New knowledge in livestock odour, Proceedings of international livestock odour conference,* 1995. 218-222.

Williams, A. G. (1984) Indicators of piggery slurry odour offensiveness. *Ag. Wastes* **10**, 15-36.

Williams, A.G. (1989) Dust and odour relationships in broiler house air. *Journal of Agricultural Engineering Research* **44**, 175-190.

Williams, A. G., Evans, M. R. (1981) Storage of piggery slurry. *Ag. Wastes* **3**, 311-321.

Working Party Report (1974). Report of the Working Party on the Suppression of Odours from offensive and selected other trades. (Part1&2). Published by Warren Spring Laboratory (DTI).

Zeisig, M. D. (1987) Experiences with the use of biofilters to remove odours from piggeries and hen houses. In: *Volatile emissions from livestock farming and sewage operations.* Nielsen, V. C., Voorburg, J. H. and L'Hermite, P. (eds). Elsevier, London. 209-216.

IT Sligo