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An Ghníomhaireacht um Chaomhnú Comhshaoil

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Spent Mushroom Compost Management and Options for Use

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

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EPA STRIVE Programme 2007–2013

Spent Mushroom Compost Management and Options for Use

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STRIVE Report

Prepared for the Environmental Protection Agency

by

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Table of Contents

Executive Summary

Stringent monitoring stipulated by contemporary environmental legislation has led to a need for cost-efficient and sustainable approaches to recycling biodegradable wastes. One notable organic waste increasing in amount in Ireland and worldwide is spent mushroom compost (SMC), a waste product of the mushroom industry. In light of this, the research presented here evolved around two main research areas pertaining to various aspects of SMC management:

1. The design and establishment of an in-house constructed wetlands trial for treating metalliferous acid mine drainage (AMD), using SMC as the organic substrate; and

2. The development of an introductory best management practice manual for mushroom growers, which was developed in order to promote effective disposal strategies and to impart ownership of SMC to the relevant mushroom growers, farmers and authorities.

In the wetlands trial, SMC was successfully employed as a substrate in constructed wetlands treating AMD, similar in composition to acidified wastewater from the Avoca mine site, Co. Wicklow, Ireland. The constructed wetlands trial consisted of four cells in series, with each established in triplicate giving a total of 12 cells. Four litres of AMD was continually passed through each quadruple set of wetlands per day using pre-programmed peristaltic pumps. The results have shown the promising capacity of the anaerobic wetland to neutralise the acidic sulphur-enriched drainage and sustain the buffering capacity of the system over an extended period of time. Furthermore, the results suggest that the system is also capable of maintaining a reducing environment through the reduction of sulphate concentrations, organic substances and possibly the activity of methanogenic bacteria over a prolonged period of time. The removal of zinc and copper and, to a lesser extent, sulphate and iron from within the system also indicates that the system is capable of receiving a much larger volume of synthetic AMD (SAMD) as much of the removal took place in the first two cells. The results suggest that this wetland system may prove to offer a long-term waste management option for SMC in Ireland, and also present an effective alternative to treating AMD. Recommendations from this trial include the requirement for an electrochemical data-logging device to be installed at large-scale constructed wetland sites so that the impact of temperature on removal rates of heavy metals is immediately recorded and actions could be taken to prevent the effluent from leaving the system by recirculating it to the receiving cell for further treatment. The projected fate and lifespan of similar wetland systems should be modelled to predict their longevity and effectiveness in the field.

The second part of this research focused on the development of a mushroom farm environmental management plan with the basic components including soiled water management, erosion control, protection of surface and groundwater sources, SMC utilisation and nutrient management, integrated pest management and, most importantly, record keeping to track all SMC movement throughout Ireland. It is anticipated that, if mushroom farms operate in agreement with these suggested guidelines, individual waste permits may not be required as mushroom production units should be managed in such a meticulous way that they will prevent any contamination of water, air and/or soil resources.

1 Review of Literature

1.1 Introduction

Spent mushroom compost (SMC) is becoming available in increasing quantities, with the Irish mushroom production industry producing an estimated 22,680 kg of SMC on a weekly basis (Young, 2008), a fact that poses a great environmental challenge in terms of its effective disposal. It is generally acknowledged that SMC is a valuable material for improving soil structure in tilled soils owing to its highly organic nature (Maher et al., 2000, amongst others) and for increasing dry-matter production on grassland soils (Mullen and McMahon, 2001). As 72% of all SMC in Ireland is applied to land (Maher et al., 2000), it is therefore imperative that systematic analysis be carried out on its exact composition, in order to evaluate its merit as a fertiliser, so that it can be applied to land in a rational and informed manner in accordance with relevant nutrient management plans.

1.2 The Mushroom Industry in Ireland

The mushroom industry has expanded rapidly during the past 25 years, with over 400 growers producing 68,000 t of mushrooms worth an estimated €130 million in 2001, as opposed to €2.3 million in 1973 (Anonymous, 2002a). Conversely, an abrupt reduction in the number of mushroom production units has been recorded within recent years, declining from approximately 580 units in 1997 to the current figure of 80 (Young, 2008). One explanation for the reduction in producers is attributable to a significant number of small-scale mushroom growers leasing their units to other, perhaps, more committed growers. In addition, with the increased labour costs and continued competition from the mushroom industry in Poland and Holland, smaller production units in Ireland were forced to close. The vast majority of growers produce mushrooms for the fresh market in Ireland, with 80% being exported to the UK (Young, 2008). In 2007, the estimated value of the mushroom industry in Ireland was nearly €100 million (Young, 2008). According to Maher et al. (2000), the majority of these producers are located in Monaghan (24%) and Cavan (11%), followed closely by Roscommon (9%), Mayo (8%) and Donegal (7%). The Irish industry is based on a satellite grower system, where spawned compost is circulated from a centralised compost company. The two main compost manufacturing companies currently operating in Ireland are Walsh Mushrooms Ltd., Gorey, Co. Wexford, and Monaghan Mushrooms Ltd., Co. Monaghan (Young, 2008), the first of which was established in Gorey in 1979, followed by the opening of a plant in Monaghan in 1980.

The dominant production method in the Irish mushroom industry is the system of growing mushrooms, mostly *Agaricus bisporus* species, in plastic bags and tunnels. This practice was originally developed in Denmark in the 1950s and has the capacity to produce mushrooms economically and of exceptional quality (Anonymous, 2000c). However, in recent years, there has been a gradual move towards an innovative production system, referred to as the Dutch shelving system. This production method involves placing the compost in steel shelves as opposed to bags, which is conducive to mechanical management and is more lucrative and less labour intensive (Anonymous, 2001). Mushroom cultivation and production involves the pure culture of spawn, composting, and pasteurisation of the substrate, followed by the meticulous regulation of growing conditions (Ball and Jackson, 1995).

It has been stated that mushrooms are the most important crop in the Irish horticultural society, with approximately 69,878 t of mushrooms being marketed by producer organisation schemes in 2007 (DAFF, 2009). Ireland is self-sufficient with regard to the mushroom industry, with almost 80% of the mushrooms produced in Ireland for the export market (DAFF, 2009). Even though this is the case, mushroom production has suffered a decline in recent times, with an estimated 15% drop in output between 2004 and 2007 (DAFF, 2009).

1.3 Mushroom Compost

Compost is defined as any product of a composting process that is successfully free from pathogens, weed seeds and inert contaminants and is subsequently suitable for an intended purpose (Szmidt and Dickson, 2001). Mushroom compost is manufactured from wheaten straw, gypsum, poultry litter and/or horse manure, with cottonseed meal and mushroom spawn as supplements. Mushroom compost is a specially designed, homogeneous and selective medium that fulfils the nutritional requirements of the mushroom crop (Anonymous, 2002a).

1.3.1 Mushroom composting process

Composting is the controlled decomposition and suitable stabilisation of blended organic substrates within an aerobic environment that allow the development of thermophilic temperatures as a result of biologically produced heat (Szmidt and Dickson, 2001). The principle of composting in relation to the mushroom industry is to contrive a substrate that encourages the growth and development of mushroom mycelia while eliminating other micro-organisms. This is achieved by manipulating the natural succession of micro-organisms present in the compost's raw materials (Ball and Jackson, 1995).

The manufacture of mushroom compost involves two stages, the first of which is performed outdoors or under a roof in large masses, where the raw materials are moistened and thoroughly mixed for up to 12 days. Moistening ensures that the different components are mixed uniformly and, more importantly, encourages microbial activity. However, this system may be susceptible to changes in the ambient temperature, especially outdoors. After this crucial pretreatment phase, these stacks are placed in long windrows undercover for 7–8 days and are mechanically aerated. The stacks heat up quickly and sometimes may reach temperatures as high as 80°C (Maher et al., 1993).

Phase 2 of this composting process is carried out in purpose-built structures, which are generally well-insulated plastic tunnels with slatted floors. The environment is carefully controlled, where the compost temperature is allowed to rise to 57–60°C for up to 12 h and is subsequently reduced by the influx of air from the air plenum below the compost. This pasteurisation stage is essential for the control of diseases and unwanted organisms. This is continued until the temperature has dropped to around 30°C and the ammonium levels are below 10 ppm, as at higher concentrations the ammonium would be toxic to the mushroom. The compost is then deemed selective to the mushroom as the level of carbohydrates, in particular cellulose, has been reduced and the nitrogen has been incorporated into the lignin to form a nitrogen-rich lignin–humus complex. At this stage, the moisture, dry matter and organic matter of the mushroom-selective medium will also have deteriorated significantly (Table 1.1), with the resulting complex being readily available to the cultivated mushroom and other basidiomycetes but not available to the majority of other micro-organisms (Maher et al., 1993).

The compost is then mixed with spawn, which is a monoculture of mushroom mycelia on cooked and sterilised grain, and then placed into plastic bags, or more economically on Dutch shelves, which are then distributed to mushroom farms around the area. After about 2 weeks, the compost is completely colonised by the mycelia and the final step in the preparation of the

Table 1.1. Compost data during compost preparation and cropping (adapted from Gerrits, 1994).

	Compost (kg)	Moisture (%)	Water (kg)	Dry matter (kg)	Organic matter (kg)
Start Phase 1	1,600	75	1,200	400	316
End Phase 1	1,000	72	720	280	196
End Phase 2	712	67	477	235	151
Casing	625	64	400	225	141
Post-cropping	458	60	276	182	100

compost involves covering the mycelia with a layer of casing. This layer generally consists of peat and calcium carbonate ($CaCO_3$), which initiates the formation of pinheads in a vertical direction. Three weeks after casing, the first mushrooms can be harvested. The used compost is sometimes sterilised for 12 h at 70°C or disinfected (Maher et al., 2000). This sterilised mixture of compost and casing soil is further available for beneficial use in agriculture and horticulture and is known as SMC.

1.3.2 Spent mushroom compost

Spent mushroom compost is a waste product of the mushroom industry (Fig. 1.1), which at the end of a production cycle remains partially decomposed. It is no longer capable of sustaining economic levels of mushroom production, as it is likely to contain not only a sizeable and diverse group of micro-organisms, but also an extensive range of extracellular enzymes that are active against wheat straw (Ball and Jacobsen, 1995).

Spent mushroom compost possesses a number of agronomic disadvantages in relation to its possible further use in horticulture or agriculture. Principally, it has a high salt content and if incorporated into land at high application rates or utilised in too high a quantity in a growing medium, it inhibits plant growth. To a lesser extent the lime (21 kg/t) and gypsum (23 kg/t) content may prevent its further use in areas where calcifuge plants are grown, as the levels present in SMC would be toxic to them (Maher and Magette, 1997). Encouragingly, SMC exhibits many favourable characteristics, some of which are typical of other organic waste by-products, which include a relatively low bulk density and a high organic matter and moisture content (Maher et al., 1993).

In the Netherlands, the exact composition of SMC was investigated in 620 SMC samples, which showed a significant variability, owing primarily to the composting time and the cropping cycle, which resulted in the overall dry matter, phosphate and ash content being considerably reduced (Gerrits, 1994). Nitrogen levels within SMC can also vary as additional nitrogen in the

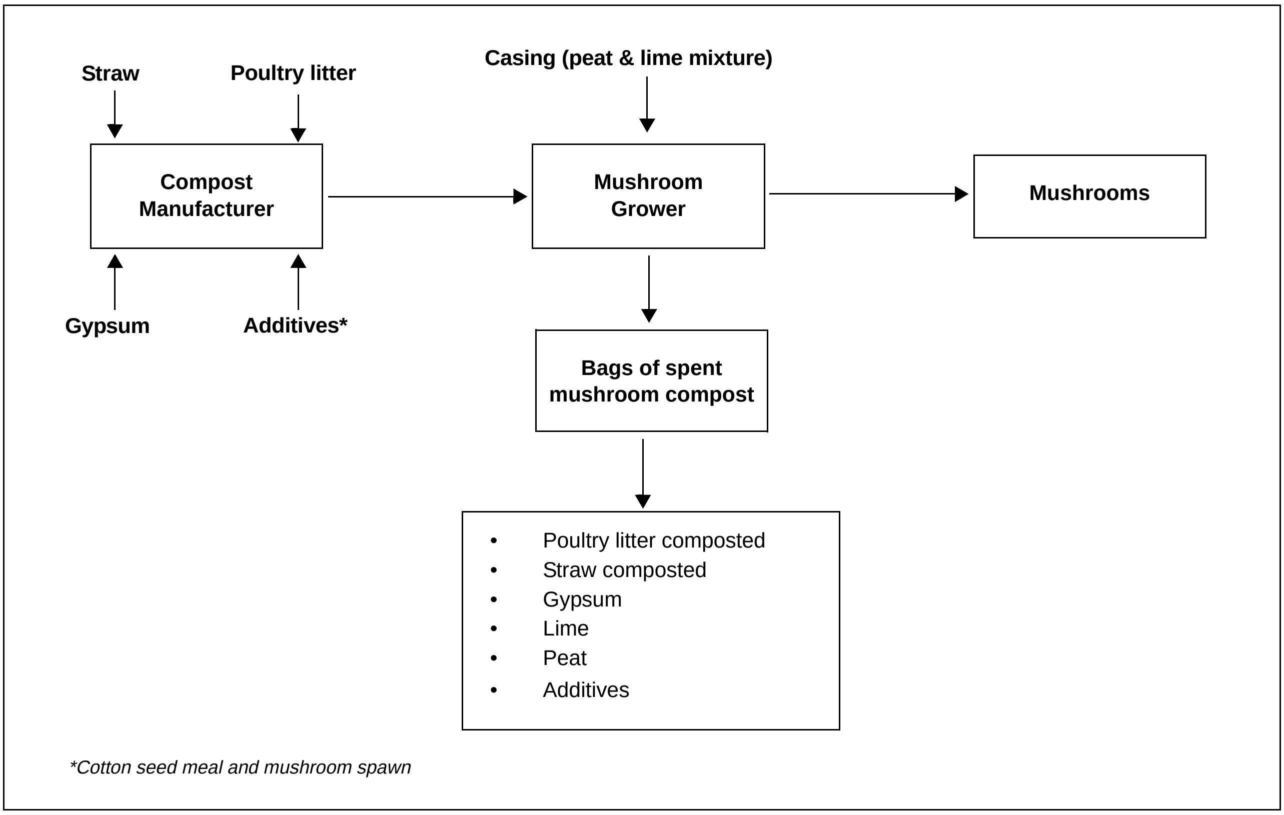

Figure 1.1. Overview of mushroom production process (adapted from Anonymous, 1997a).

form of poultry litter is often amplified in order to successfully increase mushroom productivity (Noble and Gaze, 1996).

Spent mushroom compost in Ireland displays similar inconsistencies but more so in relation to total potassium, calcium and phosphorus concentrations (Maher et al., 2000). A study on the mean composition of SMC from Ireland, the Netherlands and the United States reported that the content of nitrogen is considerably high; however, the amount of readily available nitrogen in the form of nitrate and ammonium is small. Consequently, most of the nitrogen is available slowly and is in the organic form. The phosphorus content is higher than most plant material owing to the supplementary phosphorus added to the poultry feed, but this may not always be the case as, recently, the digestive enzyme phytase has been added in increasing amounts to poultry diets, resulting in the overall reduction of phosphorus in the poultry manure (Anonymous, 2003). In contrast to nitrogen, phosphorus is water soluble, is readily available to plants, and is the main determining factor in applying SMC to land. The high calcium levels originate from the gypsum added during composting and lime added in the casing layer, with the quantity varying significantly depending on the ratio of compost to casing material used (Maher and Magette, 1997).

1.3.2.1 Comparison of fresh and composted SMC

Both physical and chemical properties of fresh and aged SMC are quite similar in nature (Table 1.2); however, higher levels of ammonia were detected in fresh SMC, resulting in significant variations in the pH (Lohr et al., 1984).

As fresh SMC is already partially composted, the duration of time required to further compost or stabilise the organic matter is significantly reduced, in comparison to that of other organic materials. Lohr et al. (1984) found that SMC composted within 6 weeks. The composting process was carried out in an in-vessel, aerated, tumble composter, where a moisture level of 50% was maintained. After the 6-week period, all mushroom mycelia were eradicated, the pH of the SMC had stabilised to 6.6 and the level of ammoniacal nitrogen (NH_4-N) had also decreased to 1 mmol/kg.

The thermophilic stage of the process transpired within the first 2 weeks of composting, with the temperature rising to 55°C, and subsequently dropping to 30°C during the maturation stage. A similar temperature pattern was also observed by Maher et al. (1993), where the resulting compost had a peat-like consistency and was dark brown in colour. Composted SMC is an exceptionally stable material and can be bagged and sold as a retail product similar to practices employed in the marketing of moss peat (Maher et al., 1993).

The weathering of SMC stockpiles in fields is commonly employed prior to reuse of SMC as a soil conditioner. Guo and Chorover (2004, 2006) found that the nutrient-enriched leachate from such masses can migrate through soil profiles through preferential channels, resulting in soil and groundwater

Table 1.2. Physical characteristics of fresh and aged spent mushroom compost (SMC) (adapted from Lohr et al., 1984).

Physical characteristics	Fresh SMC	Aged SMC
Total pore space (% by vol.)	87.1	86.3
Total water at saturation (% by vol.)	63.2	65.5
Air space (% by vol.)	24.0	20.8
Easily available water (10–50 cm) (% by vol.)	12.6	22.6[1]
Water buffering capacity (50–100 cm)	1.9	2.1
Bulk density (g/cm)	0.256	0.293[1]

[1]Fresh SMC significantly different from aged at the 5% level.

contamination. Therefore, weathering of SMC should be carried out on concrete or similar compact surfaces with no structural fissures and adequate controls provided for the diversion and treatment of surface run-off (Guo and Chorover, 2006). Such run-off could be further utilised in the irrigation of nursery trees (Jarecki, 2002), or for plant growth in hydroponic cultures (Michitsch et al., 2003; Jarecki et al., 2005).

1.3.2.2 Uses of SMC

Spent mushroom compost has a wide range of uses as follows:

- As a mulch for ornamental flower and vegetable crops (White, 1976; Lemaire et al., 1985; Chong et al., 1987; Dallon, 1987; Devonald, 1987; Lohr and Coffey, 1987; Chong et al., 1991, 1994; Wuest and Fahy, 1992; Duggan et al., 1994; Szmidt, 1994; Chong and Hamersma, 1996; Maher et al., 2000; Medina et al., 2009; Ribas et al., 2009 – amongst others).

- In animal feedstocks as highly nutritious fodder and bedding for poultry and animals (Langar et al., 1982; Wilson et al., 1983; Chang, 1984; Zhang et al., 1995; Beattie et al., 2001; Kwak et al., 2009).

- In disease control (Yohalem et al., 1994; Cronin et al., 1996; El-Fallal and Migahed, 2003).

- In the bioremediation of contaminated drainage and land (Kuo and Regan, 1992; Stark et al., 1994; Buswell, 1994; Rupert, 1995; Manyin et al., 1997; Shuman and Li, 1997; Groudev et al., 1999; Jacobson et al., 1999; Shuman, 1999a,b; Chang et al., 2000; O'Sullivan et al., 2000; Law et al., 2003; Chen et al., 2005; Jordan et al., 2008b, 2009).

- As an organic fertiliser (Gerrits, 1986; Maher, 1988, 1990; Duggan et al., 1998; Stewart et al., 1998; Mullen and McMahon, 2001; Moore et al., 2002; Rao et al., 2007).

- For incineration for renewable energy (Maher et al., 1993, 2000; Anonymous 1997a; Williams, 2001; Williams et al., 2001; Finney et al., 2009).

- As a soil conditioner in enhancing the physical and chemical properties of the soil (Male, 1981; Wang et al., 1984; Gerrits, 1986; Kaddous and Morgans, 1986; Maher, 1988; Wuest and Fahy, 1992; Maynard, 1994; Steffen et al., 1994; Levanon and Danai, 1995; McMahon, 1997; Ranganathan and Selvaseelan, 1997; Stewart et al., 1998; Holmes and Richardson, 2000; Maher et al., 2000; Mullen and McMahon, 2001; Curtin, 2005; amongst others).

1.3.2.3 SMC as a soil amendment

The integration of organic materials into soils has proven to increase soil aggregation, water-holding capacity, water infiltration, buffering capacity and aeration porosity, while it decreases soil crusting, surface run-off and bulk density. It also greatly improves cation exchange capacity, soil biota activity, tilth, plant yield and the provision of nutrients over a 4- to 6-year period (Wang et al., 1984; Wuest and Fahy, 1992; Levanon and Danai, 1995; Rupert, 1995; Steffen et al., 1994; Chenu et al., 2000; Holmes and Richardson, 2000).

However, as previously mentioned, the high salt content of SMC can become a problem in soils that already have an excessive salt content and also in regard to salt-sensitive crops, resulting in variable responses when used as a soil amendment and as a potting substrate (Wang et al., 1984; Gerrits, 1986; Chong et al., 1991). Conversely, this seems to occur less frequently in field crops as the application rate is generally lower and more leaching often occurs (Gerrits, 1986). Furthermore, if the process of pasteurisation (cook-out) is not carried out, which is often the case after cropping in the bag system, the mushroom mycelia are still alive and mushrooms may appear even after the SMC has been incorporated into the soil. If this is the case, further composting may be required to kill the mycelia (Maher et al., 1993).

1.3.2.4 Effect of SMC on growth of field crops

The relentless decrease in organic matter content in intensively cultivated soils can lead to a rapid decline in the physical status of soil and, consequently, to possible erosion. This deterioration can be prevented by the addition of organic materials which act as a nutrient supply and improve the overall soil productivity

(Pagliai and Vignozzi, 1998). The utilisation of SMC on such field crops as winter and spring wheat and potatoes has shown that it increases soil organic matter and improves soil structure (Maher et al., 2000). Spent mushroom compost is also an exceptionally valuable source of potassium and phosphorus, as well as being a provider of trace elements. It contributes nitrogen but this is not readily available to the crop until a year after application. Therefore, supplementary nitrogen fertiliser must be added (Maher et al., 2000). The rate of phosphorus addition to soils is the usual limiting factor in SMC applications. Teagasc has given phosphorus recommendations for a number of crops at soil index level 3 (7–9 mg P/l), assuming the phosphorus content of SMC is 3.9 kg/t (Maher and Magette, 1997). The suitability of land for SMC application not only involves knowledge of the soil phosphorus level but also the surface gradient, the depth of soil over the permeable bedrock, the presence of mole drains and the proximity of the land to watercourses. Spent mushroom compost must not be applied to frozen or waterlogged land (Maher and Magette, 1997).

The use of SMC in vegetable production was compared to that of poultry manure in relation to the growth of 11 different crops, as both SMC and poultry manure have a similar nutritional status. It was found that SMC could be used as an alternative to poultry manure, which is widely used in intensive vegetable production in Melbourne, Australia. However, care must be taken to ensure the absence of any phytotoxic chemicals, such as chromated copper arsenate, which were present in the original supply of SMC. This is because of the fact that this particular compost was composed of wood shavings and under acidic conditions released arsenates and chromates. Such compounds had detrimental effects on the crops (Male, 1981).

In a 3-year trial on a sandy terrace, it was found that applications of high rates of SMC supplied the fertiliser requirements for most vegetables without causing extreme nitrate leaching into the groundwater below. The nitrate had accumulated within the soil, whereas control plots were more vulnerable to nitrate leaching, but resulting from this cumulative effect, lower rates of SMC should be applied in future applications so as to minimise possible nitrate leaching during heavy rainfall (Maynard, 1994). Similarly, the effect of SMC land applications on adjacent surface water was investigated using aquatic macroinvertebrates as bioindicators. The results showed that the run-off from the nearby SMC applications did not significantly impact on the stream insect community (Reed and Keil, 2000).

1.3.2.5 Use of SMC as a potting substrate and in glasshouse soil experiments

The use of topsoil as a growing medium for pot-grown and greenhouse plants has decreased significantly due to contamination of residues from weed seeds, herbicides and nematodes, thus placing an ever-increasing demand on the use of soilless materials for growing mixes. Furthermore, the latter are relatively cheap and have all the desirable characteristics associated with a good growing medium, which include good air- and water-holding capacities, a high nutrient content and the absence of weed seeds (Dallon, 1987).

A variety of floricultural crops was grown under controlled greenhouse conditions to evaluate the feasibility and potential benefits of using SMC as a growing medium additive. Plants with the highest bud count occurred within an SMC and Speedel (Speedel Commercial Mix, Shamrock Industries, Norwich, Ontario, Canada) mix in a ratio of 1:1, while the shortest plants were produced in SMC alone (Dallon, 1987). Lemaire et al. (1985) also concluded that SMC alone was not an effective potting substrate because of its lack of stability, low water availability, high salinity level and its neutral pH, which is not suitable to all growing plants. The problem of high shrinkage of fresh SMC was also noted by Lemaire et al. (1985), which primarily was due to the breakdown of organic matter, but this can be reduced by composting and aging the SMC (Lohr et al., 1984). The salinity of SMC can be significantly reduced over 2–3 years through weathering, decomposition and leaching, resulting in floricultural crops responding favourably to composted SMC as a growing medium (White, 1976). Devonald (1987) also reported that incorporating SMC and sand in a 3:1 ratio was not an acceptable growing medium; nevertheless, when half of the SMC was replaced by peat or bark, the medium gave more favourable results. However, as the amount of SMC in the medium has been considerably reduced, its significance as a growing medium is minimal (Devonald, 1987).

Many ornamental shrubs, including cotoneaster, deutzia, dogwood, forsythia, juniper, ninebark, potentilla, rose and weigela, were reported to have grown well in containers amended with SMC at between 25% and 100% (Chong et al., 1987, 1991). This was also the case when dogwood and forsythia were grown in a medium amended with SMC and bark (Chong et al., 1987) and was attributed to the rapid early leaching of high salts from the SMC. Negatively, however, the privet species developed chlorosis within the early growing season and the potentilla also showed slight leaf discoloration within the late season when both species were amended with SMC (Chong et al., 1991).

Broccoli (moderately salt tolerant), lettuce, marigold and tomato (moderately salt-sensitive crops) were grown in a controlled greenhouse in 50% vermiculite, varying rates of fresh and aged SMC and the remaining portion consisting of Canadian peat. The percentage dry matter of the plants declined linearly while the dry weight and quality ratings showed quadratic responses as the amount of SMC in the media increased. Overall, the plants were smaller in fresh than in aged SMC (Lohr et al., 1984). Reduced growth and symptoms of ammonia toxicity were also evident in transplants of lettuce, cucumber, tomato and marigold when grown in fresh SMC (Lohr et al., 1984).

1.3.2.6 Effect of SMC on grassland production

The effect of land-spreading SMC on permanent grassland was studied in a field trial in Co. Monaghan. The results showed an increase in plant-available soil phosphorus, potassium and magnesium levels as well as soil pH and herbage dry-matter production. The age of the SMC had no apparent effect on the overall results (Mullen and McMahon, 2001). In contrast, SMC incorporated into the same soil in a pot experiment showed similar increases in plant-available soil phosphorus, pH, herbage dry-matter production and electrical conductivity (EC). The findings also suggest that application of well-aged SMC on high-pH soils may give rise to excessive plant-available soil phosphorus levels and such soils may become more vulnerable to drought (Mullen and McMahon, 2001).

1.3.2.7 SMC as an organic fertiliser

The utilisation of organic manures as a fertiliser has been customary from the beginning of agriculture. The recent developments in organic farming and sustainable agriculture have led to an increase in the use of organic as opposed to synthetic fertilisers, hence raising the demand for the utilisation of composted organic wastes for the supply of plant nutrients (Levanon and Danai, 1995). Spent mushroom compost is an ideal organic manure in that it has a low heavy metal content, it has a substantial supply of plant nutrients, in particular phosphorus and potassium, it has no weed seeds or plant pathogens, it is not odorous and, most notably, it has a high organic matter content (Maher and Magette, 1997).

Duggan et al. (1998) studied the effect of SMC as an organic manure and nutrient source on winter wheat with respect to the quality of the yield and nitrogen uptake. The trial, which was carried out on a clay loam soil in a split-plot design, received five application rates of SMC 0, 8, 16, 32 and 64 t/ha. Each plot was subdivided into three subplots that received three rates of the nitrogen fertiliser CAN (calcium ammonium nitrate). There was a substantial increase in grain yield, nitrogen uptake and percentage lodging of the wheat crop, but SMC was not deemed to be an efficient source of nitrogen as only 5.3% of added SMC nitrogen was recovered by the crop and only 14.4% of the total nitrogen was removed by the wheat at the highest application rate (Duggan et al., 1998). In contrast, urea formaldehyde, a waste product from the manufacture of timber goods, has proven to be an effective nutrient enhancer when added to SMC as it contains a substantial amount of nitrogen (Moore et al., 2002).

Spent mushroom compost can also be utilised as an organic manure for potatoes, which generally have a high nutrient requirement, where its effects on the yield, quality and nutrient uptake of the crop were also evaluated (Duggan et al., 1998). It was found that the addition of SMC, especially at high application rates, increased plant growth, nutrient uptake and tuber production.

1.3.2.8 Potential of SMC to generate renewable energy

The creation of renewable energy has developed dramatically within recent years and is enthusiastically promoted by the European Union. This has led to the evaluation of organic wastes such as poultry litter and animal manures as possible fuel generators (Anonymous, 1997a). Incineration of SMC would provide an ideal management solution, especially in areas such as Cavan and Monaghan where pig, poultry and mushroom producers are concentrated and are thus causing a restriction on land available for spreading organic manures (Maher et al., 2000). However, incineration is not a complete disposal method of SMC given that about 40% of the dry weight residue is ash (Maher et al., 1993).

Annually, 191,000 t of SMC are produced in the border counties, with this quantity alone having the capability of generating 6 MW of electricity (Anonymous, 1997a). However, in comparison with other typical fuels (Table 1.3), combustion of SMC is challenging given the amount of ash and moisture present. For every 1 kg of SMC only 25% is used to generate energy, whereas the remainder is comprised of 10% ash and 65% water. This fact has negative implications for the cost of haulage and transportation but, on a positive note, the form of sulphur found in SMC does not contribute to acid rain, which is often the case in the combustion of coal (Anonymous, 1997a).

The heat of combustion for SMC determined by Maher et al. (2000) was estimated to be ca. 9 MJ/kg on a dry-matter basis, as samples would not ignite at ~65% moisture level. It was concluded from this study that SMC could be used as a suitable alternative for supplying energy for the cement industry as the waste heat from the cement process could remove the excess moisture and the magnesium and calcium minerals present in the SMC are essential raw materials in the manufacture of cement (Maher et al., 2000).

1.3.2.9 Effects of SMC on soil physical properties

Organic materials when incorporated within a soil can successfully amend the physical structure by many mechanisms. Such mechanisms include the aggregation of clay and large mineral particles to form micro-aggregates that are further combined to generate aggregates. A hydrophobic coating is also produced on these aggregates in order to enhance their stability under wetting. Organic materials also provide nutrients to micro-organisms that enhance the stability of aggregates and also amplify the water-holding capacity and water mobility of a soil (Levanon and Danai, 1995). Overall, the chief physical structural effect is the enhancement of aggregate stability; the most notable organic components that impart this stability are polysaccharides, organic acids, humic and fulvic acids which are the products of microbial metabolism of the organic materials (Levanon and Danai, 1995).

The effects of SMC addition on the physical properties of soil have been investigated by Wang et al. (1984), Kaddous and Morgans (1986), McMahon (1997), Ranganathan and Selvaseelan (1997), Stewart et al. (1998), Maher et al. (2000), Murphy (2001) and Curtin (2005).

Wang et al. (1984) amended a low organic matter sandy loam soil utilised for growing field vegetables, with rates of 0, 2, 10, and 20 kg/m^2 SMC in spring over 2 consecutive years. Bulk density values decreased from 1.51 to 1.46 g/cm^3 with increasing SMC application owing to the high organic matter content in SMC, while small pore voids increased from 31% in the

Table 1.3. Comparison of fuel properties of spent mushroom compost with other common fuels (Anonymous, 1997a).

Fuel	Moisture (% weight)	Ash (% dry basis)	Volatile (% dry basis)	Calorific value (MJ/kg) % dry basis
Coal	2	4.9	25	29
Peat	20	4.00	65	21.0
Spent mushroom compost	61.8	36.9	53.5	12.2

control plot to 34% for the highest application of SMC. However, an inconsistent response was noted in the percentage of large pore spaces with increasing SMC application (Wang et al., 1984). pH and EC also increased with increasing SMC application and this proved beneficial to most of the vegetable crops studied. However, the elevated salinity levels within SMC can restrict the repeated or excessive use of SMC on soils producing salt-sensitive plants (Wang et al., 1984).

Kaddous and Morgans (1986) amended a loamy sand soil in New Zealand with SMC at application rates of 0, 10, 20, 40 and 80 t/ha in a 2-year field trial where four vegetables were cultivated. Spent mushroom compost successfully reduced the thermal conductance and bulk density of the soil, while the hydraulic conductivity, water retention, water-stable aggregates (>0.025 mm), organic carbon, and nitrogen, phosphorus and potassium all increased with increasing applications of SMC. Spent mushroom compost had no apparent effect on carrot crop yield, yet a decrease was noted in the yields of celery, lettuce and cauliflower (Kaddous and Morgans, 1986).

Investigations were carried out of the comparative effects of SMC incorporation and SMC land-spreading on the properties of grassland soils in Co. Monaghan, where it was noted that water-stable aggregates and bulk density of a permanent grassland were not influenced by SMC applications of 16.4 and 49.4 t/ha, respectively (McMahon, 1997; Mullen and McMahon, 2001).

In India, Ranganathan and Selvaseelan (1997) investigated the effects of applying 15 t/ha mushroom spent rice straw compost combined with nitrogen, phosphorus and potassium on the physical and physico–chemical properties of alluvial and laterite soils, which were of clay and sandy clay loam texture, respectively. The water-holding capacity, porosity and volume expansion on wetting all increased with increasing SMC application, owing to the rearrangement of soil particles by the SMC, which resulted in the formation of additional macropores, while the presence of carbonaceous materials within SMC contributed greatly to the improved water-holding capacity of the soils (Ranganathan and Selvaseelan, 1997). The bulk density and absolute specific gravity (density of soil with respect to water at 4°C) of the soils also decreased significantly when supplemented with SMC, owing to the increase in aeration, porosity and improved aggregation and friability (Ranganathan and Selvaseelan, 1997). The pH and EC of alluvial soil were not influenced by the application of SMC, which may be due to the buffering capacity of the clay content in a waterlogged environment, while both parameters increased slightly for the laterite soil owing to the increase in soluble nutrient elements arising from the mineralisation of the nutrients in both SMC and the nitrogen, phosphorus and potassium fertiliser (Ranganathan and Selvaseelan, 1997).

Spent mushroom compost was also utilised by Stewart et al. (1998) as a soil amendment in a 2-year field trial, where the effect of SMC application on the physical properties of a sandy loam soil and the growth of four vegetable crops was investigated. Spent mushroom compost was applied at rates of 0, 20, 40 and 80 t/ha with and without inorganic fertiliser and was incorporated to a depth of 80 mm in a split-plot design experiment. Spent mushroom compost again proved a favourable soil ameliorant in that the bulk density values decreased by 0.05 to 0.25 g/cm^3, with surface crust and clod development correspondingly decreasing by 16–31% and 18–94%, respectively (Stewart et al., 1998). Consequently, aggregate stability increased by 13–16%, while the associated infiltration rate and water content of the soil increased by 130–207 mm/h and 0–7% w/w, respectively. A reduction in diurnal temperature was also noted; however, some of these beneficial changes were not apparent until repeated applications of 80 t/ha were incorporated (Stewart et al., 1998).

In an experimental pot trial on a poorly structured loam soil with low organic matter status, Murphy (2001) added SMC amendment rates of 0, 25, 50, 100 and 200 t/ha, where an increase in organic carbon, water-stable aggregates and total and air-filled pores favourably increased, while bulk density values decreased with increasing SMC application. A decrease in soil bulk density and increase in the water-holding capacity were also noted by Duggan et al. (1998) and Maher et al. (2000) in a greenhouse soil amended with SMC applications of 0, 20, 100 and 200 t/ha, with no negative effects evident on soil aeration. In another laboratory pot trial involving 10 intensively cultivated tillage soils with histories of soil crusting, Curtin (2005) incorporated SMC at application rates of 0, 50, 100 and 200 t/ha, resulting in the increase in macro- and micro-aggregation, with the highest application of 200 t/ha greatly increasing the infiltration rates in all soils.

1.3.2.10 Use of SMC in land remediation

Bioremediation is a productive, profitable and environmentally friendly method for the treatment of water and soils that are polluted with toxic and/or recalcitrant organopollutants (Buswell, 1994), where microbes degrade pollutants by mineralisation to water, inorganic minerals and carbon dioxide in aerobic conditions and methane anaerobically. Spent mushroom compost can be utilised successfully in the stabilisation of disturbed and commercial sites such as abandoned coal mines, pipeline construction sites and industrial sites. It acts as a slow-releasing fertiliser and provides small amounts of calcium bicarbonate, which leads to the elevation of the soil pH. It also increases the water-holding capacity, plant yields, organic matter content and nitrogen reserve (Rupert, 1995). Spent mushroom compost micro-organisms can also be utilised in the degrading of the insecticide components carbaryl and 1-naphthol, both of which are toxic to soil and water biota (Kuo and Regan, 1992). Spent mushroom compost has also been proven successful in the remediation of contaminated water by the removal of biocide PCP (pentachlorophenol), a pesticide and wood preservative, through the presence of a PCP-degrading bacterium in SMC (Law et al., 2003).

Spent mushroom compost has also been utilised as the primary substrate in the treatment of coal-mine drainage in constructed wetlands (Stark et al., 1994; Stark and Williams, 1994; Manyin et al., 1997), as an electron donor for the biological treatment of acid mine drainage (AMD) (Chang et al., 2000) and in the removal of heavy metals in passive treatments using laboratory columns (Jacobson et al., 1999) and laboratory passive systems (Groudev et al., 1999). The microbial activity, particularly the presence of the dissimilatory sulphate-reducing (DSR) bacteria such as *Desulfovibrio* and the absorption capacity of the organic matter content within SMC, is attributed to the relevant pollutant removal properties associated with SMC (Groudev et al., 1999). Consequently, SMC is utilised in many wetland construction projects. *Desulfovibrio*, *Desulfotomaculum*, *Desulfococcus* and *Desulfobulbus* bacteria are also present in the micro-anaerobic zones in SMC and contribute to the overall reduction in sulphate concentrations in contaminated sites (O'Sullivan, 2001). In contrast, the ability of SMC to degrade polycyclic aromatic hydrocarbons (PAHs) in creosote-contaminated soil from a wood preservation site is attributed to the xenobiotic degradation capability of SMC caused by the presence of lignin peroxidase, manganese-dependent and -independent peroxidase and laccase (Eggen, 1999).

More recently, SMC has been studied as a novel biosorbent of heavy metals under laboratory conditions where it was found to have a vast sorption capacity for cadmium, lead and chromium owing to the presence of hydroxyl, phosphoryl and phenolic functional groups on the surface of the SMC (Chen et al., 2005). The highest biosorption capacity of SMC occurred at pH 6.95 for cadmium, pH 6.04 for lead and pH 4.82 for chromium, and this occurrence was mainly attributed to the decrease in surface charge density of SMC, resulting in a stronger electrostatic attraction between the positively charged metal ions and the negative surface of SMC (Chen et al., 2005). Chen et al. (2005) also noted that the removal of the various heavy metals increased with increasing quantities of SMC, but, at quantities higher that 10 g/l, the biosorption capacity of the SMC plateaued. Shuman (1999a) and Shuman and Li (1997) also attributed the absorption sites in SMC to the redistribution of zinc fractions in zinc-contaminated soil to less bioavailable fractions. Shuman (1999b) attributed the strong affinity for zinc to the surface of SMC to the high bonding energy in SMC when added to soils.

1.3.2.11 Use of SMC as a feedstock

Spent mushroom straw from which the initial flush of mushrooms is harvested can successfully be converted into fungal protein and, consequently, a feedstock for animals (Chang, 1984). Langar et al. (1982) found that spent mushroom straw provided a good supply of nitrogen in the diets of buffaloes, yet it was suggested that the ash content of the spent straw should be decreased to ensure adequate dry-matter ingestion while avoiding affecting the fungal production. Spent mushroom compost has been used to enrich the environment of intensive pig housing where it was noted to improve the welfare of the pigs by minimising injury (Beattie et al., 2001).

1.3.2.12 Effect of SMC in the control of diseases

Spent mushroom compost extracts have proved successful in the inhibition of the germination of conidia of *Venturia inaequalis*, an apple scab pathogen, due to a low molecular weight non-protein metabolite that is produced by microbes during composting (Cronin et al., 1996) and also in the treatment of broad bean plants (*Vicia faba*) infected with chocolate-spot disease caused by the infection of *Botrytis fabae* (El-Fallal and Migahed, 2003) and in the control of foliar diseases (Yohalem et al., 1994).

1.3.3 Diseases in mushrooms

Mushrooms are subject to a series of diseases and pests that have the capability to cause substantial crop losses. Most of these pests originate from the actual compost, where the process of pasteurisation was not carried out efficiently. The main pests of mushroom crops are fungal and bacterial pathogens, mites, eelworms and flies (Davoren and Fogarty, 2005). The main fungal diseases associated with mushroom losses in Ireland since 1994 are dry bubble, wet bubble, green mould and cobweb which are caused by the organisms *Verticillium fungicola, Mycogone perniciosa, Trichoderma harzianum* and *Cladobotryum dendroides*, respectively (Staunton et al., 1999). The main types of flies that affect the mushroom crop include sciarids, phorids and cecids. Tarsonemid (*Tarsonemus myceliophagus*), tyroglyphid (*Tyrophagus* spp.) and red pepper (*Pygmephorus* spp.) are the varieties of mites that can cause damage to the growth of mushrooms and which mostly originate from the straw and manure within the mushroom compost (Davoren and Fogarty, 2005).

Fungus-feeding nematodes (eelworms) commonly infest mushroom mycelia and the severity of their infestation depends primarily on the surrounding hygienic conditions. *Ditylenchus myceliophagus*, *Aphelenchoides composticola* and *Rhabditidae* are the most widespread eelworm varieties that are associated with mycelial incursion (Davoren and Fogarty, 2005). The most common bacterial disease that affects mushroom growth in Ireland is bacterial blotch, which is caused by the bacterium *Pseudomonas tolaasii*. The disease can be transmitted manually or by flies and mites, and favours a moist substrate on which to develop (Davoren and Fogarty, 2005).

1.3.4 Treatment of mushrooms – agri-chemicals and pesticides

Disinfectants are the most common agri-chemicals employed within the mushroom sector as they eradicate an extensive range of organisms such as fungi, bacteria, viruses and pests. Their main purpose is to clean the equipment and machinery and to disinfect the SMC after cropping. Environ® (phenolic based), Deosan Red Label Hypochlorite® (chlorine based) and formaldehyde are the three approved mushroom disinfectants in Ireland. These disinfectants have a long persistence and have no reported corrosive effects on tools or equipment (Davoren and Fogarty, 2005). The fact that the mushroom is a fungus makes it more difficult to find a fungicide that is not phytotoxic to the mushroom. Sporgon® (prochloraz-manganese) is the most commonly used fungicide in Ireland and when applied at normal rates has no phytotoxic effects on the mushroom crop. The use of fungicides alone is not satisfactory in upholding an effective disease control environment as ordinary fungal pathogens have a tendency to become resistant to them when used frequently (Staunton et al., 1999).

Pest control is a necessary procedure in the minimisation of mushroom yield loss through the eradication of these unwanted infesters. There are a variety of controls practised to eradicate unwanted disease organisms, which include chemical, biological and cultural practices under the integrated pest management (IPM) approach to crop protection (Staunton et al., 1999; Davoren and Fogarty, 2005). Chemical controls include the use of Dimilin® (diflubenzuron), which controls 90–95% of sciarids, but does not control phorids and can reduce the mushroom yield by 7–8%. Apex® (methoprene) is often used for the same purpose but is not as successful (Staunton et al., 1999). Successful biological controls include *Steinernema feltiae*, an insect parasitic eelworm, commercially known as Nemasys®, Stealth® or Entonem®, which controls up to 70% of sciarids and is again less effective in the control of phorids (Staunton et al., 1999). Cultural methods of control centre on the area of good hygiene and the careful regulation of the environmental conditions within the mushroom tunnel.

1.3.4.1 Effects of chemicals on the environment

Both the ecotoxicological effects and the microbiological degradation of agri-chemicals used in the mushroom industry should be considered, especially when SMC is used as a soil amendment. This in turn may eliminate some of the ecological concerns about its safe disposal (Davoren and Fogarty, 2005). A battery of tests has been successfully devised for the assessment of the environmental toxicity of Environ®, using the sensitivities of a variety of organisms from the three trophic levels of the aquatic environment (Davoren and Fogarty, 2005); similarly, a Microtox® test was also lucratively developed for the evaluation of the ecotoxicity of phenol-based disinfectants which are commonly used for the disinfection of SMC (Davoren and Fogarty, 2005).

1.4 Legislations on SMC Management

This section describes the legislations, guidelines and current practices involved in the management of SMC disposal in five developed countries, namely the United States, Canada, the Netherlands, the United Kingdom and Ireland. Table 1.4 shows data for mushroom and SMC annual production levels in 2005 in these five countries and in five additional ones.

1.4.1 Current policies on the management of SMC

With the exception of the US, none of the studied countries has special or standard legislations that are specifically enforced for the correct management of SMC immediately after cropping. Such regulations would greatly aid the mushroom grower in implementing appropriate consistent management of SMC, in terms of apposite sanitisation practices, proper storage with relevant run-off controls and, finally, providing coherent and reliable information on

Table 1.4. Mushroom production and estimated spent mushroom compost (SMC) production in 2005.

Country	Mushroom production (t)[1]	Estimated SMC produced (t)[2]
China	1,359,335	6,796,675
United States	391,000	1,955,000
Netherlands	260,000	1,300,000
France	170,000	850,000
Poland	120,000	600,000
Spain	115,165	575,825
United Kingdom	80,000	400,000
Italy	80,000	400,000
Canada	80,000	400,000
Ireland	70,000	350,000
Others	488,571	2,442,855
Total	**3,214,071**	**16,070,355**

[1]Anonymous (2005b).
[2]Mushroom production multiplied by five, based on the assumption that 5 kg of mushroom compost produces 1 kg of mushrooms (Uzun, 2004).

the further use options for SMC, in association with applicable nutrient management plans. The best practice regulations for mushroom growers in the United States are discussed along with the limited guidelines available to mushroom farmers through various waste management plans and Nitrate Directives in the Netherlands, Canada, the United Kingdom and Ireland.

1.4.2 Guidelines for disinfecting SMC prior to disposal

Most mushroom compost is subjected to the addition of a range of pesticides in order to obtain a favourable mushroom yield, with the recommended types and quantities of pesticides varying between countries. Recommended disinfectants for disease control following cropping are also variable worldwide and, in some cases, are not applied and/or not legislated. The fact that relatively little is known about the effects of such chemicals, and their subsequent leachate from SMC, on soil properties and its underlying groundwater merits further investigation and may need to be included in the relevant criteria when determining suitable land application rates of SMC (Davoren and Fogarty, 2005).

United States

The US Environmental Protection Agency (US EPA), in conjunction with the Occupational Safety and Health Administration (OSHA), regulates pesticide control within the United States and mushroom growers must adhere to these regulations for environmental and health protection reasons. Adequate information on the types of mushroom diseases is vital to ensure efficient non-excessive pesticide usage. The grower must utilise the appropriate pesticides according to label guidelines when required to manage a specific problem (Anonymous, 1997b) as an array of pesticides is available, depending on whether they can be applied to:

(a) The mushroom crop alone;

(b) Just on the compost and casing; or

(c) The empty mushroom tunnels following crop and SMC removal (Beyer, 2005).

The main disinfectants utilised in mushroom production units in the presence of the crop are calcium hypochloride, chlorine dioxide and calcium chloride, which are used for general disinfecting and sanitisation (Beyer, 2005).

Immediately following cropping, SMC and the mushroom tunnels are pasteurised by the injection of live steam into the tunnel. This reduces the possibility of disease spread, especially during the removal and transport of SMC. The use of disinfectant is generally employed only for tunnel sanitisation following SMC removal (Anonymous, 1997b). The phenol-based disinfectants generally utilised for this purpose are One Stroke® and Primisan® and are generally utilised on unit floors and walls (Beyer, 2005).

Canada

Similar to regulated practices within the US, it is deemed good practice in Canada to disinfect the SMC and the internal surfaces of the growing tunnels by the injection of live steam following the harvesting of the final flush of mushrooms. The subsequent temperature is maintained at 70°C for 12 h, resulting in the reduction of possible diseases preceding the removal of the SMC from the growing tunnel (Anonymous, 2004a).

Pesticides, such as insecticides, herbicides, fungicides and rodenticides are commonly used within the mushroom industry in an attempt to optimise mushroom quality and yields, and if utilised in accordance with recommended practices, environmental concerns should be avoided (Anonymous, 1994). However, surface and groundwater can become contaminated with pesticides through run-off or spills, with detrimental consequences. Because of this, various national management acts and guidelines exist in British Columbia to deal with pesticide management. They include the Pesticide Control Act (1996), responsible for the use, storage and disposal of pesticides, and a management programme entitled New Directions in Pesticide Management (1992), which regulates the sale and use of pesticides and endorses IPM.

Netherlands

No recommended disinfectants or pesticides are available for disease control of the spent mushroom substrate in the Netherlands, suggesting that they might not be used in the mushroom industry or are used without the sanction of the appropriate environmental legislation.

United Kingdom

In the pesticide usage survey report on mushroom crops in Great Britain (Stoddart et al., 2003), no compost sterilants were registered. The main treatment of compost during the cooking-out stage was steam injection, which was carried out in 70% of all mushroom practices, while steam treatment was also used during composting (22% of growers) and as a pre-production treatment (8% of growers). Despite various controls regulating pesticide management, such as the Plant Protection Regulations (2003) and the Control of Pesticides Regulations (1986), many unregistered disinfectants (59% of growers) and pesticides are still utilised in very large quantities prior to and during mushroom production (Stoddart et al., 2003). The main ingredients in registered disinfectants are sodium hypochlorite (87%) and formaldehyde (13%), while the predominant pesticides utilised within Great Britain include the fungicides carbendazim, prochloraz, pyrifenox and the insecticides bendiocarb and diflubenzuron. No disinfectants or pesticides usage were recorded during the cooking-out period (Stoddart et al., 2003).

Ireland

Cooking out with steam following cropping is orthodox practice in Ireland, as is the case in most countries, because it is good hygiene practice, resulting in the reduction of disease spores, the reduced risk of environmental pollution from pesticides applied to the compost, and the elimination of possible health risks associated with the inhalation of disinfectants (Anonymous, 2000c). A strong disinfectant, such as Environ®, Sudol®, Prophyl® or Panacide®, is usually applied to the surface of the spent compost to kill off surface spores and mycelia, prior to removal from the growing tunnel. When removed for transportation, care must be taken to avoid compost disturbance in order to prevent spore dispersal from beneath the surface of the compost. Dimilin® (diflubenzuron) is the most commonly used pesticide for the control of sciarids, phorids, cecids and mites on mushroom crops (Staunton et al., 1999). Other approved pesticides permitted for use in mushroom production in Ireland include the fungicides Bavistin DF® and Kapchem Carbendazim Flowable®, the insecticides Dimilin 2L and Dimilin WP-25 and the disinfectant Disolite® (Anonymous, 2004b).

1.4.3 Guidelines for appropriate SMC storage

For mushroom growers who organise SMC removal as soon as it is produced, permanent storage facilities are not mandatory on the farm. However, for the majority of production units, temporary or permanent SMC storage facilities are required as the land-spreading of waste materials is generally prohibited for the winter months. All storage facilities should be operated and maintained in an environmentally protective manner.

United States

Waste regulations within the US require each mushroom farm to record the quantity of SMC produced on a continual basis, in order to substantiate the appropriate management and disposal of SMC and its subsequent wastewater (Anonymous, 1997b). If passive composting of SMC is carried out on the mushroom farm, records of storage periods must be maintained (Anonymous, 1997b). The storage of SMC on farms must be in accordance with a Mushroom Farm Environmental Management Plan (MFEMP) and farm nutrient management plan, and should prevent surface and groundwater pollution. The Solid Waste Management Act (1980) states that if waste is stored for more than 1 year a permit is necessary in most cases (Anonymous, 1980). If SMC is stored in an area that is not a farm, the storage must comply with the Residual Waste Regulations (1996) and a permit is required for its transferral (Anonymous, 1997b). There are three options for SMC storage as outlined by the best management practices in the United States (Anonymous, 1997b). The first option is the storage of SMC on the mushroom farm where it is generated, preceding land application on another farm or its use as a co-product. Temporary storage of less than 120 days must be located at a minimum of 20 inches (50 cm) above the elevated water table, with appropriate measures in place to deal with any surface run-off. In regard to permanent storage facilities of greater than 120 days but less than 1 year, SMC must be stored on a concrete pad or on material with low permeability or under a roof-like structure. All surface run-off should be collected in a central storage facility and the maximum quantity of SMC stored on any farm must not exceed the annual amount produced on that farm (Anonymous, 1997b).

The second option for SMC storage is on the farm on which it is to be used, prior to land application. If this option is taken, then the SMC should be stored in fields or in a central point on the farm and should be distributed in conjunction with a nutrient management plan. For field storage, an approved farm management plan must be implemented and SMC must be stored at least 20 inches above the high water table, 300 feet (91 m) from domestic water supplies, 300 feet (91 m) from domestic residences and, finally, it must be over 100 feet (30.5 m) from a spring, wetland, sinkhole or stream. On-farm central location storage must also adhere to these requirements, with neither forms of storage permitted to extend over 180 days (Anonymous, 1997b).

The final option for storage in the United States is the storage of SMC on other farms where land application will not occur. Such a storage period is permitted to last up to 1 year, with all the previously mentioned precautions in regard to buffer zones adhered to. However, additional requirements are also applicable to this means of storage in that the largest amount of stored SMC is limited to 20,000 cubic yards (15,291 m^3) per year. Waste management regulations must also be abided by, in order to prevent water and air pollution, and contamination of other natural reserves. The storage landowner must record the quantity of the SMC received and exported from the storage facility, along with relevant dates, the mushroom grower and supplier details, along with a concise account on the proposed use of SMC (Anonymous, 1997b).

Best practices for minimising odour potential during SMC storage in the United States include maintaining aerobic composting conditions, avoiding the overuse of nitrogen-rich raw materials, precluding standing water and bad drainage, and the aeration of run-off water in impoundments by agitation (Anonymous, 1997b).

Canada

In Canada, permanent storage facilities must exist to cater for all the SMC generated on any particular mushroom farm and SMC should not be stored on saturated soils or in hollows that might gather rainwater, in natural drains or where run-off will access waterways, or in areas that may be subject to flooding. These storage facilities must also be located away from the mushroom tunnels to prevent the spread of diseases and insects (Anonymous, 2004a). Surface run-off and salt leaching during rainfall are said to be the main environmental concerns when storing SMC, as groundwater and surface water pollution must be prevented. Preventative measures should include the assembly of structures to avert run-off away from SMC piles, while run-off that may have contacted SMC should be accumulated, stored and recycled (Anonymous, 2004a). Storage times can vary in accordance with the relevant provincial nutrient management plans, which take into account run-off control and treatment of the waste (Anonymous, 2002).

In British Columbia, it is recommended that large masses of SMC should be stored as far as possible from mushroom houses, on covered concrete slabs for at least 2 weeks in areas of high rainfall, which should eliminate the possibility of surface run-off and leaching of salts. The code in British Columbia also states that SMC must be sheltered from 1 October to 1 April in Lower Fraser Valley and Vancouver Island (Anonymous, 1994). In dealing with smaller masses of SMC, concrete slabs are also suggested; however, the compost piles can be covered with tarpaulin that should be secured by weights such as blocks and tyres. Spent mushroom compost storage areas in British Columbia must conform to the code enforced, in that storage facilities must be situated as least 30 m away from any domestic water system and 15 m away from every watercourse. More-temporary storage facilities, which may be located in a field, must be situated 30 m from watercourses or household water reserves (Anonymous, 1994). As in the best management practices for the United States, this code also states that SMC should not be stored on saturated soils, drains or depressions and that permanent storage facilities must cater for all SMC produced on the farm and must be managed in a way that precludes pollution, with appropriate berms created to redirect run-off. Field storage of SMC is not permitted for more than 9 months and should not be situated on soils that are coarse in texture (Anonymous, 1994).

To reduce malodours during SMC storage, it is recommended that the SMC should be placed in ricks and turned frequently to amplify the rate of microbial decay. The purpose of this process is to minimise the occurrence of anaerobic decay and maximise aerobic activity, as anaerobic fermentation emits pungent odours. It is also recommended that care should be taken when handling SMC, as relatively little is known about SMC odours; however, it is thought that volatile sulphur compounds and cresol are the main odour components in SMC (Anonymous, 2004a).

Netherlands

Storage of SMC in the Netherlands is permissible only on a concrete base so as to preclude probable leaching and subsequent groundwater pollution (Gerrits, 1994). Problems with evolution of hydrogen sulphide during long-term storage of SMC have been reported. However, within recent years, SMC has not been monitored in the Netherlands as Gerrits (1994) did in the past, so information on appropriate SMC storage and application is not available (Straatsma, 2005).

United Kingdom

Despite having various regulations and enactments for waste management in Northern Ireland, which include the Controlled Waste Regulations (2002), the Waste Management Licensing Regulations (2003), the Waste and Contaminated Land Order (1997) and the Controlled Waste (Duty of Care) Regulations SR 271 (2002), none of these specifically enforce the appropriate storage and management of SMC. Consequently, there is immense confusion in regard to SMC storage as it is not known whether field storage is permitted or whether a 22-week storage duration is required over the winter period when land-spreading is not allowed (Ellis, 2005). Similarly, most environmental guidelines for nutrient management and manure management are implemented by the Environmental Protection Act (1990) in England and Wales, whereas the Department for Environment, Food and Rural Affairs (DEFRA) and the Scottish Environment Protection Agency (SEPA) are the bodies responsible for waste control in Scotland. None of these governing bodies, however, addresses the storage and subsequent management of SMC within the UK.

Ireland

Spent mushroom compost should be stored at least 2 km from mushroom tunnels (Maher at al., 2000); however, this is not always an option for mushroom growers in Ireland as many are operating on a small scale in restricted amenities. In light of this, a centralised SMC handling depot is recommended by Maher et al. (2000) for Co. Monaghan, where SMC is collected, similar to domestic waste, temporarily stored, processed and possibly transported to particular markets or end-users. The treatment of SMC should be conducted at a safe distance from mushroom production units as unwanted spores can be dispersed effortlessly (Maher at al., 2000). Spent mushroom compost is considered an organic fertiliser under SI No. 101 (2009) and any soiled water from mushroom production units is also considered under these regulations in relation to storage and application, a summary of which is presented in Chapter 6 of this report.

1.4.4 Best practice for the utilisation of SMC

Utilisation confines exist for diverse end-uses of SMC. The factors that determine the further use of SMC in agriculture or horticulture include nutrient and salt content, substrate maturity, water-holding capacity and the presence of weed seeds, insects or pesticides (Anonymous, 2004a).

United States

The various opportunities for SMC utilisation that exist for mushroom growers are outlined in Fig. 1.2 and are in accordance with waste management practices within the United States. The grower can follow many pathways in dealing with SMC management and, in many circumstances, a permit is not required, provided the best management practices are followed. The composting of SMC, both passive and active, can be conducted on the mushroom farm and must be carried out in conjunction with the land application guidelines for fresh SMC (Anonymous, 1997b).

When utilising SMC as a soil conditioner, an efficient application system is required to meet but not exceed the needs of the crop and, therefore, to minimise pollution. Therefore, many factors must be taken into

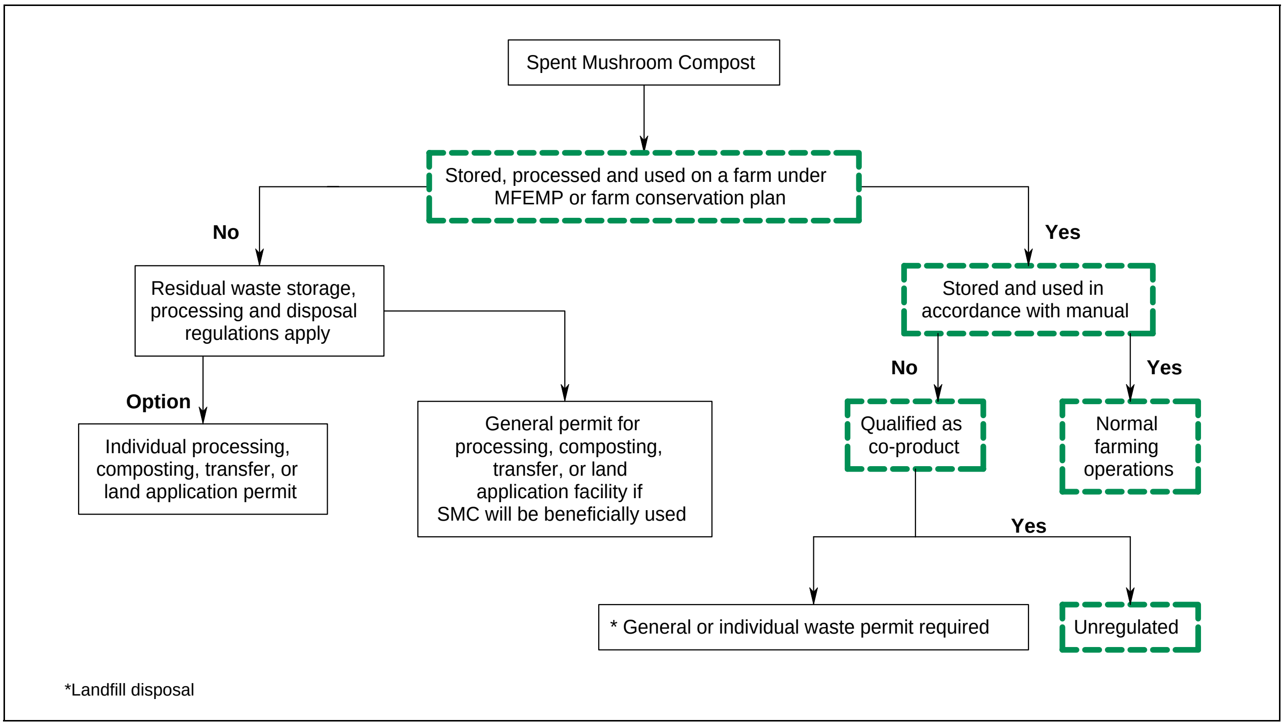

Figure 1.2. Authorised situations for spent mushroom compost (SMC) under residual waste regulations (adapted from Anonymous, 1997b) (MFEMP, mushroom farm environmental management plan).

consideration in the land application of SMC, such as site selection, the nutrient levels in SMC, timing and methods employed in applying SMC and, finally, using a suitable application rate (Anonymous, 1997b). Guidelines outlined by the Pennsylvania Code for Environmental Protection (25 Pa. Code, Chapter 102) (Anonymous, 1975) and soil maintenance must be adhered to in applying SMC to land. Firstly, a farm conservation plan must be drafted with the aid of the Natural Resources Conservation Service (NRCS) for all fields that will be supplied with SMC or wastewater, neither of which is permitted to be applied to land within 100 feet (30.5 m) of domestic water supplies, streams, lakes, sinkholes and springs (Anonymous, 1997b). Applications of SMC should be applied in spring, as it is more valuable to seasonal crops, yet summer applications are suited to pastures, non-crop fields and land following hay production. Applications in autumn should be applied to fields with winter grains, vegetation and cover crops or crop residues, but winter applications should be restricted and should only be applied in accordance with a farm conservation plan or MFEMP. Spring, summer and autumn applications can be applied to land with slopes of up to 12%, with a vegetated buffer area sited at the bottom of sheer slopes for nutrient uptake during rainfall, whereas winter treatments are constrained to 3% slopes (Anonymous, 1997b).

In determining appropriate application rates, a farm management plan or MFEMP must be designed, accommodating the nutrient content of the SMC and the requirements of the particular crop or vegetation in the vicinity (Anonymous, 2005–2006). Available nitrogen is the decisive factor in determining SMC application rates in Pennsylvania, which is in direct contrast with Ireland, where phosphorus is the restrictive nutrient. If utilising SMC as the only fertiliser in a field, the fact that nitrogen is slowly released from SMC, with approximately 20% available within the first year of application, will have an obvious effect on the permitted amount of SMC to be applied. If utilised as mulch, weed control or as a protective layer, 6 inches (~15 cm) of SMC may be applied, providing that the nitrogen requirement is not exceeded at that rate (Anonymous, 1997b).

Apart from the utilisation of SMC in farming, it can also be used in creating wetlands, revegetating landfills or in the reclamation of contaminated mine sites, and a permit and approval of the Department of Mine Reclamation and the wetland construction movement may be required. Mushroom growers must also keep records of the supplier's details, relevant dates and quantities of SMC supplied along with a brief description of the co-product and proposed use (Anonymous, 1997b). Spent mushroom compost can also be distributed as a bulk fertiliser or bagged and sold as a fertiliser or conditioner in adherence to the Pennsylvania Fertiliser and Soil Conditioner and Plant Growth Substance Laws and must be registered with the Department of Agriculture in the United States (Anonymous, 1997b), provided that the compost is cured or passively composted. The compost label must specify the amounts of nutrients, including total nitrogen, ammonia, nitrates, water-insoluble nitrogen (organic or slow acting), available phosphoric acid, soluble potash and other additional nutrients (Anonymous, 2000a). Mushroom growers who abide by the best management practices for environmental protection (Anonymous, 1997b) and who have employed a MFEMP are not obliged to acquire permits when applying SMC to land, as the relevant practices are administered on the farm in an attempt to avert pollution, and to uphold or enhance air, soil and water reserves.

Canada

Spent mushroom compost is an excellent soil conditioner as nutrients are gradually released over several years. In Canada, it is also used as a mulch, a fertiliser and as a top dressing to standing crops such as hay (Anonymous, 2004a). Due to SMC composition variability, it is recommended that nitrogen, phosphorus and potassium should be determined prior to application and, in view of possible changes in raw material formulations, additional nutrient and chemical testing is crucial. Application rates should be determined on the basis of past additions and nutrient levels in the soil along with the timing of application. Spent mushroom compost should not be applied to bare sloping land or land where water erosion may occur and should be incorporated immediately into the soil unless it is used as a mulch (Anonymous, 2004a).

The best practices code for the use of SMC in British Columbia includes its sale to municipalities or nurseries and as a soil conditioner on-site and, as in the United States guidelines, application rates depend on existing soil nutrients, the crop grown, previous applications to soil and the timing of application. Spent mushroom compost can also be incorporated into soil when establishing a lawn or in land reclamation (Anonymous, 1994). It is highlighted that if SMC were applied in late autumn, the protein nitrogen present would not be converted to ammonia, resulting in an increase in nitrate levels and the successive leaching to groundwater. If utilised as a soil conditioner, the code stipulates that certain guidelines must be adhered to in that custom testing of SMC or soil is obligatory, as yearly applications of SMC can often result in excessive nutrient accumulation in soil. When applied to land, compost must be incorporated into soil immediately to prevent wind dispersion and applications must not exceed crop requirements. The primary usage of SMC in British Columbia is its supply to the garden and nursery industry, which occurs mostly on a seasonal basis, resulting in the need for SMC to be stored for longer periods on the mushroom farm (Anonymous, 1994).

Netherlands

According to the Soil Protection Act (1986), restrictions that are in place in the Netherlands regarding the field application of manures include the prevention of manure application from 1 September to 31 January, as a leaching precautionary measure; however, SMC may be applied at any period throughout the year, except when the ground is covered with snow (Anonymous, 1993). The Decree on the Use and Quality of Other Organic Fertilisers (1993) (BOOM Decree; Besluit kwaliteit en gebruik Overige Organische Meststoffen), which includes SMC, outlines that it is not mandatory to plough the SMC into soil immediately as SMC contains no free ammonia, yet the Soil Protection Act states that manure must be ploughed into the soil within 24 h of application in order to reduce emissions (Gerrits, 1994). Spent mushroom compost is regarded as a 'clean compost' and therefore field applications are determined on phosphate concentrations, which amounts to approximately 35 m^3 of SMC (3.5 mm cover) annually (Gerrits, 1994). Dutch landowners are also given an option of applying double this amount every 2 years. Grassland is an exception to this regulation in that half of this application rate is permissible, while only one solitary treatment of 200 t of dry matter is permitted in the construction of sporting grounds (Gerrits, 1994).

In order to regulate the consistency of SMC in relation to heavy metal content, Dutch mushroom growers must supply one sample every year for analysis, which amounts to an estimated 800 samples on an annual basis (Gerrits, 1994). Spent mushroom compost must adhere to the legal limits for standard and very good compost, as outlined in the Decree for Use and Quality of Other Organic Fertilisers (BOOM) (Anonymous, 1993). In 1998, a new MINAS[1] system was implemented in regard to nitrogen and phosphorus surpluses in agriculture (Oenema and Berentsen, 2005), where farmers are obliged to document all nitrogen and phosphorus inputs and outputs in foodstuff, manure, chemical fertiliser and plant and animal products. As a direct result, a farm-level balance can be established and if a surplus over the regulated values of 180 kg/ha for grassland and 100 kg/ha for arable land in regard to nitrogen and a standard value of 20 kg/ha for phosphorus occurs, a levy will have to be paid by the farmer (Dugast, 2001). Spent mushroom compost or 'Champost' as its commonly known in the Netherlands is not specifically mentioned in these regulations, yet is probably included under the title of compost as all materials utilised or exported from a farm must be accounted for within this system.

The utilisation of SMC for the treatment of the effects of acidification in forest soils has been proposed in the Netherlands, yet this has not yet come to pass. However, the suitability of SMC in the filling of biofilters is shown in the fact that 5,000 t are used in this process annually. Composting of SMC is also widely practised; however, due to the increasing production of municipal compost, metropolises are enforced to gather and segregate organic waste and process it into compost. This municipal waste is an authentic challenger for SMC as it is used for the same functions (Gerrits, 1994). A market value of 27 Dutch Guilders (~€12.25) was determined per metric tonne of SMC in the Netherlands, which was established on the basis of the calcium, potassium and available phosphate and organic matter present. However, in many areas, the market prices are significantly less or even zero, resulting in the need for a more convincing marketing of the merits of SMC (Gerrits, 1994).

1. MINAS, Mineral Accounting System.

United Kingdom

Within Northern Ireland it is not known what application rates or volumes of SMC are sanctioned when utilising SMC as a soil conditioner or fertiliser. This uncertainty arises from the fact that it is not known if SMC is regarded as a chemical or organic fertiliser (Ellis, 2005), which is a worrying fact as Northern Ireland produces approximately 40% of the United Kingdom's total SMC production of 80,000 t.

Spent mushroom compost was one of the most commonly used soil improvers in the United Kingdom (17%) in 1999 (Anonymous, 2000b). Of a total of 282,000 m^3 of SMC produced in the United Kingdom in 1999, an estimated 190,500 m^3 were directly supplied to professional landscapers, 77,500 m^3 to amateur gardeners and the final quantity of 14,000 m^3 were supplied to local authorities. However, the provision to these three markets in Scotland and Northern Ireland is very small, with most utilised in agricultural practices. Several small-scale mushroom growers sell bagged SMC through local press, garden centres or along roadsides (Anonymous, 2000b). Despite having no statutory regulations for compost quality, the UK Soil Association includes SMC as a viable input material for composting (Hogg et al., 2002).

Ireland

The most common use of SMC in Ireland is as a soil conditioner or as an organic manure, with phosphorus concentrations determining the appropriate rates to apply as outlined in Table 1.5 (Maher and Magette, 1997). However, as over a third of the Irish mushroom industry, together with a considerable concentration of pig and poultry farming, is located within the Cavan–Monaghan vicinity, the amount of suitable land accessible for land-spreading is limited (Maher et al., 2000). Consequently, farmers in the Cavan–Monaghan area are obliged to store livestock manure for 22 weeks, whereas, in most other counties, the requirement is only a 16- or 18-week minimum storage period (SI No. 101, 2009). Maher et al. (2000) estimated that there would be a phosphorus surplus

Table 1.5. Recommended phosphorus application rate to some crops at phosphorus soil index level 3 (required by the Rural Environment Protection Scheme (REPS)) and the quantity of spent mushroom compost (SMC) required to contribute to this figure (Maher and Magette, 1997).

Crop	Phosphorus (kg/ha)	SMC (t/ha)
Cereals	20	5
Potatoes	60	15
Sugar beet	30	8
Maize	15	4
Brassicas	20	5
Grass – two cuts silage with slurry	–	–
Grass – grazing	12.5	3

from animal manure in all counties, with the exception of Dublin, based on a soil phosphorus index of 3. Furthermore, the crop requirement for phosphorus would also surpass the provision of phosphorus from animal manure in all counties, except Monaghan, if a soil phosphorus index of 2 were assumed (Maher et al., 2000).

In a survey carried out by Teagasc in Co. Monaghan in 1993, it was estimated that 35% of SMC was applied to the mushroom farmers' land (Table 1.6) while 72% of all compost was applied to different types of land (Table 1.7) (Maher et al., 1993).

In an attempt to alleviate the SMC management challenge, particularly in concentrated areas of Ireland, a model SMC management strategy was established in Co. Monaghan. This strategy analysed the possible

Table 1.6. Methods of spent mushroom compost (SMC) disposal (%) in Monaghan (adapted from Maher et al., 1993).

Method	SMC disposal (%)
Removal by contractor	40
Removal by compost supplier	0
Spread on own land	35
Other disposal on farm	20

Table 1.7. Final destination of spent mushroom compost (SMC) (%) in Monaghan (adapted from Maher et al., 1993).

Destination	SMC (%)
Land-spreading	54.3
Quarry	18.4
Wetland area	13.6
Poor land	3.8
Other	1.1
Don't know	8.7

collection and management of SMC in comparison with procedures commonly in place for the collection of domestic waste, where SMC will be transported to a central depot, temporarily stored from November to February, possibly treated or composted and finally transported to appropriate end-users (Maher et al., 2000). If developed further and implemented, such a strategy could be economically and environmentally viable. A feasibility study was also conducted on the development of a centralised anaerobic digester (CAD) for the treatment of SMC and other agricultural by-products in an area; however, this plan has not come to fruition (Mahony et al., 2001). Composted SMC is already marketed in Ireland on a relatively small basis, where bagged SMC is sold through local shops and garden centres, but the magnitude of the market for this compost is not known (Maher et al., 2000).

1.4.5 Comparison of policies

The United States environmental agencies are to the forefront in the advanced leadership and regulating of the best management practices for the mushroom production industry, not only in the management of mushroom production wastes, but also in the guidance of the manufacture of the initial mushroom growing medium, the growth and harvesting of the mushrooms while taking into account environmental management plans. Such guidance and leadership is instrumental in creating a sense of ownership among mushroom growers, particularly in regard to the wastewater and SMC generated from the industry. The best management practice plans are designed to increase mushroom productivity and diminish the need for waste permits, while at the same time fulfilling the requirements of the Department of Environmental Protection (DEP) (Anonymous, 1997b). The implementation of the MFEMP should improve soil conditions and prevent air, groundwater and surface water contamination, while showing neighbouring communities that the particular mushroom farm or composting manufacturer is functioning to the best environmental standards (Anonymous, 1997b). The marketing of SMC that is cured or passively composted as a bulk fertiliser is noteworthy, particularly the exceptional idea of labelling each batch of compost, a practice that subsequently guarantees the exact nutrients present along with providing some additional information including whether the nitrogen content is organic or slow acting (Anonymous, 2000a). This information is of great value to those who wish to use SMC as a soil conditioner or fertiliser. The latter procedure was introduced by the State of Pennsylvania, which has been commendably proactive in dealing with SMC use and disposal.

There are no guidelines or regulations in place in the Netherlands specific to the appropriate management of SMC. However, restrictions in SMC utilisation are outlined in the manure policy (BOOM Decree) and MINAS, where SMC is included as an organic fertiliser. Encouragingly, the uniformity of SMC was regulated within the Netherlands, with large numbers of samples analysed annually (1992) and a policy that SMC must adhere to standard heavy metal limits (Gerrits, 1994).

Similarly to the position regarding SMC management in the Netherlands, no specific best management practices for the mushroom community are regulated in the UK, despite the fact that SMC is the most frequently used soil improver in the UK (Anonymous, 2000b). As in the United States, Canada has excelled in the implementation of guidelines for mushroom producers. In Canada, mushroom medium manufacture is effectively addressed along with regulations regarding the growth and harvesting of the mushroom crop and the best management practices involved in the treatment and further use of SMC (Anonymous, 2004a). The main objectives of the best environmental management practices guide are to give mushroom growers in Canada realistic and useful guidelines for the appropriate management of their farms. These guidelines include attention to environmental protection and also serve to enlighten local and municipal governments on the existing regulations and standard environmental procedures on mushroom farms in Canada (Anonymous, 2004a). The regulations enforce the routine testing for nitrogen, phosphorus and potassium, along with additional nutrient and chemical analysis. These regulations stipulate that nutrient and chemical analysis of SMC should be determined prior to land application (Anonymous, 2004a). This is a very good regulation and its introduction in other countries, including Ireland, would almost certainly improve the market for SMC as the exact nutrient content is assured.

As is the case with the Netherlands and the UK, no best environmental practices specific to SMC are enforced in Ireland. However, SMC is regulated under SI 101 (2009), as it is included as an organic fertiliser. Both phosphorus and nitrogen are the decisive factors in determining appropriate application rates, with these rates varying depending on the crop requirement and applications being made only in conjunction with a nutrient management plan (SI No. 101, 2009).

1.4.6 Summary

The various forms of effective SMC management can come under a series of categories, all of which lead to the successful utilisation of SMC with respect to environmental protection. Within some countries, practices are statutory while in others they may only be recommended but not enforced. Table 1.8 summarises the extent to which SMC management is controlled in each country, where it is evident that despite having regulatory bodies implementing some practices for SMC disposal, statutory or otherwise, the magnitude of these varies extensively. It is evident that a great deal can be learnt from the United States and Canada in regard to the successful management of SMC while the United Kingdom and Ireland are somewhat deficient in many areas.

Canada and the United States appear to have no shortcomings in their management plans, yet it is perplexing to see that the main limiting factor for the land application of SMC in the United States is available nitrogen, as phosphorus is generally accepted as the limiting element in determining

Table 1.8. Summary of controls and regulations concerning spent mushroom compost (SMC) disposal in the United States, the Netherlands, the United Kingdom, Canada and Ireland.

	United States	Netherlands	United Kingdom	Canada	Ireland
Best management plan implemented for mushroom growers	Yes	No	No	Yes	No
Intensity and type of standards that incorporate SMC	Statutory PA and BC DEP	Statutory BOOM, MINAS	Voluntary DETR	Statutory CMGA	Statutory SI 101 (2009)
Planned to develop SMC market	Yes	Partly	Partly	Yes	Partly
Support implemented waste strategies	Yes	Yes	No	Yes	Yes
Safeguard human health when handling SMC	Yes	No	No	Yes	No
Requirements concerning pathogens, impurities and weeds	No	No	No	No	No
Sanitisation-controlled post-cropping steam/disinfectants	Yes Steam	Not known	Yes Steam	Yes Steam	Yes Steam and disinfectant
Regulated SMC storage time **Regulated storage conditions**	Yes Yes	No To some extent	No No	Yes Yes	Yes Yes
Regulations for the further composting of SMC	Yes	No	No	Yes	No
Regulated odour control	Yes	No	No	Yes	No
Compost stability tests in place	No	No	No	No	No
Limiting factors regarding SMC application rates on soil	Available nitrogen	Phosphorus	Not known	Based on nutrient content of soil and time of application	Phosphorus and nitrogen
Regulations on heavy metal limits	No	Yes	No	No	No
Regulations for consistent analysis of SMC	Yes, prior to land application and when sold as a fertiliser	Yes, on a yearly basis	No	Yes, prior to land application	No

PA, Pennsylvania; BC, British Columbia; DEP, Department of Environmental Protection; BOOM, Decree on the Use and Quality of Other Organic Fertilisers; MINAS, Dutch Mineral Accounting System; DETR, Department of the Environment, Transport and the Regions: London; CMGA, Canadian Mushroom Growers' Association.

appropriate rates in most countries, due to the increase in water eutrophication. However, in the land application of SMC, the MFEMP incorporates its nutrient content along with the nutrient requirements of the crop, so a surplus of nutrients should not occur in the soil subsequently.

The market for SMC appears to be quite small in the Netherlands (Gerrits, 1994), so increased awareness of the benefits of SMC should be publicised. A best management plan for mushroom growers is essential in the promotion of good practices for mushroom media manufacture, mushroom growing and harvesting and the subsequent management of SMC and its associated wastewater. Appropriate application periods should also be devised, as applying SMC all year around with the exception of when the ground is covered with snow, seems somewhat ill-advised.

Guidelines for the composting and temporary and permanent storage of SMC are vital as an estimated 1,300,000 t of SMC are generated within the Netherlands on an annual basis (Anonymous, 2005). However, the SMC situation in the Netherlands seems to be neglected within recent years, as it has not been monitored as it was in the past by Gerrits (1994), so information on suitable SMC storage and application conditions is not available (Straatsma, 2005).

Spent mushroom compost is not included in any waste management plans or legislation in the United Kingdom and its only mention in the literature is when it is compared with other soil conditioners available in the United Kingdom (Anonymous, 2000b). Such inadequacies should be addressed and a management plan similar to that in the United States drawn up, incorporating the nutrient levels in all soils and those in the vicinity of the mushroom farms. There is a market for SMC in the United Kingdom, particularly in landscaping but, as most SMC generated in Northern Ireland is applied to agricultural land, environmental pollution is inevitable if farmers apply it indiscriminately, in the absence of legislation.

Phosphorus and available nitrogen are the factors limiting SMC use on land in Ireland but there is no set application rate as this depends primarily on the crop or vegetation grown. However, some limitations are noted within these regulations as disinfectants are utilised on the SMC along with steam injection treatments. Ireland appears to be the only country in which disinfectants are used at the end of the cropping cycle and this should be taken into account when determining suitable land application rates as there is little known about the effects of such disinfectants and other pesticides used in mushroom production on the subsequent leachate from SMC (Davoren and Fogarty, 2005). Some parts of Ireland are not accessible to, or permitted to use, land-spreading, so the benefits of SMC should be promoted to landscapers and to areas where reclamation schemes are in operation such as the revegetation of the tailings management facility (TMF) in Silvermines, Co. Tipperary, and other mine sites around Ireland. Spent mushroom compost might also be used in the attempt to establish vegetation on the bauxite-processing residue commonly known as red mud at the Aughinish Alumina Ltd. Bayer Plant (Courtney and Timpson, 2004, 2005).

Composting SMC should also be investigated as a means of creating a more stable compost that would be of considerable benefit to horticulture. Such a process could be carried out in a central depot as proposed by Maher et al. (2000). Finally, Ireland and the United Kingdom are the only countries of those studied where SMC is not continually analysed and, if such a routine were in place, a consistent nutrient content would be guaranteed and would therefore promote the use of SMC, as farmers or horticulturists would be guaranteed a reliable supply of plant nutrients.

1.5 Conclusions from Literature Review

The main conclusions for this study are as follows:

- Despite the fact that an estimated 16,070,355 t of SMC are produced worldwide annually, legislations and best management practice guidelines are not regulated or imposed in some countries and, if not controlled appropriately, SMC can cause considerable environmental pollution.

- The United States and Canada, under the authority of the DEP and Canadian Mushroom Growers' Association (CMGA), respectively, have achieved regulatory guidelines for the mushroom community that can be implemented in every country. Application rates of SMC are not resolute and vary depending on the nutrient composition of SMC and the soil, along with the timing of application and incorporation of previous additions of organic matter to the particular soil. The MFEMP functioning in the United States is intuitive and provides mushroom growers with an incentive to take ownership of all generated waste from the mushroom production units.

- Best management practice plans should be devised in the Netherlands, the United Kingdom and Ireland similar to those developed in the United States, taking into account limitations that may occur at a local level, such as the volume of SMC produced in areas, the proximity of mushroom farms to other agricultural outlets, local weather patterns, and variability in soil type and nutrient content. Hence, one set of guidelines may not be suited to all parts of a country, and perhaps should be rationalised and implemented at a provincial level. This is the case in Canada, where the British Columbian government has devised specific regulations for Vancouver Island and Lower Fraser Valley (Anonymous, 1994).

- On-farm storage is not always an option in Ireland where mushroom farms are traditionally small; therefore, any proposed management plans must account for this fact. Similarly, nutrient management plans should include SMC storage on the farm of the particular end-user of SMC.

- Despite having extensive advice and guidelines on IPM and the correct use of pesticides according to relevant acts and management programmes, there is no information on the effects of residual pesticides present in the SMC on soil properties and the possibility of groundwater contamination.

- Available nitrogen is the determining factor in SMC application in the United States compared with phosphorus in the Netherlands and Ireland, prompting the possibility that both nutrients could be considered to determine a more suitable application rate long term, as nitrogen is slowly released from SMC.

- The fact that up to 6 inches (~15 cm) of SMC can be applied to reclaim land within the United States (Anonymous, 1997b) is an incentive that could be employed in most countries where land recuperation is in operation, but must take into account the nutrient requirements of the crop established on the land. This vast quantity of SMC could solve many problems in terms of SMC management, while simultaneously ameliorating problematic lands such as mine spills and petroleum, diesel or PCP-contaminated soils (Buswell, 1994).

1.6 Objectives of this Study

The main objectives of this study were:

- To establish if SMC could be successfully employed in constructed wetlands in the treatment of AMD from the Avoca mine site;

- To provide useful information to devise a possible remediation scheme for the Avoca River and equivalent contaminated water systems; and

- To advocate a best management practice approach for SMC management in Ireland.

2 Remediation of Acid Mine Drainage Using Constructed Wetlands Comprising Spent Mushroom Compost

2.1 Introduction

This section describes the various methods and materials employed for the construction and monitoring of the in-house-constructed wetlands trial utilising SMC as a novel substrate. Furthermore, the simulated AMD (SAMD) preparation and SMC treatment are outlined, along with a detailed experimental set-up and maintenance procedures performed during the trial. Outlined also are the methodologies involved in determining the various physico–chemical and biological characteristics of each wetland cell in an attempt to assess the performance of the novel treatment system. These methodologies include those for analysing various heavy metals concentrations, pH, conductivity, temperature, oxidation–reduction potential (Eh), alkalinity, sulphate and total organic carbon content.

2.2 Materials and Methods

2.2.1 Experimental design

The constructed wetlands trial was established within a polythene tunnel and consisted of four cells in series, with each established in triplicate similar to that reported by Jamieson et al. (2003). Each cell was specifically designed and manufactured from polypropylene by O'Brien Plastics Manufacturing, Cavan, Ireland, and measured 0.622 m in length, 0.464 m in width and 0.489 m in depth, similar to that reported by Jamieson et al. (2003). Polypropylene was chosen as the container material owing to its durability, flexibility and acid-resistant properties. An outlet pipe was also installed to permit the flow of the metalliferous drainage into subsequent cells, resembling that described by Jamieson et al. (2003).

Each cell was placed on a specially designed reinforced galvanised stand (Kettle Engineering Ltd, Dundalk, Ireland), with a 20-cm drop between each cell to ensure that the solution from each cell could overflow by gravity into the successive wetland cells (Fig. 2.1).

2.2.2 SMC collection and treatment

Approximately 36 kg of SMC were collected from a mushroom grower supplied with compost from Walsh Mushrooms Ltd compost manufacturing yard in Co. Armagh, Northern Ireland. Each bag of Phase 2

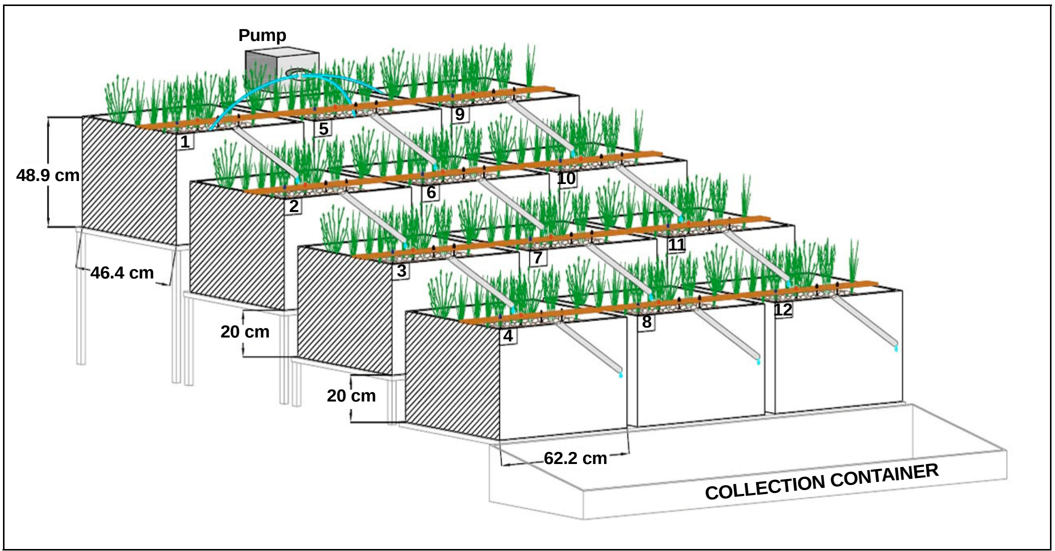

Figure 2.1. Constructed wetlands trial design and dimensions.

compost originated from the same composting cycle and had produced three flushes of mushrooms.

Each SMC sample was mixed thoroughly by hand and a subsample was immediately isolated and stored for moisture determination. A further subsample of SMC was air-dried, finely shredded (Kinematica AG, Polymix PX-MFC 90D 230V/EU/S) and stored at room temperature while awaiting further chemical analysis. The material was subsequently sieved as required by the various analytical methods employed.

The remaining fresh SMC was placed in equal proportions in each of the 12 wetland cells and compacted by hand to ensure even distribution within each cell. Spent mushroom compost was filled to approximately the 33.4-cm level in each cell, allowing 15.5 cm for flooding the cells, in addition to macrophyte seeding and growth.

2.2.3 Collection of macrophyte species

Three different macrophyte species – *Typha latifolia*, *Phragmites australis* and *Iris pseudacorus* – were utilised in the wetland trial. *Typha latifolia* and *P. australis* plants were purchased from a local garden centre, while the *I. pseudacorus* plants were collected from a local farm. The *I. pseudacorus* plants were separated into single plants, transplanted into individual potting containers filled with Shamrock Irish Moss Peat compost and flooded with water, prior to seeding in the SMC substrate. Following collection, all macrophyte species were treated in the same way, flooded and grown in a glasshouse for a 6-month period prior to transferring to the wetland trial. This ensured that the plants were fully established at the time of transplanting as per the PIRAMID Consortium (2003).

Typha latifolia and *P. australis* were chosen owing to their tolerance of elevated heavy metal concentrations, and the fact that they grow at their optimum in the pH range of 3.5–10, at a maximum water depth of 0.75 m and 0.5 m, respectively (PIRAMID Consortium, 2003). *Iris pseudacorus*, on the other hand, successfully grows in the pH range of 6–9, at a maximum water depth of 0.25 m, but is not tolerant of high concentrations of heavy metals (PIRAMID Consortium, 2003).

Following the wetland construction, excess compost was removed from the rooting system of each macrophyte species and the plants were then transplanted into the SMC media in staggered rows with 15–20 mm SMC cover (PIRAMID Consortium, 2003) and at a density of six rhizomes per m^2 (Manios at al., 2002). The cells were then flooded with water and the plants were allowed to adjust to the new environment for 1 month prior to SAMD addition (Fig. 2.2).

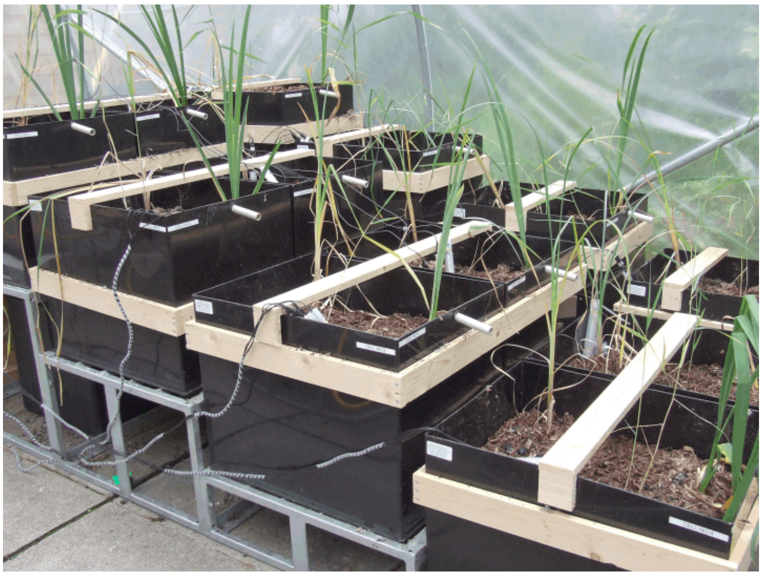

Figure 2.2. Constructed wetlands experimental set-up.

2.2.4 Experimental set-up

2.2.4.1 SAMD preparation

As AMD is chemically unstable and rapidly degrades on storage (Gray and O'Neill, 1995), SAMD was employed in this study. Synthetic acid mine drainage has comparable toxicity and acidity to real AMD, and is more chemically stable, resulting in the production of more reliant and dependable results in experimental trials (Gray and O'Neill, 1995).

The SAMD utilised was prepared to represent the major cations, anions and pH of real AMD discharged from abandoned mine adits, in the Avoca mining region, Co. Wicklow, Ireland. Laboratory-grade chemicals were used in the formulation of SAMD to ensure the exact inclusion of trace element contaminants comparable with real AMD. Stock solutions (1,000 mg/l) of each metal were prepared and the resultant AMD was prepared daily as per Gray and O'Neill (1995).

The SAMD was prepared using the following ratio of cations[2]:

- 150 mg Al/l
- 130 mg Fe/l
- 110 mg Mg/l
- 90.0 mg Zn/l
- 6.0 mg Mn/l
- 5.0 mg Cu/l
- 1.5 mg Pb/l, and
- 0.2 mg Cd/l

with the exact quantities determined using the following calculations (Gray and O'Neill, 1995):

$$\partial = \frac{\text{Atomic weight of metal}}{\text{Molecular weight of compound}}$$

where ∂ was the proportion of metal in the compound.

2. Al, aluminium; Fe, iron; Mg, magnesium; Zn, zinc; Mn, manganese; Cu, copper; Pb, lead; Cd, cadmium.

$$\beta = \frac{\text{Required weight of metal (mg)}}{\partial}$$

where β was the concentration of the compound required (mg/l).

For the most part, the SAMD was prepared using sulphate salts to attain a sulphate concentration comparable with that of the natural AMD. Finally, the pH of the SAMD was reduced to pH 3.1 using sulphuric acid (Gray and O'Neill, 1995).

2.2.4.2 Flow rate determination

The required flow rate for passing SAMD through the wetlands trial was determined using guidelines taken from the PIRAMID Consortium (2003), with sulphate being the target influent contaminant concentration used to calculate the flow rate. Equation 2.1 is the sizing formula for constructed wetlands used by the PIRAMID Consortium (2003). This was calculated using an area-adjusted removal contamination rate of 3.5 g/m^2/day.

$$A = \frac{Q_d(C_i - C_t)}{R_A} \qquad \text{Eqn 2.1}$$

where A is the required wetland area (m^2), Q_d is the mean daily flow rate (m^3/day), C_i is the mean daily influent contaminant concentration (mg/l), C_t is the concentration of contaminant in the final discharge (mg/l), and R_A is the area-adjusted contaminant removal rate (g/m^2/day).

Based on this calculation, approximately 4 l/day of SAMD were continually passed through each quadruple set of wetlands using digitised Watson-Marlow 323 peristaltic pumps (Fisher Scientific). The flow rate was increased to 5 l/day during periods of high temperature to allow for evaporation.

2.2.4.3 Electrochemical monitoring of constructed wetland

The pH, Eh and conductivity were monitored at 5-min intervals in all 12 wetland cells using electrochemical sensors that were specifically designed and developed by EA Instruments Ltd, London, UK. Wetland temperature was also measured for the duration of the trial (Fig. 2.3), which was 225 days in total. The trial

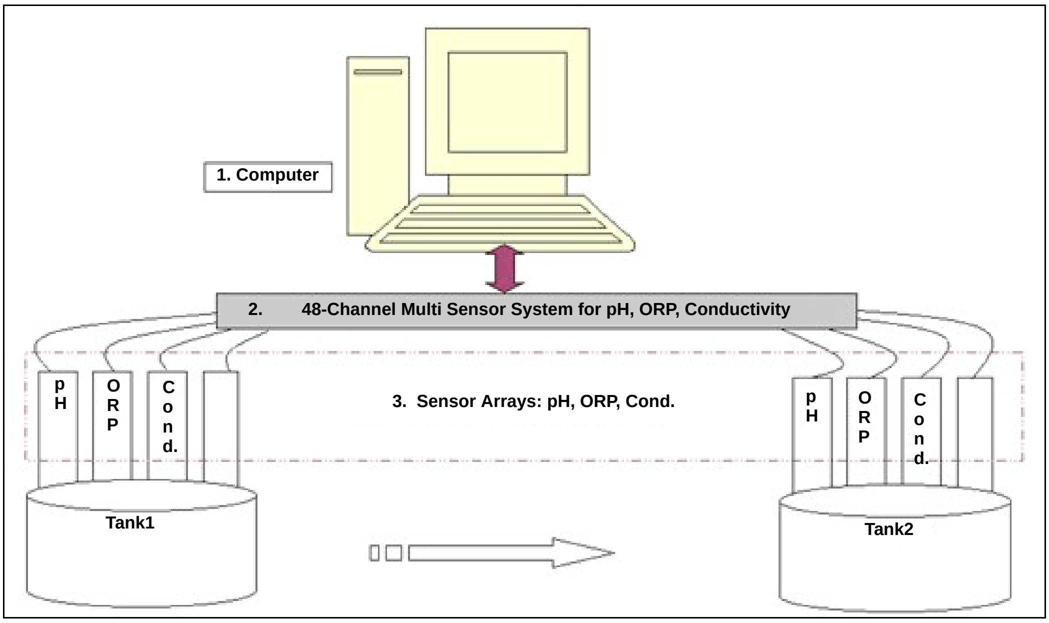

Figure 2.3. System view of the 48-channel multi-sensor system for pH, oxidation–reduction potential and conductivity.

was continued for an additional period of time after this date (Holland, 2011).

The 48-channel multi-sensor system was based on a standard 19-inch (~48 cm) sub-rack housed in a strong metal desktop enclosure. The sub-rack had 12 slots for euro cards which are printed circuit boards in 100 mm by 160 mm format (EA Instruments Ltd, 2008). The connectors for the various sensors were located on the front panels of the printed circuit boards as illustrated in Fig. 2.4.

The pH, conductivity and Eh electrodes were connected to the BNC (Bayonet Neill–Concelman) connectors of each of the electrode amplifiers, while the temperature sensors were connected to the transducer inputs.

The electrochemical sensors consisted of glass-body conductivity meters with platinum cells, platinum-rod Eh combination electrodes with gel-filled plastic body, and pellon film liquid junction pH meters (Fig. 2.5). The wetland system was grounded using a series of grounding rods.

Figure 2.4. Multi-sensor data logging system.

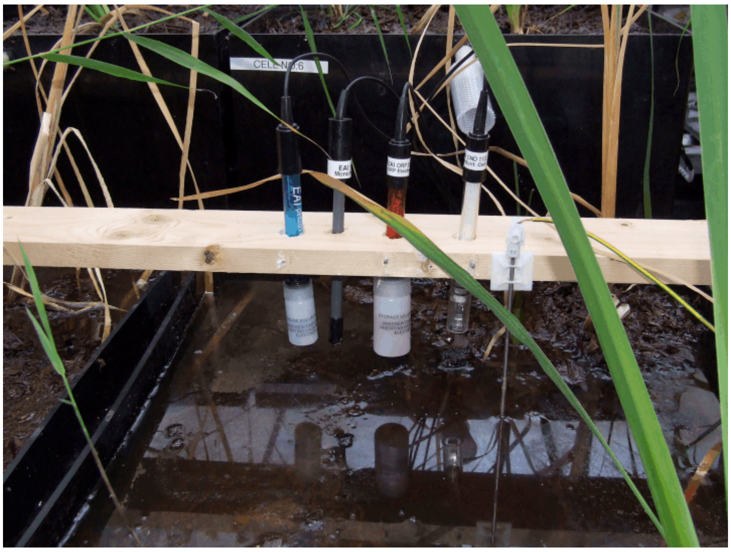

Figure 2.5. Arrangement of electrochemical sensors and grounding rod prior to trial commencement.

2.2.4.4 Measurement settings

The data logging system was set to automatically record the pH, conductivity, Eh and temperature of the cells at 5-min intervals for the duration of the trial (Fig. 2.6). The data were logged, recorded and subsequently stored in ASCII format on the connected desktop PC (Windows Professional operating system). The data generated were backed up at regular intervals on MS Office Excel 2007.

2.2.4.5 Sensor calibration

Oxidation–reduction potential sensors were not calibrated as they do not require special calibration procedures (measurements reported in millivolts). The pH sensors were calibrated simultaneously at 2-week intervals using buffer solutions, while the conductivity electrodes were calibrated at 4-week intervals using conductivity standard solutions. A sample summary of both calibrations is illustrated in Figs 2.7 and 2.8, respectively.

2.2.4.6 Sampling procedure

In addition to the sensor data, water samples were taken on a bi-monthly basis from each cell including the storage tank. Each sample was analysed for various physico–chemical parameters, including pH, conductivity, alkalinity, sulphate, dissolved organic carbon, dissolved inorganic carbon, magnesium, copper, zinc and iron as outlined below.

2.2.4.7 Sample collection

Chemical-resistant high-density polyethylene sampling containers were soaked for 24 h in a 10% hydrochloric acid (HCl) solution before being thoroughly rinsed with deionised water. The containers were then placed overnight in a LEEC glass-drying electric oven. The samples, approximately 200 ml in volume, were then collected from the overflow pipes of the lower level cells first and then subsequent cells to minimise flow disturbance. On occasion, Tefzel® rods were used to remove substrate blockages from the collection pipes.

2.2.4.8 pH measurement of wetland samples

The pH of the samples was determined using a Thermo scientific Orion 3-Star Plus pH benchtop meter, which was calibrated using buffers at pH 4 and pH 7. The pH of each sample was determined by decanting 25 ml of the sample into a sterilised 50-ml graduated sample container (Sarstedt Ltd) and allowed to stand for a further 30 min to reach room temperature. The pH was then recorded and compared with those obtained from the electrochemical pH sensor for quality assurance.

2.2.4.9 Sample filtration

Each sample was filtered through a series of three filter papers depending on the assay required. All samples were filtered through Millipore GFC filter paper before being passed through Millipore cellulose nitrate membrane filter paper (0.45 µm) to remove organic

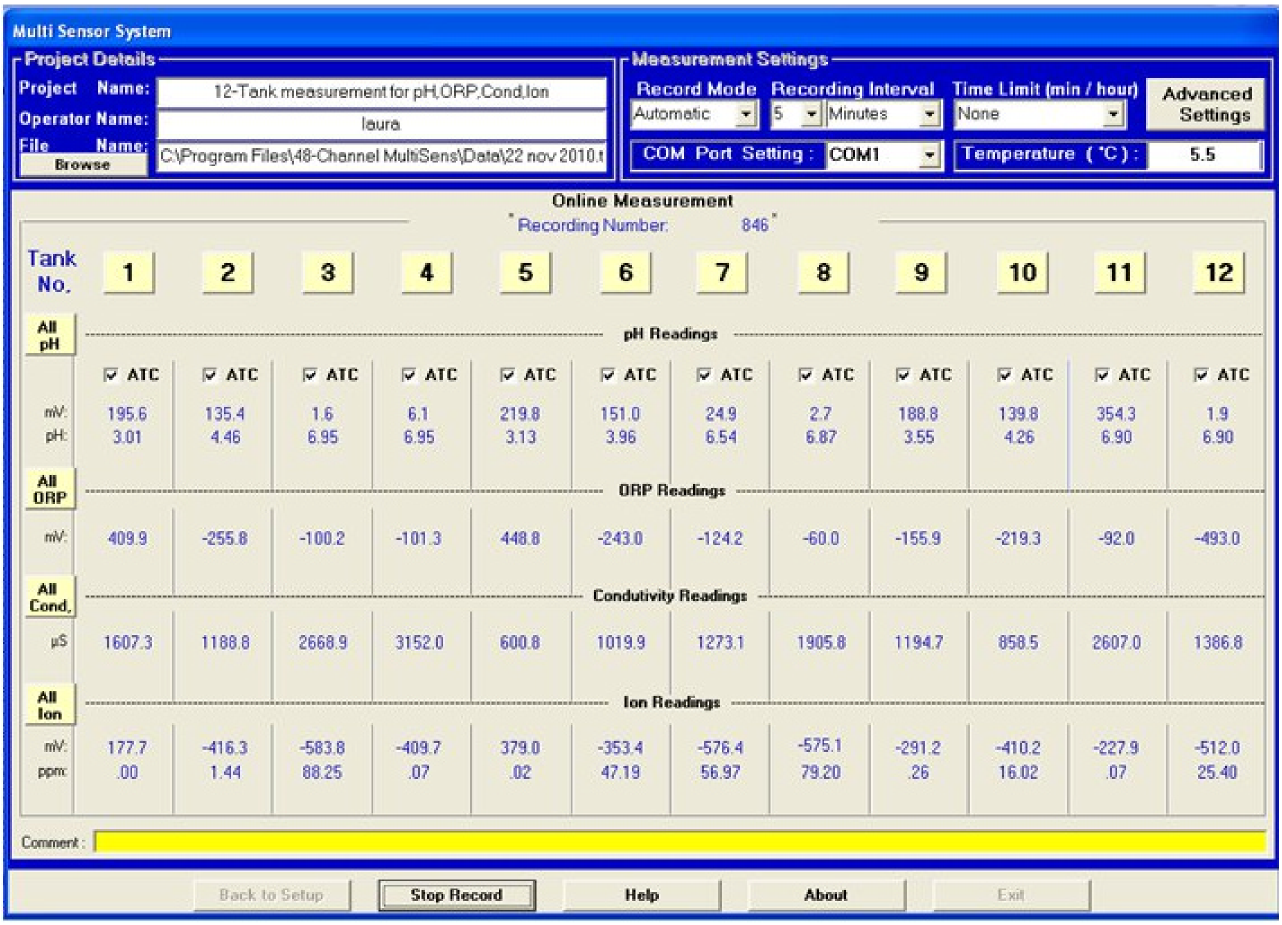

Figure 2.6. Multi-sensor system settings for 12 cells in relation to pH, oxidation–reduction potential and conductivity.

material from the solution. Approximately 50 ml of each sample were then subsequently passed through Millipore membrane filter paper (0.2 µm) as required for sulphate analysis as detailed below. Each filtration apparatus was acid washed in 10% HCl solution and thoroughly rinsed with deionised water before use.

2.2.4.10 Acidification and digestion of samples

After filtration through Millipore cellulose nitrate membrane filter paper of 0.45 µm pore size, 50 ml of each sample were acidified to pH >2 by the addition of 70% analytical grade nitric acid to preserve the samples.

The acidified samples were then digested in nitric acid using a CEM MARS 5 microwave digester (CEM, Matthews, NC, USA) and stored in 50-ml graduated storage containers (Sarstedt Ltd) in a refrigerator below 4°C (Gray and Delaney, 2008) awaiting chemical analysis.

2.2.5 Determination of total metal and macro/ micro-nutrient content

Following acid digestion of the wetland samples, metal concentrations were determined using a Varian AA240 atomic absorption spectrophotometer (AAS). All blanks and certified reference materials used were also digested in the same manner as the samples. The appropriate standards were made up according to the operating procedures of the Varian AA240 AAS for each individual element.

The linearity of the calibration graphs were accepted when R^2 coefficients exceeded 0.995 and, to ensure continued accuracy throughout the sample run, the standard graphs were re-sloped after every 25 samples and recalibrated after every 50 samples.

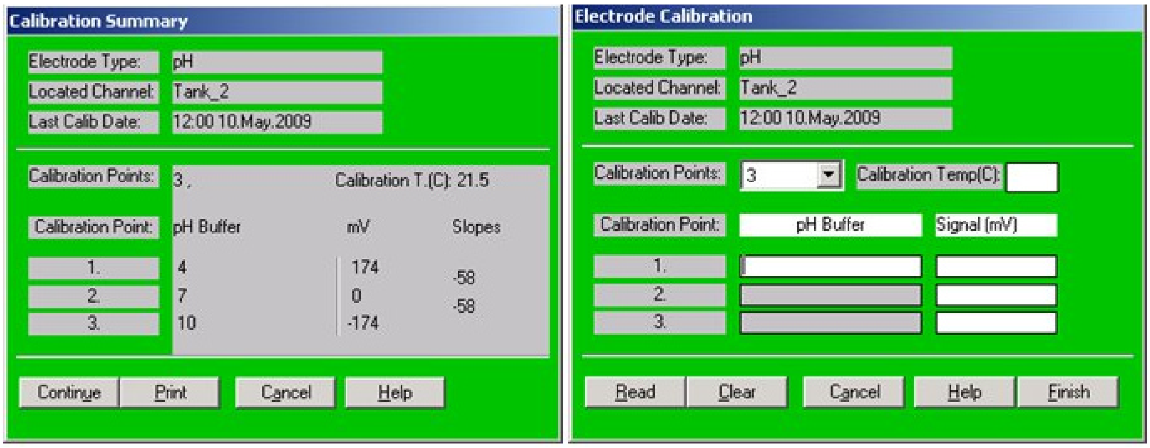

Figure 2.7. pH electrode calibration summary.

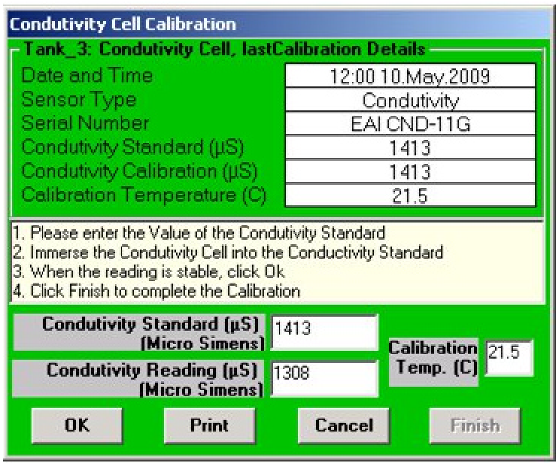

Figure 2.8. Conductivity electrode calibration summary.

Furthermore, a certified reference material (CRM) digest, which was a standard reference material 1643e (trace elements in water) (National Institute of Standards and Technology), that contained a known concentration of metals and nutrients was analysed after every 30 samples. Splits were also used to increase precision, where part of the substrate extract was re-analysed, while spikes were also introduced, through the analysis of a known quantity of analyte to ensure additional accuracy (O'Connor, 2003). Splits and spikes were introduced every 50 samples or less depending on the sample type.

2.2.6 Sulphate concentration determination

Sulphate analysis was carried out by ion-exchange chromatography (IC) using a Dionex ICS-1500 analyser on 0.2 µm filtered solution and Dionex standard IC solutions. Quality control samples (Milli-Q water) were utilised to ensure continued accuracy of results. Samples were diluted as required before analysis using a Hamilton Microlab 500 diluter to 1:100 of the original concentration, which ensured that the sulphate concentrations in the wetland samples were within the optimum working range of this particular IC.

2.2.7 Alkalinity determination

Alkalinity measurements were carried out on a monthly basis on samples from each of the 12 wetland cells prior to filtration. Twenty-five millilitres of each sample were titrated for alkalinity using a SCHOTT Instruments TitroLine® according to APHA (1992). The alkalinity (mg $CaCO_3$/l) was then calculated according to the following equation (Eqn 2.2):

$$Alkalinity = \frac{A \times N \times 50,000}{ml\ sample} \qquad \text{Eqn 2.2}$$

where A is the amount of standard acid used (ml) and N is the normality of the standard acid.

2.2.8 Dissolved organic and inorganic carbon determination

Following filtration of collected cell samples through a Millipore GFC filter and Millipore cellulose nitrate membrane filter paper (0.45 µm), samples were analysed for dissolved organic carbon and dissolved inorganic carbon using a persulphate digestion method on a Sievers 900 laboratory total organic carbon analyser.

3 Evaluation of the Remediation of Acid Mine Drainage Using Constructed Wetlands

This section focuses on the main parameters that could effectively evaluate the effect of employing an SMC substrate wetland for the bioremediation of AMD. In essence, the influence of the electrochemical properties – pH, ionic strength (electrical conductivity) and Eh – is discussed in detail owing to the fact that they are the most important parameters affected by flooding (Reddy and DeLaurne, 2008). The relationships between oxidation–reduction potential and pH are also discussed in relation to iron reduction, the metalloids copper and zinc and, more specifically, sulphate regulators.

3.1 Electrochemical Properties

The average pH results from the 225-day trial, as monitored at 5-min intervals, show that the pH of the receiving cell (Cell 1) was significantly reduced over time (Fig. 3.1), following addition of SAMD which entered the system at pH 3.1 (Fig. 3.2). Owing to the composition of the AMD entering the receiving cell, the buffering capacity of the SMC was diminished and this is shown in Fig. 3.3, where the alkalinity of the receiving cell was considerably less than the subsequent cells, and fell within the range of 600–800 mg/l for the duration of the trial.

The subsequent cells, particularly Cell 3 and Cell 4, exhibited a good buffering capacity against the AMD, with little variation in pH recorded during the trial. Cell 2 showed an uneven pH distribution throughout the trial, with a marked decrease in pH coinciding with a temperature decrease of between 1 and 2°C between Days 70 and 90. The buffering capacity of these cells is thought to be primarily due to the presence of calcium carbonate in the substrate. Furthermore, the sulphate-reducing bacteria in SMC also utilised the sulphate present in the AMD, which may have led to the production of bicarbonate which probably aided in raising the pH of the cells (Gazea et al., 1996).

The pH illustrated in Fig. 3.2, which was based on samples analysed on a bi-monthly basis, also shows similar trends to those recorded using electrochemical

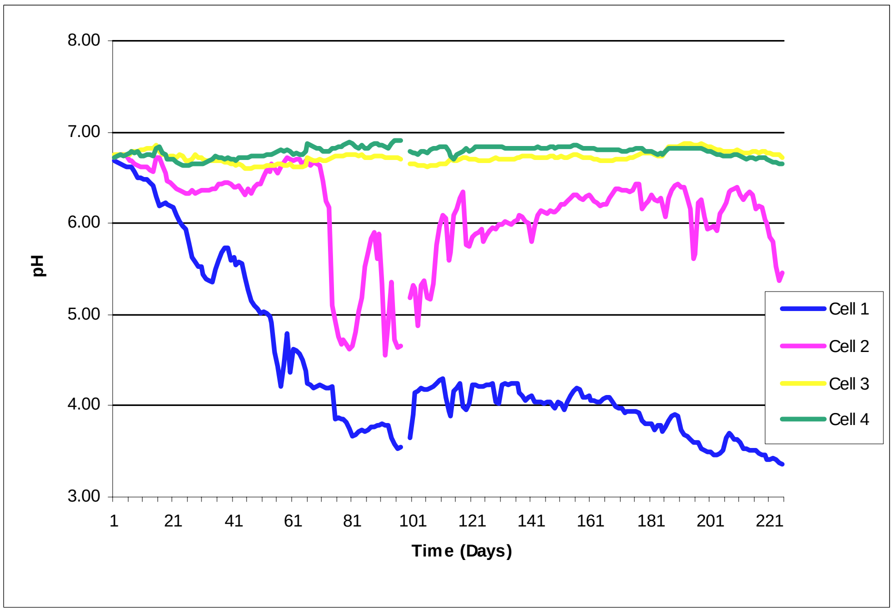

Figure 3.1. Effect of constructed spent mushroom compost wetland on the pH of acid mine drainage over time using electrochemical sensors logging pH at 5-min intervals.

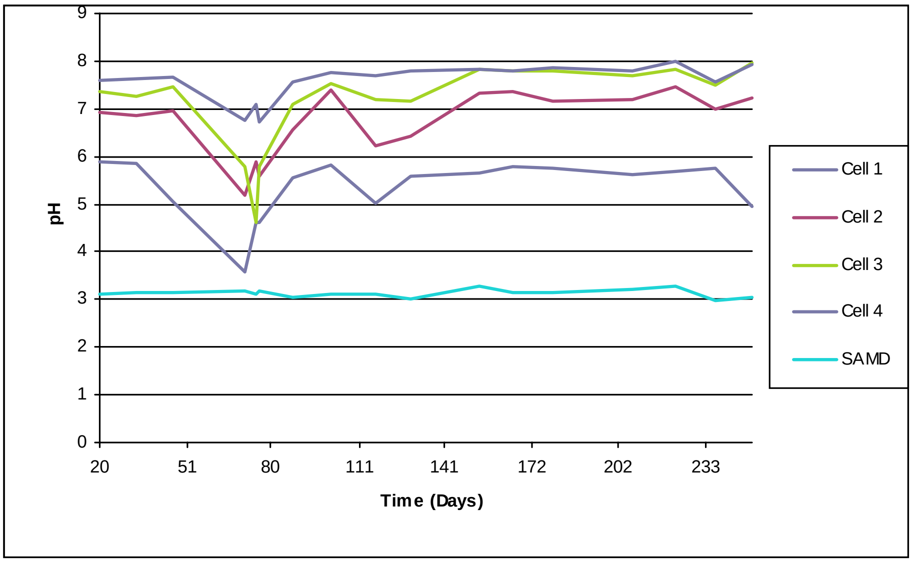

Figure 3.2. Effect of constructed spent mushroom compost wetland on pH of acid mine drainage over time as determined manually on a bi-monthly basis. SAMD, synthetic acid mine drainage.

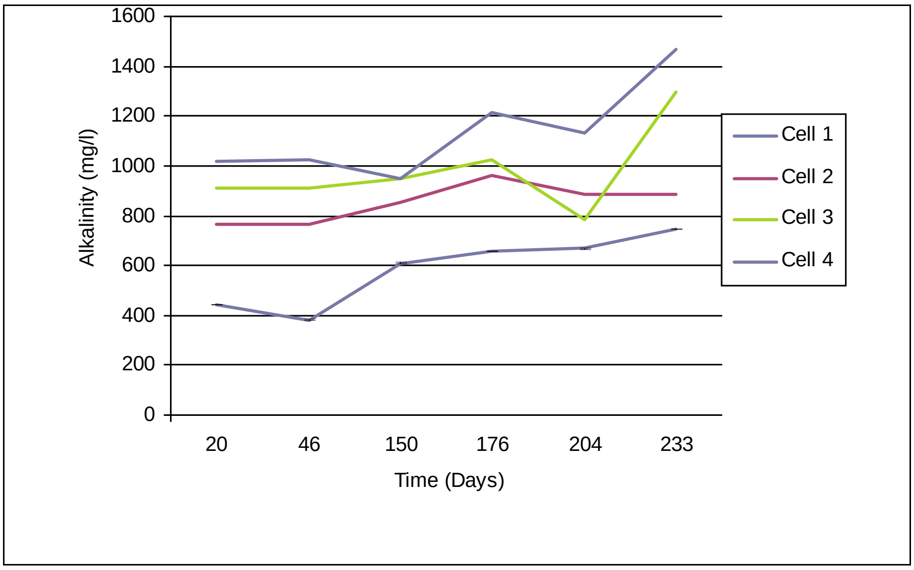

Figure 3.3. Effect of constructed spent mushroom compost wetland on alkalinity values (mg/l) over time.

sensors at 5-min intervals, with more diel fluctuations evident (Fig. 3.1), with the freshly prepared SAMD remaining at a relatively consistent pH of 3.1.

Alkalinity values, for the most part, increased as the trial progressed, with Cell 4 recording the highest value of nearly 1,500 mg/l. Increases in alkalinity values in wetlands are generally attributed to the abiotic reaction of AMD with neutralising agents present in the substrate – in this case calcium carbonate in the SMC (Vile and Wieder, 1993). Furthermore, increases in alkalinity could also be attributed to the removal of protons from the solution through attachment to cation exchange sites, as could the reduction of ferric oxyhydroxides to iron(II) and the functioning of dissimilatory sulphate bacteria. Once all neutralising agents are depleted and all cation exchange sites are occupied, a reduction in acidity results (Vile and Wieder, 1993).

Oxidation–reduction potential can withstand extensive changes in wetlands owing to hydrologic fluctuations, resulting in changes in the regulation of many biogeochemical reactions (Reddy and DeLaurne, 2008).

As shown in Fig. 3.4, the Eh values of Cells 2, 3 and 4 were significantly reduced to nearly –450 mV, which was probably due to the intense reduction of the submerged SMC including sulphates (high electron donors) and the activity of methanogenic bacteria (Baptista et al., 2003). Within the first 60 days of the trial, the Eh (mV) values recorded in the receiving cell (Cell 1) were in the range of a highly reducing environment but, after Day 60, the conditions changed to a moderately reducing range for the most part, before dropping back towards a stronger reducing environment. This phenomenon commonly occurs in soils following the addition of organic materials, where Eh values often decrease rapidly to less than –200 mV after flooding (Reddy and DeLaurne, 2008).

Oxidation–reduction potential values less than 300 mV are indicative of anaerobic conditions, with facultative anaerobes present in the range of 0–300 mV, while, below this range, obligate anaerobes tend to function (Reddy and DeLaurne, 2008).

The importance of the Eh–pH relationship in wetlands is well documented, with these two parameters responsible for the control of numerous biogeochemical reactions, such as the dissociation of acids and also the determination of the stability of minerals and nutrient restoration, in wetland substrates (Reddy and DeLaurne, 2008).

As illustrated in Fig. 3.5, it can be seen that the electrical conductivity of the cells remained quite high for the duration of the trial. All cells showed signs of a reduction in conductivity as time progressed, with Cells 1 and 2 showing a marked decrease in conductivity after Day 15, which remained relatively consistent after Day 100. The reduction appears to be less dramatic across the other two cells, where they remained in the range of 2,250–3,250 µS/cm. Overall, the results indicate high levels of dissolved solids in the cells, which are most likely due to the reduction of the SMC substrate by the combined efforts of the anaerobic micro-organisms and the AMD, resulting in the release of various cations and anions from the organic substrate. The apparent rise in conductivity towards the latter half of the trial could be due to nutrient release from vegetation dieback and plant decay (Mashauri et al., 2000; Sheoran, 2006).

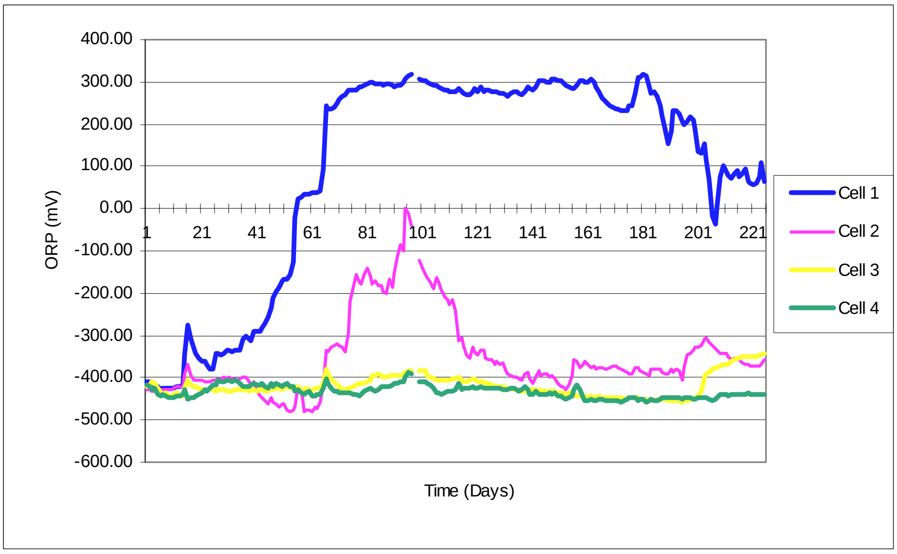

Figure 3.4. Effect of constructed spent mushroom compost wetland on oxidation–reduction potential of acidic mine drainage over time. ORP, oxidation–reduction potential.

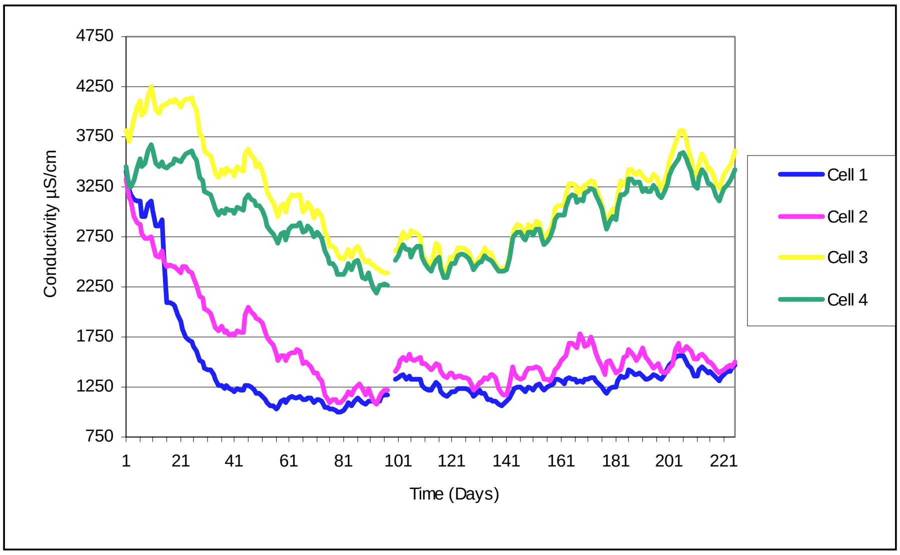

Figure 3.5. Effect of constructed spent mushroom compost wetland on the electrical conductivity of acidic mine drainage over time.

3.2 Biogeochemistry Properties

Copper is an essential trace element for plant growth but in excess it can cause the formation of reactive oxygen species, and oxidative stress also causes retardation of plant growth and leaf chlorosis (Nagajyoti, 2010). The concentration of total copper in the SAMD entering the system was approximately 5 mg/l, which is higher than the permitted reference of 3 µg/l for fresh water (Reddy and DeLaurne, 2008). Total copper concentrations remained appreciably low for the duration of the trial (Fig. 3.6), with the exception of Cells 1, 2 and 3 on one occasion during the temperature decrease. This also coincided with a considerable decrease in percentage copper removal from the system (Fig. 3.7).

Copper is found in three oxidation states, with copper(II) and copper(III) ions mostly involved in oxidation–reduction reactions in wetland systems (Reddy and DeLaurne, 2008). Studies on the stability

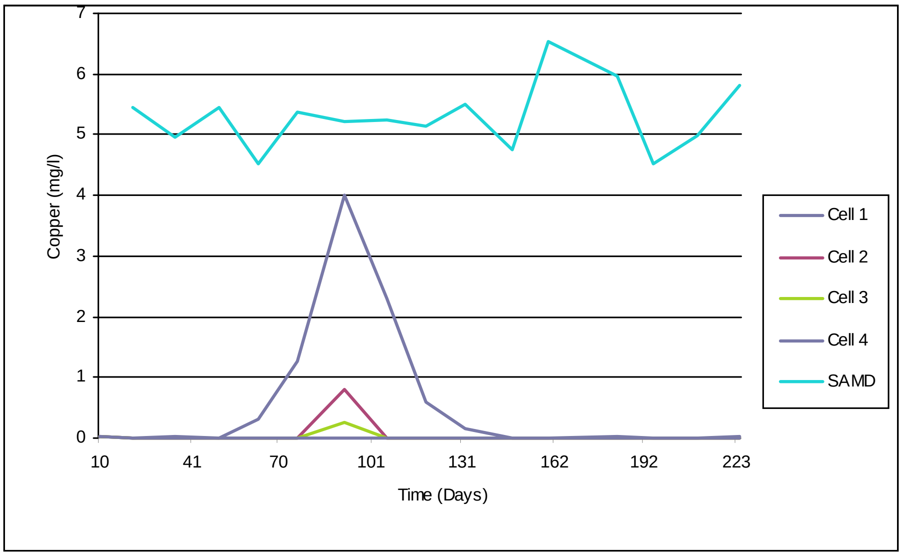

Figure 3.6. Effect of constructed spent mushroom compost wetland on the total copper concentrations (mg/l) over time.

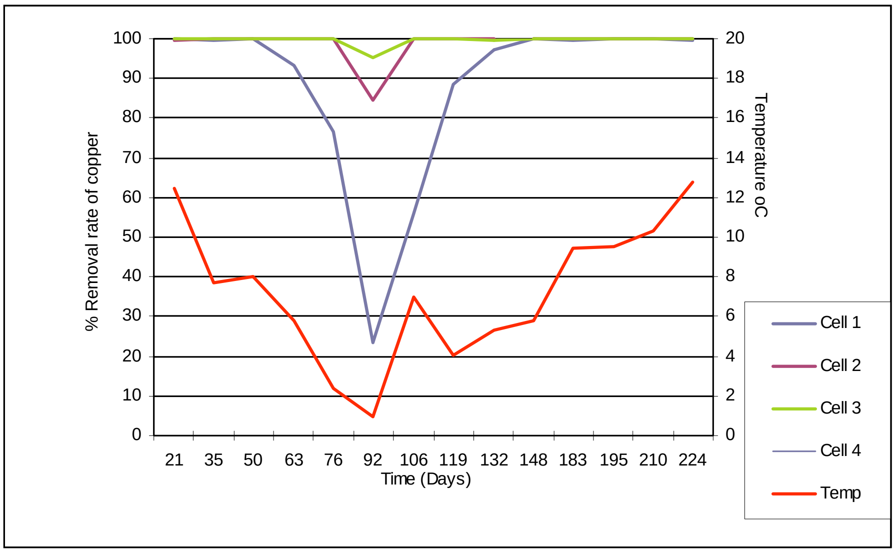

Figure 3.7. Percentage removal rate of copper in relation to temperature expressed as total removal from inlet concentrations (synthetic acid mine drainage).

of copper complexes at different oxidation–reduction conditions have shown that copper precipitates out of solution in reducing conditions owing to the displacement of copper by elevated concentrations of iron and manganese, which are released from the substrate during increased reducing conditions (Reddy and DeLaurne, 2008). Alternatively, insoluble copper sulphides could be formed at low oxidation–reduction potentials between –100 and –200 mV.

Copper in aqueous form is strongly linked to organic colloids and it is reported that almost no free copper ions are found when dissolved or particulate organic carbon is present (Reddy and DeLaurne, 2008). This phenomenon explains the trends in copper removal efficiency in Fig. 3.7, where nearly 100% copper removal was recorded with the exception of when the temperature dropped to between 1°C and 4°C between Days 80 and 100. Furthermore, a significant negative relationship was observed between copper removal and temperature in Cell 1 ($P < 0.001$) and this is thought to be due to the AMD not making sufficient contact with the substrate because of thick ice formation.

Zinc is another metal that is present in AMD and because it is non-biodegradable it can also bioaccumulate and enter the human food chain (Norton et al., 2004). With the exception of Cell 1, zinc concentrations remained consistently low in the subsequent cells, with an elevated amount of zinc detected again during the decrease in temperature between Days 80 and 100 (Fig. 3.8). Similar to the relationship of temperature with zinc removal efficiency, copper removal efficiency was also affected as illustrated in Fig. 3.9. Zinc removal in wetlands is generally attributed to its precipitation by hydrous metal oxides of manganese and iron under reducing conditions (Reddy and DeLaurne, 2008). The bioavailability of zinc and other metals is also regulated by organic and inorganic compounds and carbonates (Reddy and DeLaurne, 2008), all of which are abundant in SMC and may be attributed to its high biosorption to the substrate.

As highlighted in Fig. 3.9, SMC has the capacity to remove between 99% and 100% of zinc from the SAMD solution. As the results are expressed as a percentage removal of the total influent to the system, it can be seen that most of the zinc removal occurs in the first and second cells. As mentioned previously, the low temperature recorded midway through the experiment also coincided with diminished zinc removal rates from the system, with a significant negative relationship between zinc removal and temperature being observed in Cell 1 ($P < 0.001$). In spite of this, the overall removal rates still indicate an

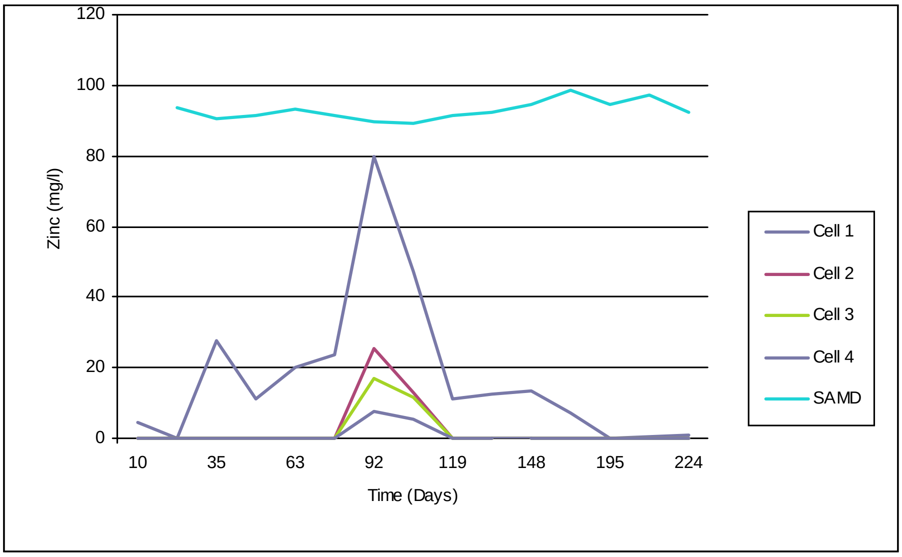

Figure 3.8. Effect of constructed spent mushroom compost wetland on the total zinc concentrations (mg/l) over time. SAMD, synthetic acid mine drainage.

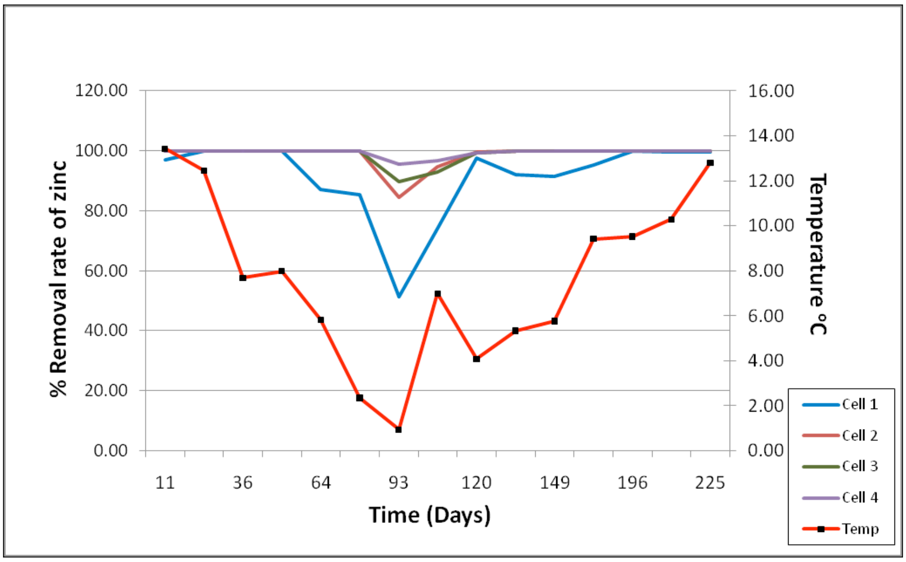

Figure 3.9. Percentage removal rate of zinc in relation to temperature expressed as total removal from inlet concentrations (synthetic acid mine drainage).

above 95% removal rate of zinc at the outlet of the system.

Iron is also an essential trace element that is present in both the Earth's crust and in oxides in aerobic environments (Reddy and DeLaurne, 2008). Similar to the trends recorded for copper and zinc concentrations in the wetland, with the exception of Cell 1 and the sampling period during the decrease in temperature, the iron concentrations were appreciably low (Fig. 3.10). The micro-organisms involved in the reduction of iron in wetlands are most likely bacteria that utilise iron(III) as electron donors from organic and inorganic substrates (Reddy and DeLaurne, 2008). These bacteria can solubilise such substrates, attach to the material and pass on electrons directly to it or transfer the substrate into the cell as a solid (Reddy and DeLaurne, 2008).

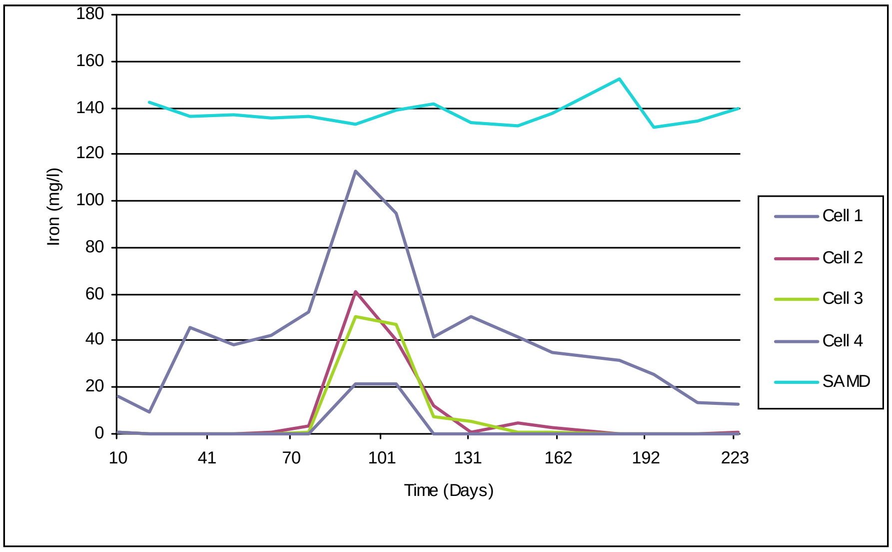

Figure 3.10. Effect of constructed spent mushroom compost wetland on the total iron concentrations (mg/l) over time. SAMD, synthetic acid mine drainage.

Unlike the high percentage removal efficiency for copper and zinc, only 66.75% of iron was removed by Cell 1, while the wetland overall removed 97.6% iron from the system (Fig. 3.11). In general, iron(II) concentrations tend to increase with decreasing Eh of wetlands as a function of time, but may be inhibited by nitrate concentrations (Reddy and DeLaurne, 2008), which in this case could be released from SMC. Therefore, the measuring of end products of iron reduction in the soluble and exchangeable phase, such as those measured in this study, may underestimate overall reduction rates (Reddy and DeLaurne, 2008).

Despite adding 110 mg/l of magnesium to the constructed wetland through the SAMD, a significant increase in magnesium was recorded in all cells, resulting in no magnesium removal efficiency

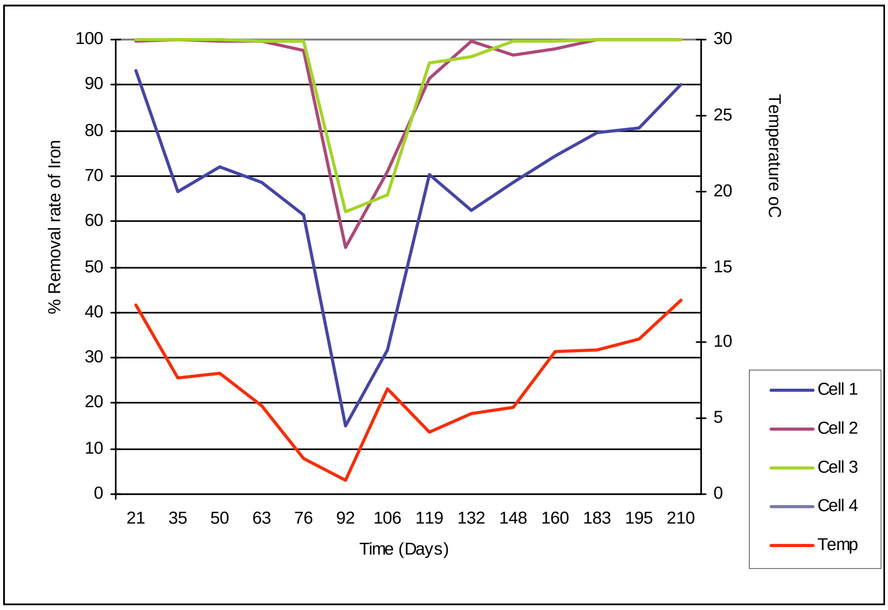

Figure 3.11. Percentage removal rate of iron in relation to temperature expressed as total removal from inlet concentrations (synthetic acid mine drainage).

(Fig. 3.12). This increase may be attributed to the reduction of the SMC substrate resulting in the release of magnesium from the compost, which contains approximately 18 g/kg, depending on where the SMC was obtained (Jordan et al., 2008).

Dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC), as illustrated in Figs 3.13 and 3.14, show some interesting trends:

- DOC reached levels up to nearly 300,000 ppb in most cells, apart from the receiving cell, prior to the decrease in wetland temperature, following which the DOC levels declined to minute concentrations; while
- In contrast, DIC concentrations remained low until approximately Day 150, when there was a steady increase in DIC concentrations recorded, while a slight increase was noted in Cell 1.

Within wetlands, DOC is produced during degradation of organic matter, and serves many functions including as an energy source for heterotrophic bacteria. Equally important is that it forms a sink or biosorption site for elements and compounds to exchange and or complex to (Reddy and DeLaurne, 2008). The fact that DOC levels have decreased significantly towards the end of the trial may indicate that the longevity of the system in terms of heavy metal removal may be jeopardised. Furthermore, DOC in all wetland cells negatively correlated ($P < 0.01$) with pH for the duration of the trial, indicating that the acidity of the SAMD is primarily responsible for the release of DOC into the water column. The extensive growth of macrophytes in the cells may be attributed in part to the organic carbon removal from the system, but the most probable cause of the reduction in DOC concentrations lies with the consumption of the labile pool of DOC by heterotrophic bacteria during respiration (Reddy and DeLaurne, 2008). In all of the cells, DOC showed significant positive correlation with sulphate ($P < 0.01$), indicating that the possible reduction of DOC in the wetlands led to the release of sulphate from iron-sulphur compounds in the organic substrate. Furthermore, DOC is hydrophobic and can transport some heavy metals and other elements to adjacent wetland cells.

Dissolved inorganic carbon showed few correlations with the additional parameters measured and, therefore, the cause of the increase in DIC towards the end of the trial is unknown. In Cell 4 only, DIC correlated with magnesium concentrations ($P < 0.05$), leading to the possibility that the elevated levels of DIC may be attributed to secondary products, such as carbon dioxide and methane, produced as part of the reduction process (Paludan and Blicher-Mathiesen, 1996).

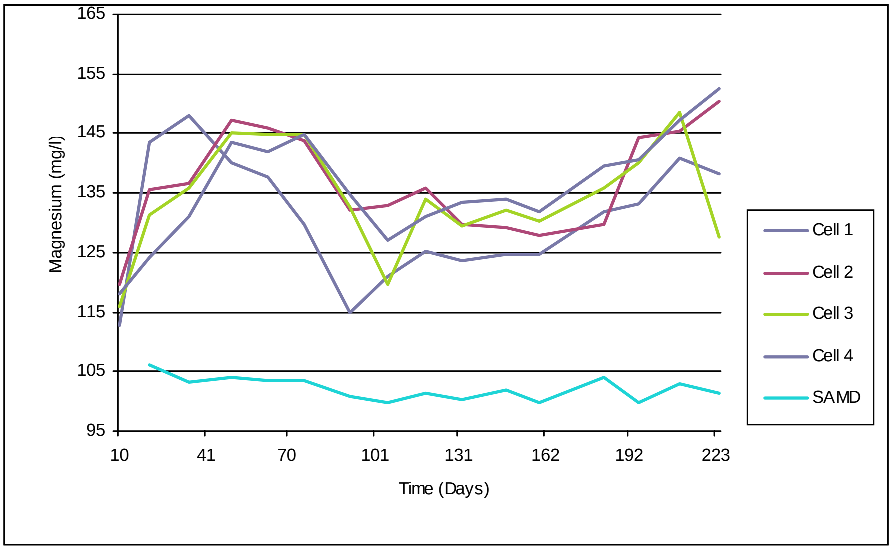

Figure 3.12. Effect of constructed spent mushroom compost wetland on the total magnesium concentrations (mg/l) over time. SAMD, synthetic acid mine drainage.

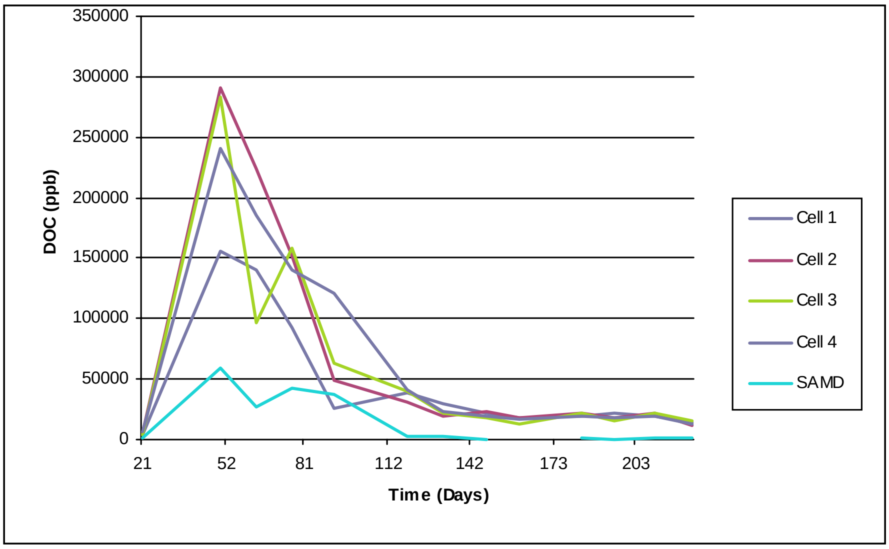

Figure 3.13. Effect of constructed spent mushroom compost wetland on dissolved organic carbon (DOC) concentrations (ppb) over time. SAMD, synthetic acid mine drainage.

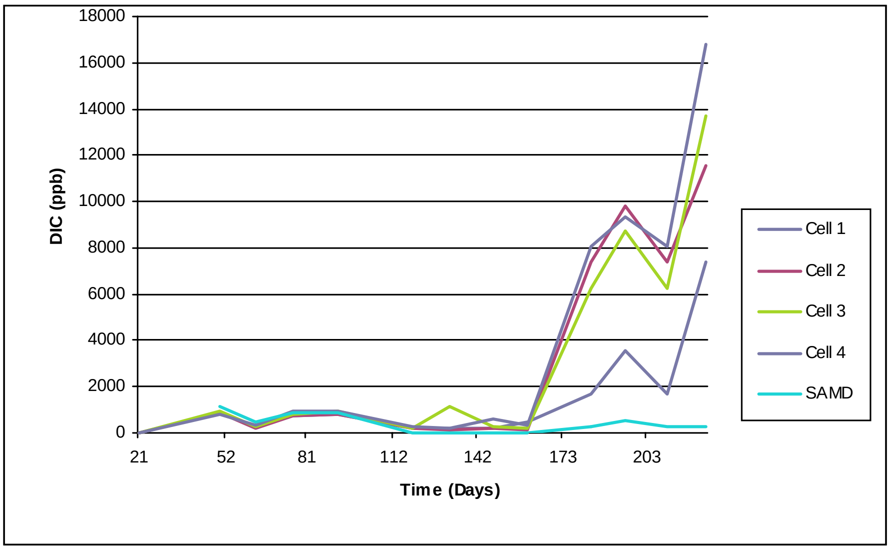

Figure 3.14. Effect of constructed spent mushroom compost wetland on dissolved inorganic carbon concentrations (ppb) over time. SAMD, synthetic acid mine drainage.

Sulphur is an abundant element in both the Earth's crust and in wetlands; it is present in both organic and inorganic forms such as hydrogen sulphide and sulphate (Reddy and DeLaurne, 2008). Similar to most other parameters measured, sulphate concentrations increased with decreasing temperature, including in the SAMD solution (Fig. 3.15). While sulphate concentrations in all cells were appreciably less than those of the SAMD, there was a reduction in sulphate concentrations during the trial which was possibly due to bacterial multiplication, with an increase in concentrations noted towards the end. Varied sulphate results were recorded during the trial and no significant correlations ($P < 0.05$) were recorded with the other parameters measured.

Sulphate concentrations were of particular interest in this study, owing to the high concentrations of sulphate

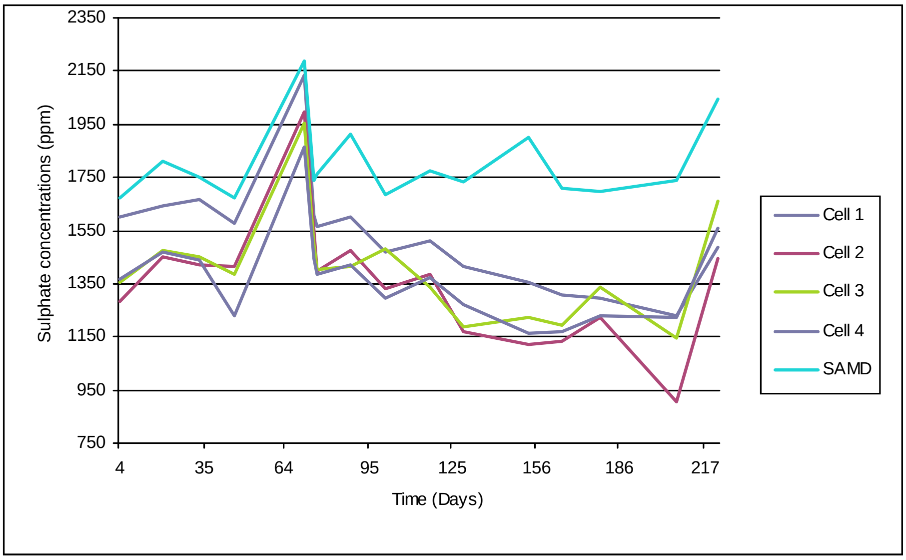

Figure 3.15. Effect of constructed spent mushroom compost wetland on sulphate concentrations (ppm) over time. SAMD, synthetic acid mine drainage.

in natural AMD, and the lack of consistent trends in sulphate reduction throughout the trial may be due to the complications associated with the presence of elevated heavy metal concentrations, as they tend to form stable sulphide complexes with some reduced sulphur species (Reddy and DeLaurne, 2008). Furthermore, sulphate is generally reduced to sulphide in wetlands, which may account for some of the variation in the trial, while other variations may be attributed to the competition between methanogens and sulphate reducers for electron donors (Reddy and DeLaurne, 2008).

3.3 Overall Discussion

Bioremediation is an environmentally friendly method for the treatment of water and soils that are polluted with toxic and/or recalcitrant organopollutants (Buswell, 1994), where microbes degrade pollutants by mineralisation to water, inorganic minerals and carbon dioxide in aerobic conditions and anaerobically to methane. Conventional treatment of wastewater in Ireland predominately revolves around the use of bioreactor tanks, which have high operational costs. The concept of using constructed wetlands to treat wastewaters has recently been developed in Ireland (Harrington and McInnes, 2009); however, the employment of wetlands in the treating of acidic mining wastewaters has received little attention in Ireland (O'Sullivan et al., 2000).

Spent mushroom compost has a good potential for use as a substrate for treating AMD in constructed wetlands as it can provide an electron donor for the biological treatment of AMD (Chang et al., 2000) and has the ability to biosorb heavy metals owing to the presence of hydroxyl, phosphoryl and phenolic functional groups on the surface of the SMC (Chen et al., 2005).

In this trial, SMC was successfully employed as a substrate in constructed wetlands treating AMD, similar in composition to acidified wastewater from the Avoca mine site, Co. Wicklow, Ireland. The presence of cation exchange sites for the removal of protons from the solution, in addition to the presence of the neutralising agent, calcium carbonate, in the SMC substrate ensured that the wetland cells continued to buffer against acidity at the end of the 225-day trial. The anaerobic conditions required for the biogeochemical reactions to occur efficiently in constructed wetlands were maintained for the duration of the trial. The employment of an electrochemical data logging device was instrumental in monitoring the electrochemical properties of the system and would be recommended for wetlands constructed at industrial scale.

The rate of removal of copper and zinc concentrations from the wetlands trial was impressive, with percentage removal rates exceeding 95%; while iron and sulphate concentrations also decreased, the percentage removal rates were more variable as the reduction in these parameters is more complex in wetland systems. If such a system were employed at field scale, the most important parameter that should be continually logged remotely would be temperature as in this study it had a significant impact on the ability of the system to remove particular contaminants. In the case of temperatures decreasing to less than 4°C over an extended period of time, the effluent should be recirculated into the system to prevent elevated contaminant concentrations entering freshwater systems in exceedance of appropriate EPA guidelines.

Overall, the intensively monitored wetlands system functioned through natural passive biological processes but longer trials would be required to determine the capacity and longevity of such a wetland design to continue to operate effectively over an extended period of time. Owing to the complexity of this trial and in order to establish the longevity of the system, the trial will continue to be monitored until spring 2012 (Holland, 2011). From these data, the fate and lifespan of the wetland system will be modelled to predict its durability and effectiveness in the field. The AMD generated in Avoca, Co. Wicklow, can be effectively treated using this type of passive, cost-effective technology, with land requirement being the only limiting factor in upscaling such a system.

4 Conclusion from Constructed Wetlands Trial

The results have shown the promising capacity of the SMC anaerobic wetland to neutralise the acidic sulphur-enriched drainage and sustain the buffering capacity of the system over an extended period of time. The results also suggest that the system is capable of maintaining a reducing environment through the reduction of sulphates, organic substances and possibly the activity of methanogenic bacteria over a prolonged period of time.

Spent mushroom compost has a good potential for use as a substrate for treating heavy-metal-contaminated wastewaters as it can provide an electron donor for the biological treatment of AMD and has the ability to biosorb heavy metals owing to the presence of various functional groups on the surface of the SMC.

The removal of zinc and copper and, to a lesser extent sulphate and iron, within the system also indicates that the system is capable of receiving a much larger volume of SAMD as much of the removal took place in the first two cells. The results are promising and indicate that this wetlands system may indeed prove to offer a long-term waste management option for SMC in Ireland, and also present an effective alternative to treating AMD.

However, the presence of elevated levels of organic substrates in the effluent leaving the system would suggest that the SMC wetland could possibly release nitrogen and phosphorus compounds during the treatment process and, as a result, a sand filter or similar polisher may be required at the end of the wetland to remove any elevated nutrient concentrations.

5 Recommendations

The following recommendations are made as a result of this wetlands trial:

- If installing SMC anaerobic wetlands at a large-scale level, small in-house trials similar to this study should be carried out for at least 1-year duration to prevent any unforeseen complex biogeochemical processes affecting effluent quality and also to aid in the optimisation of the system.
- The employment of an electrochemical data logging device is recommended for wetlands installed at industrial scale to monitor pH and oxidation–reduction potential. The data could be monitored remotely for quality assurance purposes.
- If such a system was employed on a field scale, the most important parameter that should be continually logged remotely is temperature as, in this study, it had a significant impact on the ability of the system to remove particulate contaminants. In the case of temperatures decreasing to less than 4°C over an extended period of time, the effluent should be recirculated into the system to prevent elevated contaminant concentrations entering freshwater systems in exceedance of appropriate EPA guidelines.
- The projected fate and lifespan of similar wetland systems should be modelled to predict their longevity and effectiveness in the field. It is recommended that a tracer dye would accurately quantify the retention time of the system which would aid in future attempts to use data modelling systems to assess the removal performance of the wetland system.
- In order to establish the main attributes responsible for heavy metal sequestration in wetlands of this type, isothermal and thermodynamic studies of the biosorption of SMC would determine and quantify the various functional groups responsible for metal immobilisation in addition to the identification of the microbial population in constructed wetlands as it controls some of the biogeochemical process involved in metal removal from the system.

6 Best Practices for Environmental Protection for the Mushroom Farming Industry

6.1 Introduction

While most mushroom farm operations operate to stringent practices, the management of SMC and associated wastewater falls short of best practices and these may become prospective pollutant sources. Regulatory best management practices, introduced in the form of MFEMPs, similar to those developed in Pennsylvania (Anonymous, 1997b), would represent a simple management tool for monitoring the movement and utilisation of mushroom industry wastes throughout Ireland while complying with all aspects of SI No. 101 (2009). To ensure that mushroom farms are operating to an appropriate environmental level, MFEMPs should be submitted to all relevant regulatory authorities.

6.2 Management of Wastes from Mushroom Growing Operations

This section details the main areas that should be addressed in MFEMPs in Ireland based on the Pennsylvanian model (Anonymous, 1997b) and, where relevant regulations or best management practices are not legislated in Ireland, possible suggestions have been included in an attempt to create more stringent ownership of SMC utilisation and management. While the basis of the MFEMP should ideally be a regulatory document, particularly in the area of waste permit application and approval, this section merely states, suggests and develops the various concepts in developing a mushroom grower's manual based on best management practices in Ireland and the subsequent introduction of the initiative of developing a MFEMP in Ireland.

As MFEMPs have not been developed in Ireland, this section also outlines the various steps that should be incorporated in an environmental management plan, similar to that developed for the mushroom farm industry in Pennsylvania as outlined in Section 1.4.4 (Anonymous, 1997b).

6.3 Mushroom Growing Operations and Permit Requirements

As outlined in Fig. 1.2, those authorised waste management requirements for the Pennsylvania mushroom industry that apply to the mushroom grower in addition to the person who purchased SMC or mushroom industry wastewater from the grower are highlighted.

Mushroom growers can opt for several best management practice scenarios to deal with waste management, some of which do not require a permit as shown in Figs 6.1–6.4 (adapted from Anonymous (1997b)).

Figures 6.1–6.4 illustrate the importance of SMC storage and potential utilisation, such as in soil conditioning and in horticulture, in terms of meeting regulatory requirements. For the purposes of classifying SMC utilisation in 'normal farming operations', such uses of this material in contaminated site and landfill revegetation, horticulture as a potting substrate and for crop growth and soil conditioning are all deemed acceptable when carried out in accordance with the guidelines in this section.

Spent mushroom compost is legislatively considered a waste in Ireland, yet it has a number of documented potential uses that would render it a valuable commercial resource. If the guidelines as outlined in Fig. 6.4 are adhered to by mushroom farm operators, SMC could be qualified as being a co-product in that it can be used instead of a raw material in the mushroom compost production process (Anonymous, 1997b). A co-product by definition is a material produced by a manufacturing process that is not a product. It must be chemically and physically comparable with the material that it is replacing, must exhibit no greater hazard to the environment than the material it is replacing, and finally it must be utilised regularly (Anonymous, 1997b). The particular criterion for classifying SMC as a co-product needs to be stringently monitored and if

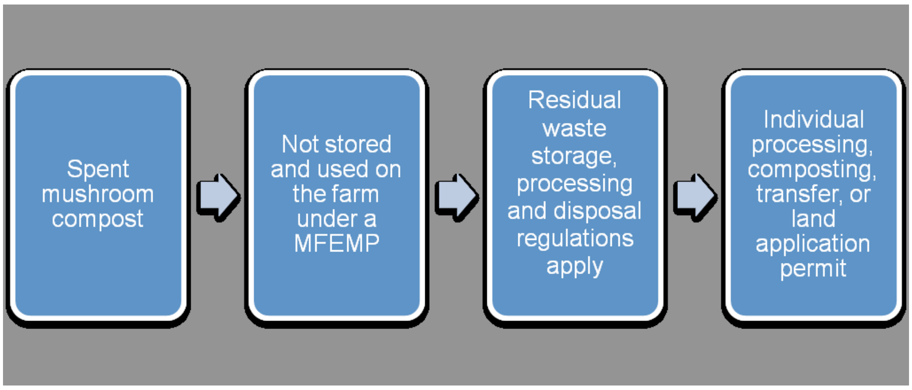

Figure 6.1. Case Study 1 for spent mushroom compost management with no mushroom farm environmental management plan (MFEMP) in place.

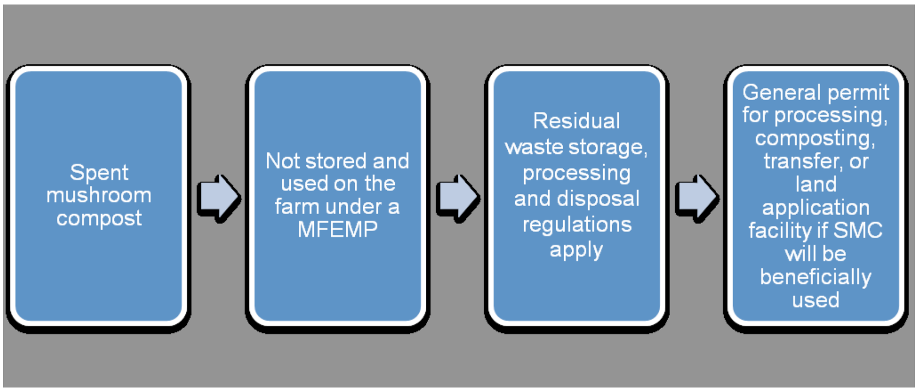

Figure 6.2 Case Study 2 for spent mushroom compost (SMC) management with no mushroom farm environmental management plan (MFEMP) in place.

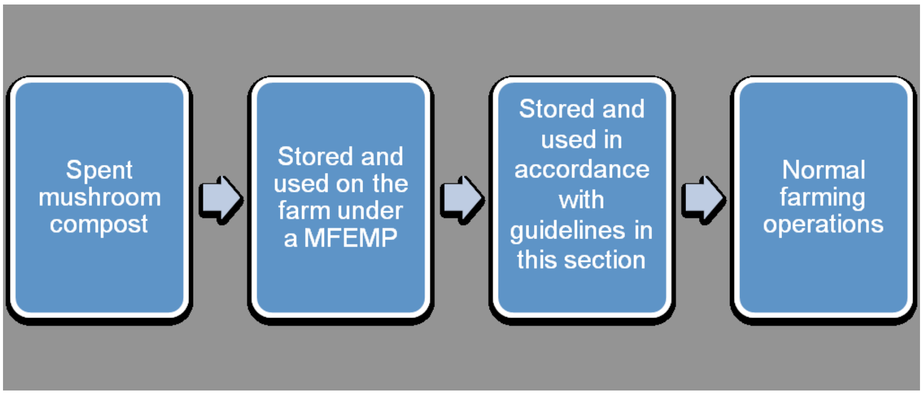

Figure 6.3. Case Study 1 for spent mushroom compost management with a mushroom farm environmental management plan (MFEMP) in place.

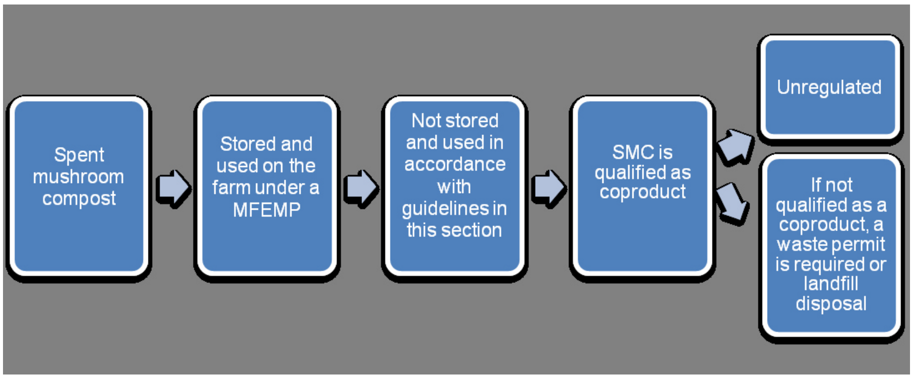

Figure 6.4. Case Study 2 for spent mushroom compost (SMC) management with a mushroom farm environmental management plan (MFEMP) in place.

any potential environmental stress is created owing to improper storage and/or associated management of SMC at a particular mushroom growing operation, then the co-product status should be removed from the SMC produced at that operation (Anonymous, 1997b).

If SMC does not qualify as a co-product or if it is not managed as part of the normal mushroom farming operation, it is then classified as a regulated waste which requires landfill disposal or a permit for its reutilisation in an alternative enterprise (Anonymous, 1997b).

6.3.1 Record keeping

Record keeping regarding SMC and wastewater management or disposal is not regulated in Ireland, yet it is a cost-effective practice that would guarantee the correct use and disposal of all wastes from the mushroom growing industry. Record keeping is an integral part of the residual waste regulations in Pennsylvania (25 Pa. Code Chapters 287–299) and should be introduced in Ireland to impart ownership of the relevant wastes on the mushroom growers, collectors and end-users of SMC, in addition to the provision of documentation that the mushroom production operation is functioning in compliance with the best management practices as outlined in this section, as well with those legislated under SI No. 101 (2009).

It is recommended that record keeping should be an integral part of every mushroom growing business irrespective of the scale of SMC produced and whether the SMC is utilised on the farm or exported for use elsewhere. In order to control and monitor the movement of all waste materials from mushroom production, record keeping should be regulated to ensure that SMC is exported and managed in an environmentally friendly manner. Information recorded should include the date of exportation, the quantity of exported material, the identity and contact details of the collector, the transport method used and a description of the proposed use and location of where the SMC will be utilised. In the absence of geographical co-ordinates, the address of the pre-agreed location should also be recorded, and in instances where the collector is not the end-user of the SMC, the identity of the end-user must be recorded. These records should also be maintained where SMC may be determined as a co-product.

All records completed by the mushroom grower must be made available to the end-user of the SMC and signed both by the collector and the end-user. This will ensure that a paper trail exists for all SMC generated in Ireland and will be available to all local authorities upon inspection.

Where SMC is used, treated or stored on the mushroom farm or indeed on any farm where SMC is received, all the associated management practices should be carried out in accordance with SI No. 101 (2009). Information on the dates when SMC was stored and subsequently removed should be recorded, in addition to the volume of the waste stored.

In relation to wastewater generated during the mushroom production process, which is regulated by

SI No. 101 (2009), information should be recorded if wastewater is exported from the mushroom production unit similar to that required for SMC management. If wastewater is utilised on the farm in compliance with SI No. 101 (2009) and in accordance with a nutrient management plan, record keeping is not required.

6.3.2 Storage of SMC and associated wastewater prior to reuse

Spent mushroom compost and soiled water storage is regulated under SI No. 101 (2009), where it is stated that storage facilities should be managed and maintained in order to prevent surface and groundwater deterioration. In addition, soiled water from mushroom house washings must be minimised and the storage facility should have the capability of holding washings generated over a 10-day period. Furthermore, the capacity of each storage facility must be adequate for all eventualities, particularly where storage periods might need to be extended owing to prolonged periods of unfavourable weather conditions, resulting in further land application restrictions.

Land application of organic wastes in Ireland is prohibited from 15 October to 31 January in Cavan, Monaghan, Donegal and Leitrim, from 15 October to 15 January for holdings in Clare, Galway, Kerry, Limerick, Longford, Louth, Mayo, Meath, Roscommon, Sligo and Westmeath, and from 15 October to 12 January for the remaining 11 counties (SI No. 101, 2009). These restrictions are based on soil conditions and geology in the particular regions.

With regard to maintaining the storage facilities and general mushroom production holding, all clean water from higher ground, roofs and clean paved areas must be diverted away from the soiled holding area and prevented from entering waste storage facilities (SI No. 101, 2009). Rainwater gutters and downpipes must also be maintained in compliance with these regulations.

Up until now, the maximum storage period for SMC has not been regulated in Ireland. Under the Solid Waste Management Act, Act 97 of 1980 in the Commonwealth of Pennsylvania, the storage of wastes exceeding 1 year is considered to be disposal. In the case of SMC, a permit is required if it is stored for more than 1 year unless a longer storage period is applied for and approved preceding the end of the first year of storage (Anonymous, 1997b). The rate of SMC deposition is taken into account during this application process and, if successful, this approval is integrated into the farm nutrient management plant. If SMC is not stored on a farm, a general or individual permit is required for the transfer operation (Anonymous, 1997b).

6.3.3 On-farm SMC treatment options

There are many regulated options for the on-farm treatment of SMC in the Commonwealth of Pennsylvania (Anonymous 1997b), including passive and active composting. If such options were regulated in Ireland, the management of certain aspects of on-farm SMC storage and subsequent treatment would be more stringently controlled.

On-farm passive composting involves the curing of SMC in small piles, which permits the SMC to decay to carbon dioxide, water vapour and a stabilised residue compost that has become enriched with inorganic ions. This process is predominantly microbiological, mediated by prokaryotes and fungi, which are either mesophiles or thermophiles, depending on their optimum growth temperature (Bardos and Lopez-Real, 1988). Under optimal conditions, composting proceeds through three phases – the first stage is the mesophilic period (moderate-temperature phase), which lasts for a small number of days, while the second stage is the thermophilic period (high-temperature phase), which can last from a few days up to several months, and, finally, the maturation phase takes place when the compost cools and this phase can also last for up to several months (Polprasert, 1989). Passive composting systems are much slower than active systems owing to the low temperatures achieved due to the lack of adequate aeration.

Cured SMC, which is a more stabilised residue, is regulated similarly to fresh SMC and when managed in this manner, it is seen as a normal farming operation in Pennsylvania (Anonymous, 1997b). In some circumstances, cured SMC may be used as a co-product; if not, a permit is mandatory for carrying out on-farm composting and consequent use of the cured SMC (Anonymous, 1997b).

The best management practices for carrying out a passive composting operation of SMC in Pennsylvania include requirements that the passive composting process must be carried out in accordance with an approved MFEMP and must not exceed 3 years duration (Anonymous, 1997b). Spent mushroom compost heaps are not permitted to exceed 3 feet in depth, the operation must control run-off and, to reduce run-off and air dispersion, a vegetative cover must be established on the surface (Anonymous, 1997b). Other restrictions include setback distances from the composting operation to nearby surface or groundwater and, finally, 2 resting years must be permitted in the field area where the initial composting operation took place (Anonymous, 1997b).

If passive composting is carried out in accordance with the guidelines in this section, no groundwater monitoring is required, but if the operations are modified, particularly in relation to more SMC being applied, extensive chemical groundwater monitoring may be necessary (Anonymous, 1997b).

On-farm active composting of SMC entails windrow-style composting operations, which are usually aerated and/or agitated by manual mechanical means. This composting operation is a relatively quick process owing to the introduction of air into the compost mass, resulting in the attainment of higher compost temperatures. The subsequent regulations around the management of the actively cured compost are identical to those for passively cured SMC.

In comparison with the passively composted SMC, the best management practices associated with active composting operations state that the compost process must be finished within 1 year and the composting operation must be carried out on a concrete-like base or indoors so that all wastewater generated can be collected and stored in accordance with an approved MFEMP (Anonymous, 1997b). The quantity of SMC permitted for active composting at any one time is limited to 6,000 cubic yards per acre, while the composting facility must not exceed 5 acres in size and various setback distances are regulated in relation to distances from the composting operation to nearby water systems (Anonymous, 1997b). Wastewater reuse and storage from SMC composting operations are also regulated in accordance with normal farming operations.

6.3.4 Nutrient content of SMC and associated wastewater

Encouragingly, from the standpoint of using it as a soil amendment, SMC exhibits many favourable characteristics, some of which are typical of other organic waste by-products, including a relatively low bulk density and high organic matter and moisture content (Maher et al., 1993). The mean composition of SMC samples in Ireland, the Netherlands and the US is outlined in Table 6.1, where it is evident that variability can occur particularly between micro- and macronutrients. Such variations may be a result of the initial formulation of raw materials, along with the

Table 6.1. Mean composition of spent mushroom compost (adapted from Maher et al., 1993).

Composition	Ireland	Netherlands	United States
Dry matter (%)	35	35	43
Organic matter (mg/kg)	61	55	–
Nitrogen (mg/kg)	2.8	2.4	1.9
Phosphorus (mg/kg)	1.0	0.8	0.4
Potassium (mg/kg)	2.0	2.8	2.4
Calcium (mg/kg)	6.6	12.6	4.9
Magnesium (mg/kg)	0.5	0.5	0.7
Manganese (mg/kg)	313	–	333

composting time, and the cropping cycle incurred during the manufacture of the mushroom medium (Gerrits, 1994). Spent mushroom compost is an ideal organic manure, in that it has a low content of heavy metals, contains a substantial supply of plant nutrients, in particular phosphorus and potassium, has no weed seeds or plant pathogens, is not odorous and, most notably, has a high organic matter content (Maher and Magette, 1997).

According to SI No. 101 (2009), 8.0 kg/t of nitrogen and 2.5 kg/t of phosphorus are present in SMC, with 45% nitrogen and 100% phosphorus available for crop growth. However, the nutrient composition of SMC wastewater is not known and can vary depending on SMC composition and the general management practices in the mushroom production unit. Under SI No. 101 (2009), soiled water application is regulated in that it must be applied in a uniform manner, but not on soil that is waterlogged, or likely to flood, if the land is snow-covered or frozen, if rain is forecast within 48 h or on steep slopes. However, the nutrient composition of soiled wastewater from mushroom production is not considered in these regulations.

In contrast, the Commonwealth of Pennsylvania requires that each mushroom grower must analyse SMC and the associated wastewater to determine their exact nutrient content due to their composition variability. Once the nutrient content of each is verified, it is not required that the analyses are repeated unless the composition of the substrate is altered or the mushroom grower changes management practices (Anonymous, 1997b).

6.3.5 Land application of SMC and associated soiled water

Spent mushroom compost and the associated soiled water are not permitted to be applied to land within 100–200 m of the abstraction point of any watercourse used for human consumption. Furthermore, SMC and soiled water cannot be applied to land within 25 m of a spring, borehole or well used for human consumption. Finally, neither substance can be applied to land within 20 m of a lake, 5 m from other watercourses and 15 m from karstified limestone features (SI No. 101 of 2009).

The following methods of application for both SMC and soiled wastewater are not permitted under SI No. 101 (2009):

- By either an umbilical system or a tanker with upward-facing splashplates;
- By a sludge irrigator mounted on a tanker; or
- From a passageway adjoining the land.

Furthermore, soiled water should not be applied to land by irrigation at a rate greater than 3 mm/h or in quantities that exceed 50,0000 l/ha within a 42-day period. Further regulations are also included for applied soiled water in karst areas (SI No. 101 of 2009).

6.4 Spent Mushroom Compost Use Outside Normal Farming Operations

The use of SMC to remediate contaminated sites, either through the establishment of constructed wetlands or by in-situ bioremediation technologies, is considered to be outside normal farming operations. Other similar operations include the use of SMC in animal feedstocks as a highly nutritious fodder, as bedding for poultry and animals, and for incineration for renewable energies. Such operations outside of conventional farming operations may only be carried out as part of a permit and integrated into a MFEMP. In such cases, a determination may be made to establish if SMC qualifies as a co-product, and, if successful, a waste permit may not be required (Anonymous, 1997b). Further approval may be required from relevant authorities in relation to using SMC in these circumstances. As always, record keeping is an integral part of managing SMC effectively, and its use outside normal farming operations should also be carefully documented as outlined in Section 6.3.2.

6.5 Spent Mushroom Compost Distribution and Sale Requirements

Supplementary to meeting the conditions in this section in relation to SMC management, storage and treatment, SMC that is sold in bulk or bagged as an organic fertiliser or soil amendment should be regulated and registered by the relevant authorities in Ireland. Furthermore, bagged SMC, whether cured or fresh, should include guaranteed information on total nitrogen and phosphorus species present, additional plant nutrients as required by the regulators, and relevant information on whether particular nutrients are slow acting or if the compost is organic in nature (Anonymous, 1997b).

6.6 Overview of Mushroom Farm Environmental Management Plans

If mushroom farms operate as outlined here and have carefully developed and implemented a MFEMP, individual waste permits may not be required as it is anticipated that such meticulous management would prevent any contamination of water, air and/or soil resources (Anonymous, 1997b). Such MFEMPs must be developed not only by mushroom growers but also by those receiving or processing SMC.

The basic components of a MFEMP include soiled water management, erosion control, protection of surface and groundwater sources, SMC utilisation and nutrient management, integrated pest management and, most importantly, record keeping to track all SMC movement throughout Ireland.

6.7 Conclusions to Best Practices for Environmental Protection

- Spent mushroom compost is legislatively considered a waste in Ireland, yet it has a number of documented potential uses that would render it a valuable commercial resource. Mushroom farm environmental management plans are required in Ireland.

- If the suggested guidelines for normal farm operations were adhered to, the correct use and disposal of all wastes from the mushroom industry would be virtually guaranteed. Based on the suggested best practice plan for Ireland, mushroom growers can opt for several best management practice scenarios to deal with waste management, some of which do not require a waste permit, if treated in the correct manner.

- In some cases, SMC can qualify as a co-product in that it can be used instead of a raw material in the mushroom compost production process. If SMC does not qualify as a co-product or is not managed as part of the normal mushroom farming operation, it is then classified as a regulated waste that will require landfill disposal or a permit for reutilisation in an alternative enterprise.

- Record keeping should be introduced in Ireland to impart ownership of the relevant wastes on the mushroom growers, collectors and end-users of SMC, in addition to the provision of documentation that the mushroom production operation is functioning in compliance with the best management practices as outlined in this chapter, in addition to those legislated under SI No. 101 (2009).

- The nutrient composition of soiled wastewater from mushroom production processes in Ireland is not known, making recommendations on its application difficult to devise.

- The market for SMC as an organic fertiliser or potting substrate is relatively unknown in Ireland.

6.8 Recommendations for Developing a Mushroom Farm Environmental Management Plan

- It is recommended that record keeping should be an integral part of every mushroom growing industry, irrespective of the scale of SMC produced and whether the SMC is utilised on the farm or exported for use elsewhere. In order to control and monitor the movement of all waste materials from mushroom production, record keeping should be regulated to ensure that SMC is exported and managed in an environmentally friendly manner.

- Where SMC is used, treated or stored on the mushroom farm or indeed any farm where SMC is received, all the associated management practices should be carried out in accordance with SI No. 101 (2009). Information on the dates when SMC was stored and subsequently removed should be recorded, in addition to the volume of the waste stored.

- The maximum storage period for SMC should be established in Ireland and anything in excess of this period should be classified as disposal.
- Guidelines on on-farm SMC treatment options should be made available to deal specifically with both passive and active composting.
- The nutrient composition of soiled wastewater from the mushroom industry should be investigated for inclusion in nutrient management plans and to determine composition variability.
- Spent mushroom compost that is sold in bulk or bagged as an organic fertiliser or soil amendment should be regulated and registered by the relevant authorities in Ireland. Furthermore, bagged SMC, whether cured or fresh, should include guaranteed information on total nitrogen and phosphorus species present and additional plant nutrients, as required by the regulators. As a consequence, the market for SMC may become more viable.

References

Anonymous, 1975. *25 Pennsylvania Code*. Chapter 102 Regulations. Commonwealth of Pennsylvania, USA. http://www.pacode.com/secure/data/025/chapter102/chap102toc.html (accessed September 2007).

Anonymous, 1980. *Solid Waste Management Act.* 35 P.S. §§ 6018.101 *et seq.* US.

Anonymous, 1993. *Decree for Use and Quality of Other Organic Fertilisers (BOOM Decree).* Netherlands.

Anonymous, 1994. *Environmental Guidelines for Mushroom Producers.* Ministry of Agriculture, Food and Rural Affairs, British Columbia, Canada. pp. 1–27.

Anonymous, 1996a. *Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates.* Department of Agriculture, Food and Forestry, Dublin, Ireland. pp.1–57.

Anonymous, 1996b. *Residual Waste Regulations.* 25 Pennsylvania Code Chapters 287–299. Commonwealth of Pennsylvania, USA. http://www.pacode.com/secure/data/025/articleIDIX_toc.html (accessed October 2007).

Anonymous, 1996c. *Waste Management Act.* Irish Statute Book. Government of Ireland, Dublin, Ireland. pp. 1–106.

Anonymous, 1997a. *Assessment of Spent Mushroom Compost Resource and Potential Processing Options for the Generation of Renewable Energy.* Dungannon and Monaghan Councils. pp. 1–62.

Anonymous, 1997b. *Best Practices for Environmental Protection in the Mushroom Farm Community.* Department of Environmental Protection, Pennsylvania, USA. pp. 1–74.

Anonymous, 2000a. *The Pennsylvania Fertilizer, Soil Conditioner and Plant Growth Substance Law.* Department of Environmental Protection, Pennsylvania, USA. http://members.aol.com/StatutesP8/3U.Cp.3a.html (accessed September 2007).

Anonymous, 2000b. *Monitoring and Assessment of Peat and Alternative Products for Growing Media and Soil Improvers in the UK (1996–1999*). Department of the Environment, Transport and the Regions, London, UK. pp. 1–86.

Anonymous, 2000c. *Mushroom Newsletter.* Teagasc, Dublin, Ireland.

Anonymous, 2000d. *Water Pollution (Agricultural) Bye-Laws.* Tipperary (North Riding) County Council, Ireland. pp. 1–18.

Anonymous, 2000e. *Water Pollution (Agricultural) Bye-Laws.* Westmeath County Council, Ireland. pp. 1–13.

Anonymous, 2000f. *Water Pollution (Agricultural) Bye-Laws.* Cavan County Council, Ireland. pp. 1–12.

Anonymous, 2000g. *Water Pollution (Agricultural) Bye-Laws* (draft). Kerry County Council, Ireland. http://www.kerrycoco.ie/environment/byelaws.asp (accessed September 2007).

Anonymous, 2001. *Mushroom Newsletter.* Teagasc, Dublin, Ireland.

Anonymous, 2002a. *Mushroom Newsletter.* Teagasc, Dublin, Ireland.

Anonymous, 2002b. *Nutrient Management Act.* Ministry of Agriculture, Food and Rural Affairs, Ontario, Canada. pp. 1–70.

Anonymous, 2003. *Mushroom Newsletter.* Teagasc, Dublin, Ireland.

Anonymous, 2004a. *Best Environmental Management Practices for Mushroom Growers in Canada.* Canadian Mushroom Growers' Association, Canada. pp. 1–25.

Anonymous, 2004b. *Mushroom Newsletter*, Teagasc, Dublin, Ireland.

Anonymous, 2005–2006. *Penn State Agronomy Guide.* The Pennsylvania State University, PA, USA. http://agguide.agronomy.psu.edu/ (accessed September 2007).

Anonymous, 2005a. *European Communities (Good Agricultural Practice for Protection of Waters) Regulations.* Department of the Environment and Local Government, Dublin, Ireland. pp. 1–47.

Anonymous, 2005b. *FAO Production Yearbook.* http://faostat.fao.org (accessed February 2008).

APHA, 1992. *Standard Methods for the Examination of Water and Wastewater.* 18th Edn. Joint publication of the American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC, USA.

Ball, A.S. and Jackson, A.M., 1995. The recovery of lignocellulose-degrading enzymes from spent mushroom compost. *Biotechnology Technology* **54(3):** 311–314.

Baptista, J.D.C., Donnelly, T., Rayne, D. and Davenport, R.J., 2003. Microbial mechanisms of carbon removal in subsurface flow wetlands. *Water Science Technology* **48:** 127–134.

Bardos, R.P. and Lopez-Real, J.M., 1988. The composting process: susceptible feedstocks, temperature, microbiology, sanitisation and decomposition. *In:* Bidlingmaier, W. and L'Hermite, P. (Eds) *Proceedings – Compost processes in Waste Management, Monastery of Neresheim (FRG).* CEC, Brussels, pp. 179–190.

Beattie, V.E., Sneddon, I.A., Walker, N. and Weatherup, R.N., 2001. Environmental enrichment of intensive pig housing using spent mushroom compost. *Animal Science* **72(1):** 5–42.

Beyer, D.M., 2005. *Mushroom growers information site.* The Pennsylvania State University, PA, USA. http://mushgrowinfocas.edu/siteindex.htm (accessed September 2007).

Bower, C.A. and Wilcox, L.V., 1965. Soluble salt. *In:* Black, C.A. (Ed.), *Methods of Soil Analysis. Part II. Chemical Methods.* American Society of Agronomy, Madison, USA. pp. 933–951.

Briton, W.F., 2001. An international look at compost standards. *Biocycle* **42(4):** 74–76.

Buswell, J.A., 1994. Potential of spent mushroom substrate for bioremediation purposes. *Compost Science and Utilization* **3(1):** 31–35.

Chang, I.S., Shin, P.K. and Kim, B.H., 2000. Biological treatment of acid mine drainage under sulphate-reducing conditions with solid waste materials as substrate. *Water Research* **34(4):** 1269–1277.

Chang, S.T., 1984. Conversion of agricultural and industrial wastes into fungal protein. *Conservation and Recycling* **7(2–4):** 175–180.

Chen, G.-G., Zeng, G-M., Tu, X., Huang, G.-H. and Chen, Y.-N., 2005. A novel biosorbent: characterization of the spent mushroom compost and its application for removal of heavy metals. *Journal of Environmental Sciences* **17(5):** 756–760.

Chenu, C., Le Bissonnais, Y. and Arrouays, D., 2000. Organic matter influence on clay wettability on soil aggregate stability. *Soil Science Society of America Journal* **64(4):** 1479–1486.

Chong, C and Hamersma, B., 1996. Using spent mushroom compost as a container substrate. *American Nurseryman* **184(11):** 63–66.

Chong, C., Cline, R.A., Rinker, D.L. and Allen, O.B., 1991. Growth and mineral nutrient status of containerised woody species in media amended with spent mushroom compost. *Journal of American Society for Horticultural Science* **116:** 242–247.

Chong, C., Cline, R.A. and Rinker, D.L., 1987. Spent mushroom compost and papermill sludge as soil amendments for containerized nursery plants. *International Plant Propagators Society* **37:** 347–353.

Chong, C., Cline, R.A. and Rinker, D.L., 1994. Bark- and peat-amended spent mushroom compost for containerised culture of shrubs. *HortScience* **29(7):** 781–784.

Courtney, R.G. and Timpson, J.P., 2004. Nutrient status of vegetation grown in alkaline bauxite processing residue amended with gypsum and thermally dried sewage sludge – A two year field study. *Plant and Soil* **266(1–2):** 187–194.

Courtney, R.G. and Timpson, J.P., 2005. Reclamation of fine fraction bauxite processing residue (red mud) amended with coarse fraction residue and gypsum. *Water, Air, & Soil Pollution* **164:** 91–102.

Cronin, M.J., Yohalem, D.S., Harris, R.F. and Andrews, J.H., 1996. Putative mechanism and dynamics of inhibition of the apple scab pathogen *Venturia inaequalis* by compost extracts. *Soil Biology and Biochemistry* **28(9):** 1241–1249.

Curtin, J.S., 2005. *An Investigation into the use of Spent Mushroom Compost as a Soil Conditioner on Intensively Cultivated Tillage Soils in Ireland.* Unpublished Ph.D. Thesis, University of Limerick, Limerick, Ireland. pp. 1–271.

DAF, 2004. *Minimum Specifications for Manure Pits and Dungsteads.* S108, Department of Agriculture and Food, Dublin, Ireland. pp. 1–15.

DAF, 2005. *Ireland, National Action Programme under the Nitrates Directive,* Department of Agriculture and Food, Dublin, Ireland. pp. 1–33.

DAFF, 2009. Producer organisations in the fruit and vegetables sector. *National Strategy for Sustainable Operational Programmes 2009–2013.* Department of Agriculture, Fisheries and Food, Dublin, Ireland. pp. 1–45.

Dallon, J., 1987. Effects of spent mushroom compost on the production of greenhouse-grown crops. *Combined Proceedings of the International Plant Propagators Society.* **37:** 323–329.

Daniel, W.W., 1999. *Biostatistics: A Foundation for Analysis in the Health Sciences.* 7th Edn. John Wiley and Sons, New York, USA. pp. 1–780.

Davoren, M. and Fogarty, A.M., 2005. Ecotoxicological evaluation of the biocidal agents sodium *o*-phenylphenol, sodium *o*-benzyl-*p*-chlorophenol, and sodium *p*-tertiary amylphenol. *Ecotoxicology and Environmental Safety* **60(2):** 203–212.

Devonald, V.G., 1987. Spent mushroom compost, a possible growing medium ingredient? In: *Compost Production, Quality and Use. Proceedings of a Symposium organised by the Commission of the European Communities, Directorate-General Science, Research and Development.* Udine, Italy. Elsevier, London, UK. pp. 785–791.

Dugast, P., 2001. Recent developments affecting fertiliser use in Western Europe. *IFA Production and International Trade Conference.* Fairmont Le Château Frontenac, Quebec City, Canada. pp. 1–14.

Duggan, J., Maher, M.J. and Hennerty, M.J., 1994. *The*

Effects of Spent Mushroom Compost as a Soil Amendment on Glasshouse Tomatoes. Kinsealy Research Report, Teagasc, Dublin, Ireland. pp. 7–8.

Duggan, J., Maher, M.J. McCabe, T. and Hennerty, M.J., 1998. *The Use of Spent Mushroom Compost as an Organic Manure*. Kinsealy Research Report, Teagasc, Dublin, Ireland. pp. 9–12.

Eggen, T., 1999. Application of fungal substrate from commercial mushroom production – *Pleurotus ostreatus* – for remediation of creosote contaminated soil. *International Biodeterioration and Biodegradation* **44(2–3):** 117–126.

El-Fallal, A.A. and Migahed, F.F., 2003. Metabolic changes in broad bean infected by *Botrytis fabae* in response to mushroom spent straw. *Asian Journal of Plant Sciences* **2(14):** 1059–1068.

Ellis, C., 2005. *Personal communication,* Mushroom Business Development Adviser, DARDI, Ireland.

Eriksson, K-E.L., Blanchette, R.A. and Ander, P., 1990. *Microbial and Enzymatic Degradation of Wood and Wood Components.* Springer, Berlin, Germany. pp. 1–407.

Finney, K.N., Ryu, C., Sharifi, V.N. and Swithenbank, J., 2009. The reuse of spent mushroom compost and coal tailings for energy recovery: Comparison of thermal treatment technologies. *Bioresource Technology* **100(1):** 310–315.

Gerrits, J.P.G., 1986. Compost for mushroom production and its subsequent use for soil improvement. In: *Compost: Production, Quality and Use.* Proceedings of a Symposium organised by the Commission of the European Communities, Directorate-General Science, Research and Development, Udine, Italy. pp. 431–439.

Gerrits, J.P.G., 1994. Composition, use and legislation of spent mushroom substrate in the Netherlands. *Compost Science and Utilization* **2(3):** 24–30.

Gazea, B., Adam, K. and Kontopoulos, A., 1996. A review of passive systems for the treatment of acid mine drainage. *Minerals Engineering* **9:** 23–42.

Gray, N.F. and Delaney, E., 2008. Comparison of benthic macroinvertebrate indices for the assessment of the impact of acid mine drainage on an Irish river below an abandoned CueS mine. *Environmental Pollution* **155:** 31–40.

Gray, N.F. and O'Neill, C., 1995. Artificial acid mine drainage for use in laboratory simulation studies. *Fresenius Environmental Bulletin* **4:** 481–484.

Groudev, S.N., Bratcova, S.G. and Komnitsas, K., 1999. Treatment of waters polluted with radioactive elements and heavy metals by means of a laboratory passive system. *Minerals Engineering* **12(3):** 261–270.

Guo, M. and Chorover, J., 2004. Solute release from weathering of spent mushroom substrate under controlled conditions. *Compost Science and Utilization* **12:** 225–234.

Guo, M. and Chorover, J., 2006. Leachate migration from spent mushroom substrate through intact and repacked subsurface soil columns. *Waste Management* **26:**133–140.

Harrington, R. and McInnes, R., 2009. Integrated Constructed Wetlands (ICW) for livestock wastewater management. *Bioresource Technology* **100:** 5498–5505.

Hogg, D., Barth, J., Favoino, E., Centremoero, M., Caimi, V., Amlinfer, F., Devliegher, W, Brinton, W. and Antler, S., 2002. Comparison of compost standards within the EU, North America and Australasia. *Review of Compost Standards in Ireland.* WRAP, Banbury, Oxon., UK.

Holland, L., 2012. *Remediation of Acid Mine Drainage Using Constructed Wetlands: A Greenhouse Trial*. Postgraduate Research Thesis (in preparation). Dundalk Institute of Technology, Dundalk, Ireland.

Holmes, S. and Richardson, S., 2000. Recycling used mushroom substrate (spent mushroom compost) as a soil improver. *Mushroom Journal* 17–19.

Ibrahim, R. S., Sawada, T., Shahata, M. and Ibrahim, A., 2000. Cross-protection and antigen expression by chicken embryo-grown *Pasteurella multocida* in chickens. *Journal of Comparative Pathology* **123(4):** 278–284.

Jacobson, B.A., Unz, R.F. and Dempsey, B.A., 1999. An analysis of manganese as an indicator for heavy metal removal in passive treatment using laboratory spent mushroom compost columns. *In:* Bengson and Bland (Eds) *Proceedings Annual Meeting of the American Society for Sfc. Mining and Reclamation,* Scottsdale, AZ, USA. pp. 89–90.

Jamieson, TS., Stratton, GW., Gordon, R. and Madani, A., 2003. The use of aeration to enhance ammonia nitrogen removal in constructed wetlands. *Canadian Biosystems Engineering* **45:** 1.9–1.14.

Jarecki, M., 2002. *Evaluation of Compost Leachate as a Source of Irrigation Water and Nutrients in Field and Hydroponic Experiments*. Unpublished PhD Thesis, University of Guelph, Ontario, Canada.

Jarecki, M.K., Chong, C. and Voroney, R.P., 2005. Evaluation of compost leachates for plant growth in hydroponic culture. *Journal of Plant Nutrition* **28:** 651–667.

Jordan, S.N., Mullen, G.J. and Murphy, M.C., 2008a. Composition variability of spent mushroom compost in Ireland. *Bioresource Technology* **99(2):** 411–418.

Jordan, S.N., Mullen, G.J. and Courtney, R.G., 2008b. Utilization of spent mushroom compost for the revegetation of lead-zinc tailings: Effects on physico-chemical properties of tailings and growth of *Lolium perenne. Bioresource Technology* **99(17):** 8125–8129.

Jordan, S.N., Mullen, G.J. and Courtney, R.G., 2009. Metal uptake in *Lolium perenne* established on spent mushroom compost amended lead-zinc tailings. *Land Degradation and Development* **20(3):** 277–282.

Kaddous, F.G.A. and Morgans, A.S., 1986. Spent mushroom compost and deep litter fowl manure as an ameliorant for vegetables. In: *Surface Soil Management*. Proceedings of the New Zealand Society of Soil Science–Australian Society of Soil Science Inc., Joint Conference. pp. 138–147.

Kallis, G. and Butler, D., 2001. The EU water framework directive: measures and implications. *Water Policy* **3(2):** 125–142.

Kuo, W.S. and Regan, R.W., 1992. Degradation of carbaryl and 1-naphthol by spent mushroom compost microorganisms. *Water Science Technology* **26(9–11):** 2081–2084.

Kwak, W.S., Kim, Y.I., Seok, J.S., Oh, Y.K. and Lee, S.M., 2009. Molasses and microbial inoculants improve fermentability and silage quality of cotton waste-based spent mushroom substrate. *Bioresource Technology* **100(3):** 1471–1473.

Langar, P.N., Senegal, J.P. Rana, V.K., Singh, M.M. and Garcha, H.S., 1982. Utilisation of A. Bisporus cultivated spent wheat straw in the ruminant diets. *Indian Journal of Animal Science* **52(8):** 634–637.

Law, W.M., Lau, W.N., Lo, K.L., Wai, L.M. and Chiu, S.W., 2003. Removal of biocide pentachlorophenol in water system by the spent mushroom compost of *Pleurotus pulmonarius. Chemosphere* **52(9):** 1531–1537.

Lemaire, F., Dartigues, A. and Rivière, L.M., 1985. Properties of substrate made with spent mushroom compost. *Acta Horticulturae* **172:** 13–20.

Levanon, D. and Danai, O., 1995. Chemical, physical and microbiological considerations in recycling spent mushroom compost. *Compost Science and Utilization* **3(1):** 72–79.

Lohr, V.I. and Coffey, D.L., 1987. Growth responses of seedlings to varying rates of fresh and aged spent mushroom compost. *HortScience* **22(5):** 913–915.

Lohr, V.I., Wang, S.H. and Wolt, J.D., 1984. Physical and chemical characteristics of fresh and aged spent mushroom compost. *HortScience* **19(5):** 681–683.

Maher, M.J., 1988. Spent mushroom compost as an organic manure and potting compost component. *In:* Bidlingmaier, W. and L'Hermite, P. (Eds) *Proceedings of Compost Processes in Waste Management,* Monastery of Neresheim (FRG), CEC, Brussels, Belgium. pp. 71–82.

Maher, M.J., 1990. The Value of Spent Mushroom Compost as an Organic Manure. *Proceedings of 8th Mushroom Conference.* Teagasc, Dublin, Ireland. pp. 29–34.

Maher, M.J. and Magette, W.L., 1997. Solving the spent mushroom compost problem. *In:* Staunton, L. and Grant, J. (Eds) *Advances in Mushroom Production*. Teagasc, Dublin, Ireland. pp. 73–82.

Maher, M.J., Lenehan, J.J. and Staunton, W.P., 1993. *Spent Mushroom Compost – Options for Use.* Teagasc, Dublin, Ireland. pp. 1–44.

Maher, M.J., Smyth, S., Dodd, V.A., McCabe, T., Magette, W.L., Duggan, J. and Hennerty, M.J., 2000. *Managing Spent Mushroom Compost,* Teagasc, Dublin, Ireland. pp. 1–40.

Mahony, Y., O'Flaherty, V., Killilea, E., Scott, E., Curtis, J. and Colleran, E., 2001. *Feasibility Study for Centralised Anaerobic Digestion for Treatment of Various Wastes and Wastewaters in Sensitive Catchment Areas.* Final Report, Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland. pp. 72–118.

Male, R.T., 1981. The use of spent mushroom compost in vegetable production. *Mushroom Science* **6:** 111–121.

Manios, T., Kypriotakis, Z., Manios, V. and Dialyna, G., 2002. Plant species in a two-year-old free water surface constructed wetland for domestic wastewater in the island of Crete. *Journal of Environmental Science and Health* **A37(7):** 1327–1335.

Manyin, T., Williams, F.M. and Stark, L.R., 1997. Effects of iron concentration and flow rate on treatment of coal mine drainage in wetland mesocosms: An experimental approach to sizing of constructed wetlands. *Ecological Engineering* **9(3):** 171–185.

Mashauri, D.A., Mulugu, D.M.M. and Abdul Hussein, B.S., 2000. Constructed wetland at the University of Dar Es Salaam. *Journal of Water Research* **24:** 1135–1144.

Maynard, A., 1994. Protecting groundwater while recycling nutrients. *Biocycle* **35(5):** 40.

Medina, E., Paredes, C., Pérez-Murcia, M.D., Bustamante, M.A. and Moral, R., 2009. Spent mushroom substrates as component of growing media for germination and growth of horticultural plants. *Bioresource Technology,* **100(18):** 4227–4232.

McMahon, C.A., 1997. *Utilisation of Spent Mushroom Compost on Co. Monaghan Grassland Soils. Unpublished M.Sc. Thesis*, University of Limerick, Limerick, Ireland. pp. 1–155.

Michitsch, R., Chong, C., Voroney, R.P., Holbein, B. and Liu, H.-W., 2003. Use of spent mushroom compost leachate for growing turf and nursery species in hydroponic culture. *Mushroom World* **14(3):** 21–23.

Moore, J.C., Holden, N.M. and Maher, M.J., 2002.

Utilisation of urea formaldehyde enhanced spent mushroom compost. *Proceedings of the Agricultural Research Forum*, Tullamore, Co. Offaly, Ireland. p. 5.

Mullen, G.J. and McMahon, C.A., 2001. The effects of land spreading and soil incorporation of spent mushroom compost on Co. Monaghan grassland soils. *Irish Journal of Agricultural and Food Research* **40(2):** 189–197.

Murphy, C., 2001. *Spent Mushroom Compost as an Amendment on Tillage Land*. Unpublished M.Sc. Thesis, University of Limerick, Limerick, Ireland. pp. 1–85.

Nagajyoti, P.C., Lee, K.D. and Sreekanth, T.V.M., 2010. Heavy metals, occurrence and toxicity for plants: a review. *Environmental Chemistry Letters* **8:** 199–216.

Noble, R. and Gaze, R.H., 1996. Preparation of mushroom (*Agaricus bisporus*) composts in controlled environments: factors influencing compost bulk density and productivity. *International Biodeterioration and Biodegradation* **37:** 93–100.

Norton, L., Baskarana, K. and McKenzie, T., 2004. Biosorption of zinc from aqueous solutions using biosolids. *Advances in Environmental Research* **8:** 629–635.

O'Connor, A., 2003. *An Investigation of Soil Quality Parameters Relating to Agricultural Reuse and Land Disposal Options for the Management of Biosolids*. Unpublished M.Sc. Thesis, Institute of Technology, Sligo, Ireland. pp. 1–174.

O'Sullivan, A., 2001. *Constructed Wetlands for the Passive Biological Treatments of Mine Tailings Water at Tara Mines, Ireland*. Unpublished PhD Thesis. University College Dublin, Dublin, Ireland. pp. 1–229.

O'Sullivan, A.D., Murray, D.A. and Otte, M.L., 2000. Development of constructed wetlands for treatment of sulfate-enriched water originating from (Pb/Zn) mine tailings. *Landbauforschung Völkenrode Sonderheft* **218:** 81–84.

Oenema, O. and Berentsen, P.B.M., 2005. *Manure Policy and MINAS: Regulating Nitrogen and Phosphorus Surpluses in Agriculture of the Netherlands.* Environment Directorate Centre for Tax Policy and Administration, OECD, Paris, France. pp. 1–47.

Pagliai, M. and Vignozzi, N., 1998. Use of manure for soil improvement. *In:* Wallace, A. and Terry, R.E. (Eds) *Handbook of Soil Conditioners*. Marcel Dekker, Inc., New York, USA. pp. 119–139.

Paludan, C. and Blicher-Mathiesen, G., 1996. Losses of inorganic carbon and nitrous oxide from a temperate freshwater wetland in relation to nitrate loading. *Biogeochemistry* **35:** 305–326.

PIRAMID Consortium, 2003. *Engineering Guidelines for the Passive Remediation of Acidic and/or Metalliferous Mine Drainage and Similar Wastewaters*. University of Newcastle-Upon-Tyne, Newcastle-Upon-Tyne, UK. ISBN 0-9543827-1-4.

Polprasert, C., 1989. *Organic Waste Recycling*. John Wiley and Sons, New York, USA. pp. 1–426.

Ranganathan, D.S. and Selvaseelan, D.A., 1997. Effect of mushroom spent rice straw compost on soil physical and physico-chemical properties of alluvial and laterite soils. *Madras Agricultural Journal* **84(1):** 15–19.

Rao, J.R., Watabe, M., Stewart, T.A., Millar, B.C. and Moore, J.E., 2007. Pelleted organo-mineral fertilisers from composted pig slurry solids, animal wastes and spent mushroom compost for amenity grasslands. *Waste Management* **27(9):** 1117–1128.

Reddy, K.R. and DeLaurne, R.D., 2008. Biogeochemistry of wetlands: Science and applications. CRC Press, Boca Raton, FL, USA. 756 pp.

Reed, W. and Keil, C., 2000. The effect of spent mushroom substrate land applications on adjacent surface water using aquatic macroinvertebrates as bio-indicators. *Mushroom News* **48(11):** 4–13.

Ribas, L.C.C., de Mendonça, M.M., Camelini, C.M. and Soares, C.H.L., 2009. Use of spent mushroom substrates from *Agaricus subrufescens* (syn. *A. blazei*, *A. brasiliensis*) and *Lentinula edodes* productions in the enrichment of a soil-based potting media for lettuce (*Lactuca sativa*) cultivation: Growth promotion and soil bioremediation. *Bioresource Technology* **100(20):** 4750–4757.

Richards, J.E., 1993. Chemical characterisation of plant tissue. *In:* Carter, M.R. (Ed.) *Soil Sampling and Methods of Analysis*. Canadian Society of Soil Science, Manitoba, Canada. pp. 115–139.

Rowell, D.L., 1994. *Soil Science: Methods and Applications.* Longman Group Ltd., UK. pp. 1–327.

Rupert, D.R., 1995. Use of spent mushroom compost in stabilising disturbed and commercial sites. *Compost Science and Utilization.* **3(1):** 80–83.

Sharma, H.S.S., 1996. Compositional analysis of neutral detergent, acid detergent, lignin and humus fractions of mushroom compost. *Thermochimica Acta* **285(2):** 211–220.

Sheoran, A.S., 2006. A laboratory treatment study of acid mine water of wetlands with emergent macrophyte (*Typha angusta*). *International Journal of Mining, Reclamation and Environment* **20:** 209–222.

Shuman, L.M., 1999a. Organic waste amendments effect on zinc fractions of two soils. *Journal of Environmental Quality* **28(5):** 1442–1447.

Shuman, L.M., 1999b. Effect of organic waste amendments on zinc adsorption by two soils. *Soil Science* **164(3):** 197–205.

Shuman, L.M. and Li, Z., 1997. Amelioration of zinc toxicity in cotton using lime or mushroom compost. *Journal of Soil Contamination* **6(4):** 425–438.

Snapir, N., Robinzon, B., Godschalk, M., Heller, E.D. and Perek, M., 1973. The effect of intrahypothalamic administration of sodium pentobarbital on eating behaviour and feed intake in chickens**.** *Physiology and Behavior* **10(1):** 97–100

Soffe, R.J., 1995. *The Agricultural Notebook*. 19th Edn. Blackwell Science Ltd., Oxford, UK. pp. 1–646.

Soon, Y.K. and Abboud, S., 1993. Cadmium, chromium, lead and nickel. *In:* Carter, M.R. (Ed.) *Soil Sampling and Methods of Analysis*. Canadian Society of Soil Science, Manitoba, Canada. pp. 101–107.

Stark, L.R. and Williams, F.M., 1994. The roles of spent mushroom substrate for the mitigation of coal mine drainage. *Compost Science and Utilization* **2(4):** 84–94.

Stark, L.M., Wenerick, W.R., Williams, F.M., Stevens, S.E. and Wuest, P.J., 1994. Restoring the capacity of spent mushroom compost to treat coal mine drainage by reducing the inflow rate: a microcosm experiment. *Water, Air, & Soil Pollution* **75(3–4):** 405–420.

Staunton, L., Dunne, R.M., Cormican, T. and Davoren, M., 1999. *Chemical and Biological Control of Mushroom Pests and Diseases.* Teagasc, Dublin, Ireland. pp. 1–18.

Steffen, K.L., Dann, M.S., Fager, K., Fleischer, S.J. and Harper, J.K., 1994. Short-term and long-term impact of an initial large-scale SMS soil amendment on vegetable crop productivity and resource use efficiency. *Compost Science and Utilization* **2(4):** 75–83.

Stephens, J.M., Henry, G.C., Castro, B.F. and Bennett, D.L., 1989. Mushroom compost as a soil amendment for vegetable gardens. *Proceedings of the Florida State Horticultural Society* **102:** 108–111.

Stewart, D.P.C., Cameron, K.C. and Cornfort, I.S., 1998. Effects of spent mushroom substrate on soil chemical conditions and plant growth in an intensive horticultural system: a comparison with inorganic fertiliser. *Australian Journal of Soil Research* **36(2):** 185–198.

Stoddart, H., Garthwaite, D.G. and Thomas, M.R., 2003. *Pesticide Usage Survey Report 197: Mushroom Crops in Great Britain.* Department of Environment, Food and Rural Affairs and Scottish Executive Environment and Rural Affairs Department, UK. pp. 1–22.

Straatsma, G., 2005. *Personal Communication*. Wageningen University and Research, Applied Plant Research, Mushroom Research Unit (formerly 'Mushroom Experimental Station'), Horst, Netherlands.

Szmidt, R., 1994. Recycling of spent mushroom compost substrates by aerobic composting to produce novel horticultural substrates. *Compost Science and Utilization* **2(3):** 63–72.

Szmidt, R.A.K. and Dickson, A.W., 2001. *Use of compost in agriculture*. Remade Scotland, Scottish Agricultural College, available on: http://www.remade.org.uk/Organics/organics_documents/20010424_AgriFAQ_Report.pdf (accessed in September 2007).

Uzun, I., 2004. Use of spent mushroom compost in sustainable fruit production. *Journal of Fruit and Ornamental Plant Research* **14:** 157–165.

Vile, M.A. and Wieder, R.K., 1993. Alkalinity generation by Fe (III) reduction versus sulphate reduction in wetlands constructed for acid mine drainage treatment. *Water, Air, & Soil Pollution* **69:** 423–441.

Wang, S.H.L., Lohr, V.I. and Coffey, D.L., 1984. Growth response of selected vegetable crops to spent mushroom compost application in a controlled environment. *Plant and Soil* **82(1):** 31–40.

White, J.W., 1976. Mushroom casing soil and sphagnum moss peat: growing media for Easter lilies. *Mushroom News* **6:** 17–19.

Williams, B.C., 2001. Energy from spent mushroom compost. *The Mushroom People* **3a(120):** 18.

Williams, B.C., McMullan, J.T. and McCahey, S., 2001. An initial assessment of spent mushroom compost as a potential energy feedstock. *Biotechnology Technology* **79(3):** 227–230.

Wilson, L.L., Turner, M.L. Weiss, M.J. and Harpster, H.W., 1983. Mushroom industry wastes studied as livestock feeds. *Science in Agriculture* **30:** 7.

Wuest, P.J. and Fahy, H.K., 1991. Spent mushroom compost. Traits and Uses. *Mushroom News* **39(12):** 9–15.

Wuest, P.J. and Fahy, H.K., 1992. Spent mushroom compost, its origin, components and impact on water quality. *Mushroom News* **40:** 27–33.

Yohalem, D.S., Harris, R.F. and Andrews, J.H., 1994. Aqueous extracts of spent mushroom substrate for foliar disease control. *Compost Science and Utilization* **2(4):** 67–74.

Young, P., 2008. Farm diversification: Mushrooms. *Farm Management.* 4 pp.

Zhang, C.K., Gong, F. and Li, D.S., 1995. A note on the utilisation of spent mushroom compost in animal feeds. *Biotechnology Technology* **52(1):** 89–91.

Acronyms

AAS	Atomic absorption spectrophotometer
Al	Aluminium
AMD	Acid mine drainage
BC	British Columbia
BNC	Bayonet Neill–Concelman
BOOM	Decree on the Use and Quality of Other Organic Fertilisers
$CaCO_3$	Calcium carbonate
CAD	Centralised anaerobic digester
CAN	Calcium ammonium nitrate
Cd	Cadmium
CMGA	Canadian Mushroom Growers' Association
CRM	Certified reference material
Cu	Copper
DEFRA	Department for Environment, Food and Rural Affairs
DEP	Department of Environmental Protection
DETR	Department of the Environment, Transport and the Regions
DIC	Dissolved inorganic carbon
DOC	Dissolved organic carbon
DSR	Dissimilatory sulphate-reducing
EC	Electrical conductivity
Eh	Oxidation–reduction potential
Fe	Iron
IC	Ion-exchange chromatography
IPM	Integrated pest management
MFEMP	Mushroom farm environmental management plan
Mg	Magnesium
MINAS	Mineral Accounting System
Mn	Manganese
NRCS	Natural Resources Conservation Service
OSHA	Occupational Safety and Health Administration
PA	Pennsylvania
PAH	Polycyclic aromatic hydrocarbon

Pb	Lead
PCP	Pentachlorophenol
REPS	Rural Environment Protection Scheme
SAMD	Synthetic acid mine drainage
SEPA	Scottish Environment Protection Agency
SMC	Spent mushroom compost
TMF	Tailings management facility
US EPA	United States Environmental Protection Agency
Zn	Zinc

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government