MANAGING SPENT MUSHROOM COMPOST

Project 4444

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Summary

This project addressed how to manage spent mushroom compost (SMC), an issue of critical importance to the continued development of the Irish mushroom industry. The most important aim of the project was to devise a feasible strategy for the management of this material on an industry wide basis. There were two main components of the project, which were conducted in parallel. One analysed the structure of the mushroom industry and the logistics of handling, transporting and processing SMC. The other studied the agronomic properties of SMC in an effort to develop improved guidelines on the best use of SMC in crop production.

Our analysis of the SMC management problem led us to conclude that a centralised approach should be taken when developing the solution strategy. The model solution that was formulated is based on the establishment of centrally located depots for SMC collection, temporary storage and possible processing. This approach facilitates a variety of environmentally acceptable SMC end uses ranging from land application to incineration.

We examined a variety of possible end uses for SMC, including its use as an alternative fuel. In the immediate future, we believe the predominant end use for SMC will be as an organic manure for field crop production and as a soil conditioner in the landscaping industry. Uses of this type are in line with both Irish and EU legislation regarding waste management. Our analysis suggests

that tillage and horticulture offer the best promise for realising the beneficial properties of SMC.

We have tested SMC on field crops such as winter and spring wheat and potatoes and on glasshouse crops such as tomatoes. These experiments have shown that SMC increases soil organic matter and improves soil structure.

SMC is a very effective source of K and P and also provides trace elements. It makes a contribution to N nutrition but most of the N does not become available to the crop in the first year. For best results therefore, supplementary N must be applied.

Overall, our results indicate that SMC can be used with beneficial effects in field crop production.

The mushroom industry should move forward with establishing centralised SMC handling facilities to enable the efficient collection, temporary storage, further processing and transportation of SMC to end users.

An education and awareness campaign should be conducted amongst farmers, in areas removed from mushroom production, to introduce them to the benefits of SMC and ways to effectively utilise this material.

Introduction

The mushroom industry has been the most spectacular success of Irish horticulture in recent years. It produces IR£85m worth of mushrooms per year of which 70% are exported. Full time employment in the mushroom industry in 1998 was 1,400 with another 3,500 part time jobs, underlining this industry’s importance in providing employment in rural areas.

The Irish system is based on the centralised production of mushroom compost which is then distributed, spawned or spawn run and in plastic bags, to a large number of mushroom growers, called satellite growers. These growers, who produce the mushrooms on small to medium size units, utilise inexpensive insulated polyethylene covered tunnels. Once harvested, the mushrooms are supplied back to the compost manufacturer who markets them. The system combines the advantages of large scale production of the compost, a highly mechanised and specialised process, with small production units utilising family and local labour as mushroom harvesting is extremely labour intensive. It produces mushrooms of high quality and long shelf-life.

The fact that marketing of the mushrooms is carried out largely by the compost manufacturers means that the marketing is far more organised than for any other Irish horticultural product.

Location of the industry

The data on mushroom compost usage and number of mushroom farms (Table 1) show that the industry is widely distributed throughout the country but with a great concentration in Monaghan (24% of production) followed by Cavan (11%), Roscommon (9%), Mayo (8%) and Donegal (7%). Other important mushroom producing counties are Wexford (6%), Kildare (5%), Meath (4%), Louth (4%) and Galway (4%).

Mushroom production system

Mushroom compost is manufactured from wheaten straw and poultry manure with the addition of water and gypsum (calcium sulphate). These undergo composting and pasteurisation processes after which the compost is selective for the mushroom fungus. The compost is then spawned with mushroom mycelium filled into polyethylene bags, each containing 20 kg of compost, and delivered to the mushroom farms. The bags are laid out on a concrete floor in an insulated polyethylene-clad tunnel. When the mushroom mycelium has colonised the compost, a 5 cm layer of peat mixed with ground limestone is placed on top. This casing layer induces formation of the sporophores or mushrooms. About a week later harvesting the mushrooms commences and this continues for about four to six weeks. The whole process takes 10-12 weeks allowing about 5 crops per year.

Table 1 : Amount of compost used and the number of farms in the mushroom industry in Ireland in 1998. (Source: Teagasc, Census of mushroom production)

County	Tonnes of compost	No. of farms
Monaghan	68,400	152
Cavan	30,705	59
Roscommon	26,150	60
Mayo	22,067	40
Donegal	19,200	36
Wexford	17,543	34
Kildare	14,248	26
Meath	12,280	15
Louth	10,280	19
Galway	10,225	20
Longford	9,850	21
Westmeath	7,570	14
Clare	5,452	5

County	Tonnes of compost	No. of farms
Wicklow	4,059	6
Carlow	3,544	8
Offaly	3,233	8
Leitrim	2,985	7
Cork	2,210	4
Dublin	2,045	4
Waterford	1,870	3
Sligo	1,723	4
Kilkenny	1,575	3
Tipperary	1,158	3
Laois	918	2
Kerry	756	1
Total	280,046	554

An inevitable by-product of mushroom production is the spent mushroom compost (SMC) which remains after the mushroom crop has ceased harvesting. In 1999 approximately 280,000 tonnes of mushroom compost was used in the republic of Ireland for mushroom production. During the cropping cycle there is a continuous loss of dry matter from the compost due to removal by the mushrooms and continued breakdown of the organic material.

Starting from 1 tonne of fresh compost with a dry matter content of 30% (300 kg DM), the loss of dry matter is of the order of 50 kg. This weight loss is countered by the addition of the casing layer so that the weight of the spent compost may be similar to the weight of incoming fresh compost.

Composition of SMC

The average composition of 13 samples SMC obtained from a number of producers in 1997 is shown in Table 2. In the water soluble nutrients, the outstanding feature is the very high level of K and electrical conductivity (EC). EC is a measure of the total water soluble salt content and in a typical commercial growing medium would be about 120-150 mS/m.

There was more variation in the K level than was the case with other nutrients and this is probably a consequence of the fact that nearly all the K is water soluble and can be readily leached. The EC level in the SMC was very closely related to the available K level and this is illustrated in Figure 1. This suggests that it is the K in the SMC that is mainly responsible for the high salt level.

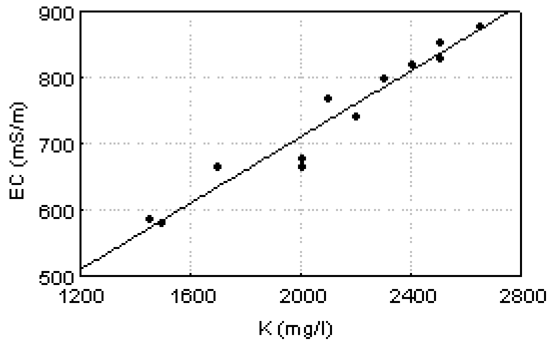

Figure 1 : Relationship between electrical conductivity (EC) and water soluble K in SMC.

The total nutrient levels, along with the dry matter content, indicate an average content of 8.0 kg N, 3.9 kg P and 7.9 kg K per tonne of fresh SMC.

Assuming that the weight of the SMC is similar to that of the mushroom compost used, then the total amount of N in the SMC generated by the mushroom industry amounts to 2,240 t and that of P to 1,092 t. These nutrients are, in fact, transfers from other sectors of agriculture, namely poultry and tillage, but they have to be managed by the mushroom industry.

In comparison, the amount of N and P produced by farm animals per annum in Ireland, both housed and unhoused, is 603,000 and 95,000 tonnes respectively. However, the fact that mushroom production occurs in relatively concentrated regions where there may already be an abundance of nutrients from other sources makes a challenge of managing even the relatively modest quantities of N and P in SMC.

Table 2 : Composition of Irish spent mushroom compost

Constituent	Mean	Minimum	Maximum
Available nutrients[*]			
PH	6.6	5.9	7.4
EC (mS/m)	750	580	903
NO_3-N	62	21	87
NH_4-N	49	2	133
P	31	11	73
K	2,130	1,450	2,650
Na	253	160	350

Constituent	Mean	Minimum	Maximum
Available nutrients[*]			
Cl	118	40	157
Total nutrient content			
N (g/kg DM)	25.5	23.1	28.2
P	12.5	10.3	15.3
K	25.0	17.0	32.0
Ca	72.5	42.0	99.0
Mg	6.7	5.2	8.7
S	15.9	9.6	22.0
Na	2.67	1.70	3.20
Fe (mg/kg DM)	2153	1300	3200
Mn	376	320	460
B	37	32	43
Cu	46	36	65
Zn	273	220	390
Bulk Density (g/l)	319	257	395
% Dry Matter (DM)	31.5	24.1	35.1
% Ash	35.0	30.4	41.5

[*] mg/l in a 1½ distilled water to 1 SMC volume extract.

In the past, this challenge has not been addressed very successfully.

Like so many organic by-products from agricultural and horticultural systems, some of the constituents in SMC cause difficulties for managing the wastes. Such is the case with P in SMC. Due to the heightened concern over eutrophication of Irish waters, there is increasing scrutiny of the use of P in agricultural systems. Because of this, and a general improvement in the soil P status of Irish soils over the last number of years, the quantities of P that are recommended for crop production have recently been revised downward.

Other characteristics of SMC

SMC exhibits many of the characteristics typical of other organic waste by-products;

- relatively low bulk density,
- high moisture content,
- high organic matter content,
- moderate plant nutrient content,
- “unbalanced” distribution of major plant nutrients.

In addition, a number of factors related to the nature of the mushroom industry complicate the SMC management problem. Mushroom production can operate independently of a land base and many producers have only a small area of land. This is good in the sense that it has allowed entrepreneurs with limited capital and land resources to become successful mushroom producers. However, it also means that they often do not have sufficient land to safely absorb the SMC generated.

The mushroom industry is concentrated in relatively few production centres. Over one third of the industry is located in the Monaghan/Cavan area where there are also concentrations of poultry and pigs. The concentration of so many sources of P in a relatively small region throws extra pressure on available land for spreading organic wastes.

Although the industry is concentrated, the size of the individual production units is quite small. Therefore SMC is produced in a dispersed manner within the region of concentration which makes it difficult to handle on an organised bulk basis.

SMC can contain organisms that are potentially pathogenic to actively growing mushrooms. This implies that any handling of SMC, which would facilitate dispersal of spores, should be carried out at a safe distance from mushroom farms.

In the Irish system of mushroom cultivation the plastic bags also constitute a serious waste management and potential pollution problem. Over the country, about 14 million plastic bags are discarded annually. Typically these are disposed of in landfills or incinerated.

SMC is generated constantly, but many traditional outlets for SMC are available only intermittently. Mushroom growers operate within a highly competitive marketplace in which increased costs, such as for SMC management, are extremely difficult to absorb, due to narrow profit margins.

This combination of factors creates logistical impediments to managing SMC in a manner that is environmentally sensitive, yet economically efficient.

Project aims and scope

The main aims of the present project were ;

- to study the problems of handling, processing and transport of SMC from the mushroom farms to the end user,
- to quantify the benefits of using SMC as a manure on the physical properties of the soil, on soil fertility and on crop performance,
- and through these, to enable the continued development of the mushroom industry in a sustainable way by providing environmentally friendly re-use of the spent compost.

We divided our activities into two main areas. One part studied the logistics of handling and transporting SMC and evaluated a range of end uses for SMC. An analysis of the availability of suitable land for spreading SMC was carried out. A model solution was developed and costed for the Monaghan area.

The second part studied the effects of SMC on soil fertility and physical properties. The availability of nutrients in SMC to plants was investigated. The effects of SMC when used as an organic manure on the performance of glasshouse tomatoes and lettuce, and field potatoes and cereal crops was studied.

Overcoming logistical impediments to improved smc management

Study Approach

We used various techniques to evaluate possible SMC management strategies and develop a solution satisfactory for implementation on a regional basis. To ascertain the current situation regarding SMC management, mushroom production constraints, and other industry information, we met with representatives from all levels of the mushroom industry. We also met with numerous other stakeholders that were believed to have a potential role in SMC management, including members of local and national government, the food industry and other commercial enterprises that ranged from electricity supply to cement manufacture. Stakeholders with whom we had considerable contact are shown in Table 3.

Table 3 : Stakeholders in SMC management interviewed during the study.

Public Sector	Private Sector	
Bord Glas BioResearch Ireland Enterprise Ireland ESB OSI EPA Monaghan County Council DunLaoghaire Rath-down County Council	Monaghan Mushrooms, Ltd. Barretstown Fruit & Veg., Ltd. Goldshield Mushrooms, Ltd. Irish Mushroom Growers Assoc. Irish Farmers Association	Genesis Composting Ltd. Vermiculture Research Scientist Methogen (anaerobic digestors) Lakeland Biofuels M. Martin Landscaping Irish Cement, Ltd. Papertech, Ltd. Monsanto

We also undertook a comprehensive review of available literature, both scientific and trade, as a means of evaluating SMC management strategies in use elsewhere. We conducted laboratory studies, most notably investigations of biodegradable compost bags and SMC drying experiments, to develop information we believed was crucial to our assessment of one or more potential solution strategies.

Solution Specifications

Whereas the classical definition of “logistics” is associated with the military science of procuring, maintaining and moving material and personnel, we defined the logistics of SMC management as including virtually anything that influenced the movement of SMC from mushroom tunnels to an “acceptable” end use. We developed a specification for an acceptable SMC end use, *i.e.*, it is one that:

- conforms to environmental legislation/regulations;
- is compatible with current mushroom production practices;
- is sustainable environmentally and economically;
- can accommodate large quantities SMC alone or by integrating with other acceptable uses;
- is readily available (*e.g.*, proven technologies); and
- can be implemented continuously in Irish climatic conditions.

Biodegradable Compost Bags

The plastic bags normally used to contain mushroom compost inhibit every conceivable end use of SMC. A biodegradable bag would, therefore, facilitate any SMC management option ranging from simple land application to incineration.

An initial exploratory trial was conducted to assess the potential of (1) kraft paper bags coated with Biopol®, a biodegradable plastic film; (2) hemp bags preserved with pentachlorophenol; and (3) woven polypropylene without UV degradation inhibitors. Two Biopol® bags, 4 hemp bags, and 5 woven polypropylene bags were filled with spawned compost and placed on the concrete floor of a standard mushroom tunnel for a typical growing cycle of 8 weeks. Strips 300 mm long and 10 mm to 24 mm wide were taken at random locations from the sides of each bag at weekly intervals. These samples were tested for tensile strength according to British Standards method 2576 using a Model 441 Instron Universal Testing System. Results are summarised in Table 4. In short, Biopol® bags decomposed too quickly and also appeared to stimulate the growth of green mould (*Trichoderma*). Polypropylene bags did not decompose rapidly enough. Hemp bags showed signs of decomposition but remained intact so that they could be removed from the tunnel using traditional procedures, without spilling their contents of SMC.

Table 4 : Performance of alternative compost bags after 8 weeks in production conditions.

Measure	Biopol®	Polypropylene	Hemp
Loss of tensile strength	48%	15%	37%
Appearance	Disintegrated at floor	No apparent change	Rotting at floor, but still intact
Trichoderma	Heavily infected	Infection not obvious	Moderately infected

Based on results from the exploratory trial, a more comprehensive evaluation of hemp bags was undertaken using a Latin square statistical design. Forty hemp bags were compared against 40 polyethylene bags. The standard treatment was 20 polyethylene bags filled with spawned compost and placed directly on the concrete floor of a standard mushroom tunnel. Likewise, 20 hemp bags were treated similarly. In addition, 20 hemp bags were placed on wire mesh pallets that kept the bags 6 mm off the tunnel floor. Twenty polyethylene bags were treated similarly. Over the course of a 10-week growing cycle, strips 200 mm long and 50 mm wide were taken at random locations from the sides of each bag at weekly intervals. These were tested for tensile strength according to British Standards method 2576 using a Model 441 Instron Universal Testing System. Mushroom yield was also measured. Hemp bags were also monitored for strength changes after an additional 8 weeks in an unmanaged compost heap of discarded SMC.

Results are shown in Table 5. Hemp bags lost two-thirds of their tensile strength over the 10-week production cycle, nevertheless they were still stronger than plastic bags at the end of the trial. Hemp bags supported off the concrete floor appeared to be more structurally sound than those placed directly on the floor, but bags in both treatments remained intact and could be discarded from the tunnel in the traditional manner without spilling their contents of SMC. Hemp bags continued to decompose in an unmanaged compost heap, as indicated by a further 55% loss of tensile strength over 8 weeks. From a structural standpoint, hemp bags are a suitable biodegradable alternative to the polyethylene bags currently in use. Problems with a higher than normal *Trichoderma* infestation in the hemp bags, as well as a decrease in mushroom yield, will have to be addressed before these bags will be accepted by the industry as replacements for plastic bags. Cost differences in the two bag materials also must be addressed. Ignoring the management costs of proper plastic disposal, plastic bags appear to be 10p to 12p per bag cheaper than hemp bags. This price differential would be much smaller if the environmental costs associated with plastic bags were included in their purchase price.

Table 5 : Performance of hemp vs. polyethylene compost bags after 10 weeks in production conditions.

Measure	Treatments			
	Plastic on Floor	Hemp on Floor	Plastic on Pallet	Hemp on Pallet
Loss in tensile	9%	68%	10%	64%

Measure	Treatments			
	Plastic on Floor	Hemp on Floor	Plastic on Pallet	Hemp on Pallet
strength*				
Trichoderma infection	7%	20%	7%	20%
Yield**	224	197	236	183

**At the end of 10 weeks, hemp bags were approximately 86% stronger than plastic bags.*

***kg mushrooms / tonne compost*

Drying SMC

At *ca*. 65 - 70%, the moisture content of SMC is an impediment to all potential end uses of the material. On a mass basis, two-thirds of the transportation costs involved in moving SMC are associated with transporting water. The high moisture content is particularly problematic if SMC is considered as an alternative fuel.

An efficient, yet inexpensive means of drying SMC would facilitate all end uses. We examined three means of drying SMC: uncovered ambient drying, covered ambient drying, and forced drying. For the ambient drying, three depths of SMC (4, 6 and 8 cm) were placed in perforated plastic drying trays 24 cm wide and 34 cm long in a completely randomised design. The trays were placed out-of-doors on a grassed surface in a sheltered area in south Dublin. The uncovered trials were conducted by exposing the trays to naturally occurring climatic conditions (sunshine, rainfall, & wind) for a period of approximately one month. Covered trials followed immediately and utilised the same trays of SMC as used previously, however, the trays were protected from rainfall by a tarpaulin suspended *ca*. 10 cm above the trays. During each trial, samples of SMC were removed from random locations in each tray at approximately weekly intervals, and analysed for moisture content gravimetrically.

Typical results of the two sets of trials are shown in Figure 1 and Figure 2. No statistically significant differences were observed in SMC drying due to the depth of compost used. The lack of differences was probably due to relatively small sample size used in the experiments (3 replications of each treatment); the small differences in the depths of SMC examined; and the relatively large variations in moisture content of the SMC during the trials. In short, uncovered ambient drying was not found to be a reliable mechanism for reducing the moisture content of SMC (Figure 2). However, when rainfall is excluded through the use of a cover over the SMC, ambient drying can produce consistent and predictable moisture content reductions (Figure 3). Nevertheless, the capital costs of such a structure to accommodate large volumes of SMC could be prohibitive, if drying were the only operation conducted.

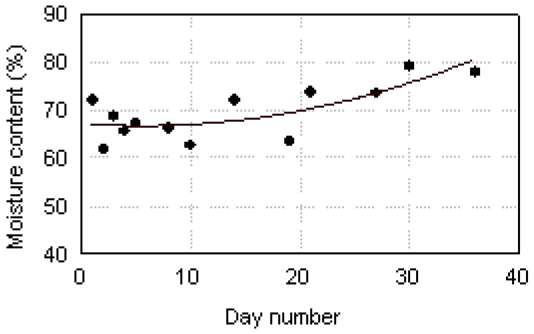

Figure 2 : Typical drying curve of SMC under ambient climatic conditions (Dublin in October/November), rainfall not excluded.

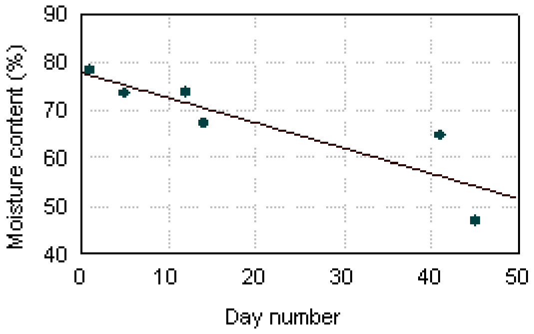

Figure 3 : Typical drying curve of SMC under ambient climatic conditions (Dublin in November/December), rainfall excluded.

A contrast to ambient SMC drying was examined using a laboratory scale rotary dryer 300 mm in diameter and 320 mm long rotating at approximately 30 rpm. SMC at approximately 70% moisture was placed in the rotary dryer through which ambient air (*ca*. 15°C and 50% relative humidity) was forced at approximately 1.5 m s^{-1} for 6 hours. Samples of SMC were removed from the dryer at hourly intervals and analysed for moisture content gravimetrically.

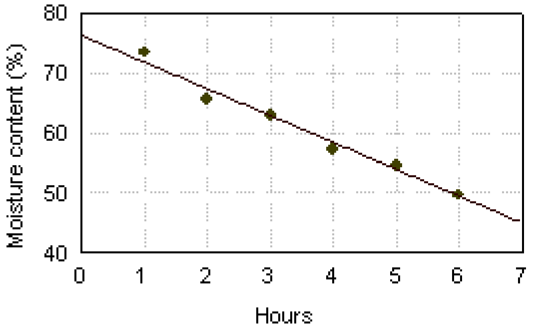

Figure 4 : Typical drying curve of SMC using forced air (rotary dryer) at ambient temperature and humidity

Typical results are shown in Figure 4. The results clearly demonstrate the viability of forced air drying of SMC, even using unheated air. Although capital expense would be encountered in using this drying technique, the same drying could be accomplished in 6 hrs as would be accomplished by covered ambient drying in 30 days. Drying times would be shortened using heated air, however this would come at the cost of an energy input, if a source of waste heat were not available.

SMC as an alternative fuel

Incineration of SMC has been an often-discussed management option since Teagasc conducted an analysis of nutrient flows in County Monaghan in 1994. Incineration would provide a continuous end use for SMC, irrespective of time of year or weather conditions. The resulting ash would become the management responsibility of those operating the incinerator. During this study, no data were available on SMC incineration characteristics.

Consequently, limited testing of SMC was conducted using an oxygen bomb calorimeter to determine the heat of combustion (*i.e.*, energy value). Relatively consistent values of *ca*. 9 MJ/kg DM were obtained for the samples tested. These compared to a literature value of approximately 13.5 MJ/kg DM cited in Teagasc’s 1994 Monaghan study, and a value of 5.5 MJ/kg DM obtained by the ESB using calorimetry. However, the samples would not ignite at 65% moisture content, reinforcing the need to dry SMC, or blend it with other dry feed stock, prior to incineration.

A desk study was conducted to make a cursory evaluation of the potential for SMC to become an alternative energy source for the cement industry. Results were encouraging. Cement manufacture requires large energy inputs, and there is typically waste heat from the process that could be used to dry the SMC. In addition, the magnesium and calcium contained in SMC are, in fact, raw materials for cement. Likewise, phosphorus in the SMC, when absorbed in the pre-heater of the cement kiln, can be balanced by potassium in the alkali cycle. Laboratory tests confirmed that SMC can be transported pneumatically, an essential requirement for loading the kilns. Air velocity of 5 m s^{-1} was shown to satisfactorily move SMC at low moisture contents. Lastly, laboratory tests also showed that dried SMC has a specific heat on the order of 0.25 cal $g^{-1}\,^{o}C^{-1}$, which is in the range of that for coal, cellulose, charcoal and coke. These findings suggest that SMC may be burned successfully at cement manufacturing plants, without damage to cement quality, and at relatively low cost.

Viability of other SMC management options

Numerous end uses were evaluated against the criteria set forth above. These included:

- land application of SMC to agricultural land;
- use of SMC in the horticultural / landscaping industry;
- vermiculture;
- briquetting and pelleting as a home fuel source;

- anaerobic digestion in on-farm digesters;
- processing for the home and garden centre market and/or export;
- recycling into casing material.

For one or more reasons, only the first two options above met the criteria developed for an acceptable SMC end use. Briquetting and anaerobic digestion failed for technological reasons. Re-use of SMC in the mushroom industry was not acceptable because of hygienic considerations. Vermiculture was not deemed capable of accommodating huge quantities of SMC. Home and garden centres are a potential end use (as is export to the UK), however the viability of these outlets would be extremely price-sensitive. Despite being technically feasible, the potential use of SMC in the landscaping industry is still largely un-quantified and would require a comprehensive market survey to assess the level of demand.

Land Application of SMC

Land application of SMC is attractive as an end use for SMC because it has been practised successfully for a number of years. However, as concern over eutrophication of Irish waters has increased, the use of phosphorus in agricultural systems has come under closer scrutiny. Phosphorus is, therefore, the land limiting constituent in SMC. Most crops on soils of moderate to good P status require very little P from external sources.

Thus, in areas where mushroom growers are concentrated, such as Co. Monaghan, need outstrips the supply of suitable land on which to apply the quantities of SMC generated. Weather and cropping considerations further restrict the availability of land that can receive SMC. In addition, there is competition for suitable spreading areas posed by other organic sources of nutrients, most notably manure from livestock.

We conducted cursory mass balance analyses (based on phosphorus) of each county to identify those that had the potential to utilise phosphorus contained in SMC. The potential need for phosphorus in a county was calculated simply as the difference between crop demand for P and P supplied in animal wastes within a county.

Crop demands for external sources of P are a function of soil P status. Sufficiently detailed national data on soil P levels do not exist to facilitate a precise estimate of the demand for P exerted by crops produced in the country. As a conservative estimate of crop demand we assumed soils were at various soil indices, and assigned P application rates that are recommended at these indices for environmentally friendly farming (as described in the Rural Environment Protection Scheme).

Likewise, we estimated the amount of P contained in animal wastes using “book values” from REPS to describe manure characteristics. Data on crop production and animal populations in each county were obtained from the Central Statistics

Office. We ignored P inputs from commercial fertilisers, as we had no data on these sources.

Assuming that all soils were at a soil P index of 3 (the goal of REPS), our analysis showed that all counties except Dublin had a surplus of P from animal manure alone (Figure 5). However, if it were assumed that all soils were at a soil P index of 2, crop demand for P would exceed the supply of P provided in animal manure in all counties except Monaghan. As expected assuming various ratios of soils at index 2 and at index 3 produced intermediate demands. Interestingly, assuming a 50:50 distribution of soils in soil P index 2 and in soil P index 3 still resulted in a surplus of P in all counties except Dublin, Kildare, Louth, Clare, Leitrim, and Sligo (Figure 6).

Such an analysis is obviously an oversimplification. For example, even within counties that "on average" have a true P surplus, it would be logical to find individual farms that have a genuine need for phosphorus. However, this cursory analysis illustrates the importance of a thorough soil-testing programme in order to determine P application rates. It also illustrates the potential difficulty of finding suitable areas within the country that can accept SMC. Figure 6 suggests that these areas are likely to be in counties with significant tillage lands.

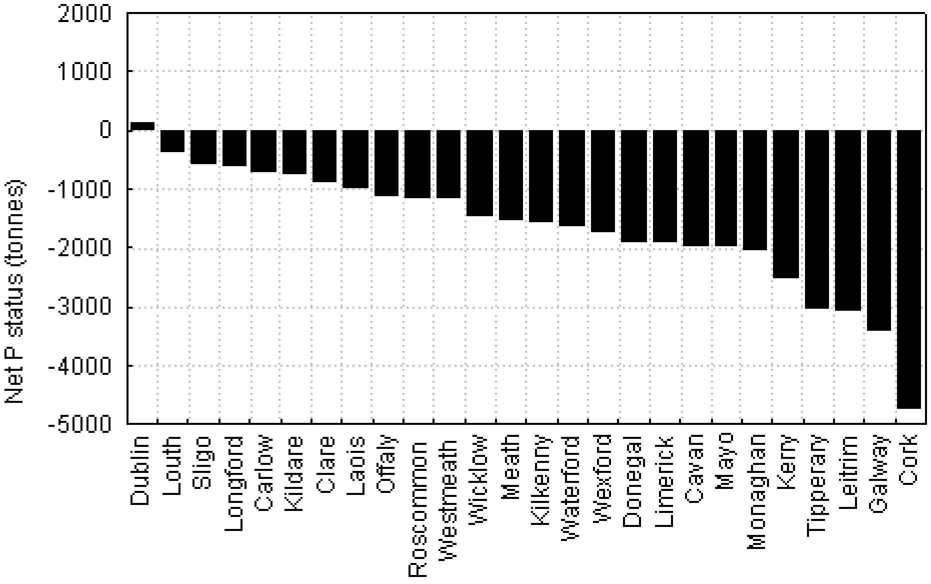

Figure 5. Differences between crop demand for P and P available in animal manure, assuming all soils at soil P index 3. Negative values indicate P supply in animal manure exceeds demand for P by crops.

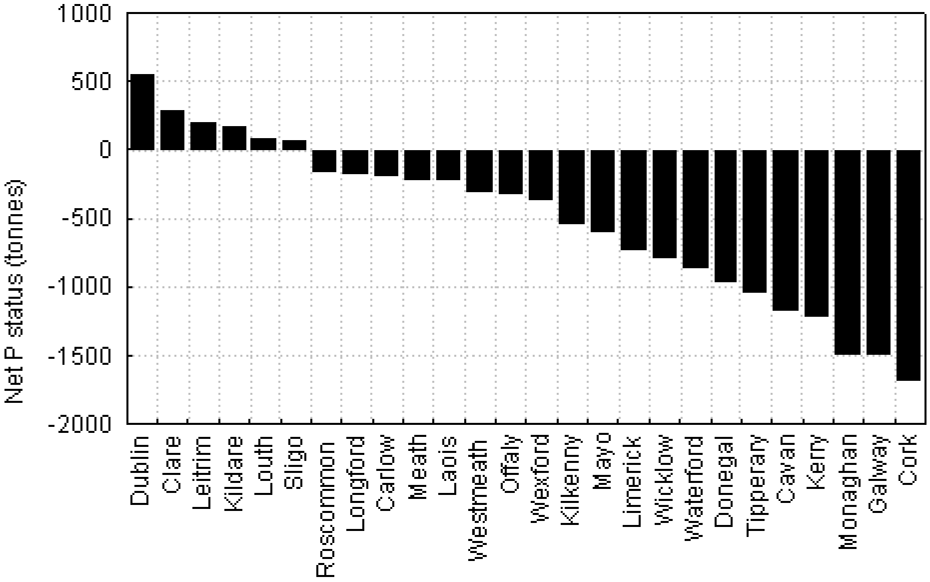

Figure 6 : Differences between crop demand for P and P available in animal manure, assuming 50% of soils at soil P index 3 and 50% of soils at soil P index 2. Negative values indicate P supply in animal manure exceeds demand for P by crops.

Model SMC Management Solution

To develop a model SMC management strategy, we used Co. Monaghan as a representative of those regions that have high concentrations of mushroom (and SMC) producers. We based the strategy on the solution specifications described previously.

On balance, our view was that land application of SMC was the most immediately available and environmentally sustainable end use for large quantities of SMC. Whereas this end use could encompass agricultural and landscaping demands, for purposes of illustration we sought a model solution oriented toward application of SMC to agricultural land.

By performing a mass P balance similar to that described previously, we determined where SMC might be effectively used. Teagasc data show that the mean soil P content of all non-REPS soil samples analysed is *ca*. 8 mg l^{-1}, which places these soils at a soil P index of 3. Given that achieving a soil P index of 3 is the also goal of the REPS programme, we estimated the crop demands for P based on REPS recommendations for soil P index 3. However, we modified our estimate of the amount of P supplied in animal manure by counting only that P produced by animals during the time they were confined. The rationale for this assumption was that P produced during grazing would naturally be recycled in the plant-animal system. This is a debatable simplification, but it reduced the amount of P that must be managed from cattle and sheep by 63% and 97%, respectively. The resulting balance identified a number of counties that could utilise P from any number of sources, but particularly SMC (Figure 7.) Of special interest are the counties that are within approximately 100 km of Monaghan (*i.e.*, Dublin, Kildare, Louth, Meath, Leitrim, Roscommon, Westmeath, and Longford). From a transport perspective, these would be the most logical areas to target for the distribution of SMC.

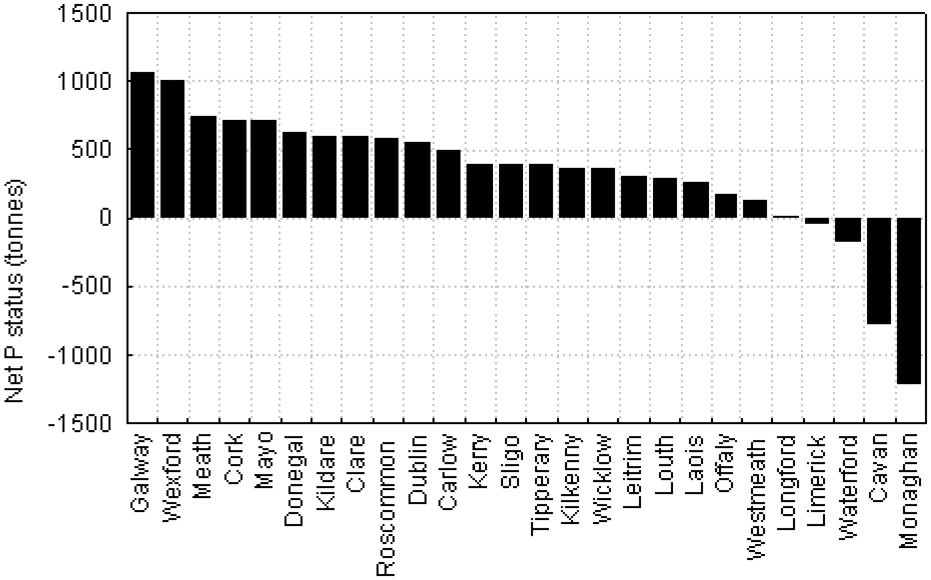

Figure 7. Differences between crop demand for P and P available in animal manure, assuming all soils at soil P index 3, but only 37% of cattle manure and 3% of sheep manure needs to be "managed". Negative values indicate P supply in animal manure exceeds demand for P by crops.

SMC collection, further processing and distribution.

SMC is generated continuously, yet land is available to receive SMC only intermittently. This implies the need for some system of SMC storage. Onsite SMC storage (in fact, storage within 2 km of an active mushroom production facility) is not possible for hygienic reasons. Further, mushroom growers are widely dispersed geographically and have limited financial resources to implement a frequent SMC haulage scheme. All mushroom producers have the same objectives regarding SMC management.

The scenario described above is completely analogous to the management of domestic refuse. Domestic solid waste is collected from small generation points (households) that are dispersed within a defined catchment area, and the waste is then taken to a centralised point for possible further processing (and/or an ultimate end use). Our SMC management strategy was based on this well-proven model. We envisioned one or more centralised SMC depots that would receive SMC from producers *via* refuse freighters (*i.e.*, compactor trucks) such as are used for domestic waste management. These vehicles would need to be disinfected when entering and exiting mushroom production facilities.

In our model solution based on Co. Monaghan, we determined potential sites for centralised SMC depots using industry supplied data describing the locations of mushroom growers and their capacities for generating SMC. Using a geographical information system (GIS) we were able to locate optimum sites for depots according to various criteria. Figure 8 illustrates the location of a depot that would be at the centre of the mass of SMC generated in Co. Monaghan annually. Typically, the centre of mass of waste generated at dispersed locations represents the optimal location of a centralised facility based on transport considerations.

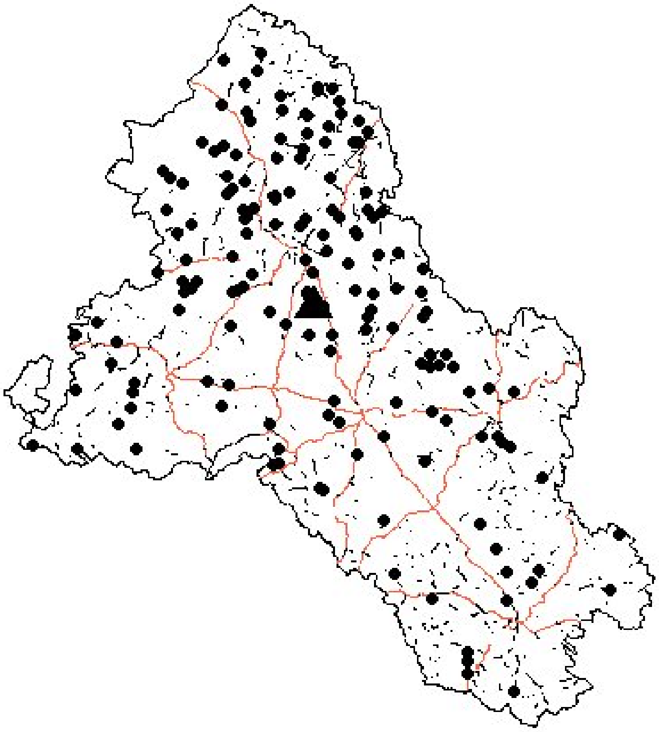

Figure 8. Distribution of mushroom growers (circles) and location of centre of mass of SMC production (triangle), County Monaghan (1996 data).

However, in locating a centralised SMC handling depot, a number of other considerations would affect such a decision; among these are quality of the road network, predominant wind direction and speed, hygienic considerations, public concerns, planning permission constraints and regulatory requirements.

We developed a theoretical design of a centralised SMC handling facility capable of accommodating 650 t SMC wk^{-1}. A facility of this size could handle one-half of the annual quantity of SMC produced in Co. Monaghan. At a minimum, four crucial tasks would be accomplished at the SMC handling facility:

- receipt (*via* compactor truck) and mechanical de-bagging of SMC;
- storage of SMC for the months of November to February;
- further composting of SMC during storage periods; and
- organised distribution of SMC to end uses *via* an affiliated distribution network and/or private hauliers.

Additional operations could be accomplished at the centralised SMC depot as dictated by market demand. For example, SMC could be blended with other ingredients to specifications required by the landscaping industry. Or, the depot could facilitate management of other solid wastes (*e.g.*, composting of green wastes) in a joint venture with the County Council.

Cost of a centralised SMC facility

A centralised SMC depot would achieve economies of scale in the management of SMC not possible with management approaches undertaken by individual growers. In addition, trained personnel would be responsible for operating the facility in a quality-assured manner. This would alleviate SMC management problems of the past that have tarnished the environmental image of the industry and made it more difficult for new growers to obtain planning permissions. The cost of achieving these benefits would depend on the size of facility and on the way in which it was operated. We developed cost estimates for the 650 t wk^{-1} facility described above operated using two composting strategies: high capacity bunkers and aerated piles. Bunkers would facilitate odour treatment using biofilters, but we did not estimate the costs of such devices. Odour control in the aerated pile system would be accomplished by mechanically turning the piles using a front-end loader. The estimated costs of each system, not including labour costs, are shown in Table 6.

These costs could be shared among those utilising the scheme. Annual operating costs would be *ca*. £250,000 for the size of facility that could serve approximately 100 growers in Co. Monaghan. Shared equally, these costs would represent an annual SMC management cost of £2,500 per producer. Growers currently pay *ca*. £150 per tunnel per clean-out for unlicensed contractors to remove SMC. Assuming 10-wk production cycles, each tunnel would be cleaned out 5 times per year, at an annual cost of £750. For a grower that had 4 mushroom tunnels, centralised and quality assured SMC management would cost very little more than the relatively haphazard management strategy that currently exists. However, this cost analysis excludes the initial capital cost of a centralised SMC depot and is based on several assumptions. Also, it ignores any potential economic value of the processed SMC. As in any business endeavour, a more thorough economic analysis would be warranted before proceeding with this approach. It would seem likely, however, that the initial costs of a centralised depot would have to be subsidised, perhaps by local or national government.

Table 6 : Estimated costs for a 650 t wk^{-1} centralised SMC depot using two composting techniques.

Cost Category	Bunker System	Aerated Pile
Depot structure & machinery	£1,080,000	£ 625,000
Compactor truck (30 m^3)	130,000	130,000
Running costs	22,000 p.a.	22,000 p.a.
Contract haulage, 20 loads per week, 24 t truck	202,800 p.a.	202,800 p.a.

Smc in crop production

Introduction

If SMC is to be used successfully in crop production it is necessary to know what contribution the plant nutrients in SMC will make towards the nutrition of the crop and what effects SMC may have on the physical properties of the soil. A number of experiments under glasshouse conditions and also in the field were carried out to provide information on these aspects.

Nutrient release pattern of SMC

SMC, of known composition, was mixed with silica sand and filled into 20 cm deep plastic columns. The columns were placed in funnels with bottles underneath to capture any drainage water. They were covered with perforated plastic to prevent evaporation. Once a week for seven weeks the columns were washed with distilled water. The drainage water was collected and analysed for N, P and K.

The cumulative amounts of N, P and K recovered in the leachate, expressed as a percentage of the amounts of these nutrients added in the SMC, are shown in Figure 9.

Nearly all the K is recovered in the first two leachings whereas only a small proportion of the N and P is recovered over the period of the experiment.

The results indicate that the bulk of the K in SMC is water soluble and therefore immediately available to plants. The K in SMC can be considered equivalent to the K in water soluble inorganic fertiliser. The position for N and P is more problematic.

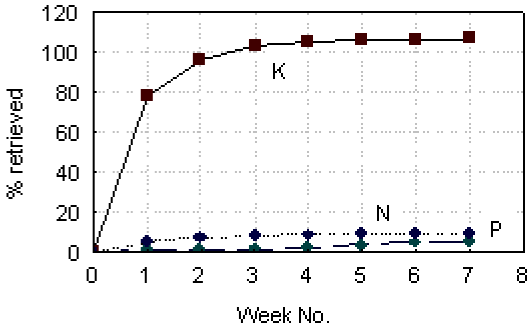

Figure 9 : Cumulative recovery of nutrients from successive leaching of SMC with distilled water as % of total contained.

SMC as a source of N and P

The aim of these experiments was to study the availability to plants of the N and P in SMC and to compare it with that of inorganic fertilisers. The test crop used was perennial ryegrass (*Lolium perenne* cv. Spelga) which was grown in sphagnum peat in 2-litre pots . In the N experiment, SMC and CAN were added to peat to provide 50, 100, 200, 400 and 800 g of N per m^3 of peat. The peat had previously been dressed with lime and fertilisers to provide all nutrients except for N. Subsequently, throughout the experiment, the pots were irrigated with a solution containing P and K. The rates of P were 25, 50, 75, 100, 125 and 150 g per m^3 of peat and the sources were SMC and superphosphate. In this experiment the peat was dressed with lime and all nutrients except P and the subsequent irrigations contained N and K.

The pots were placed on glasshouse bench in saucers to allow any leachate to be recycled. The grass was harvested when the more vigorous treatments reached about 20 cm in length. Then it was cut back to 2 cm and allowed to re-grow. Harvesting continued over 18 months until growth virtually ceased in all treatments. The cut grass was oven dried to a constant weight and then ground and analysed.

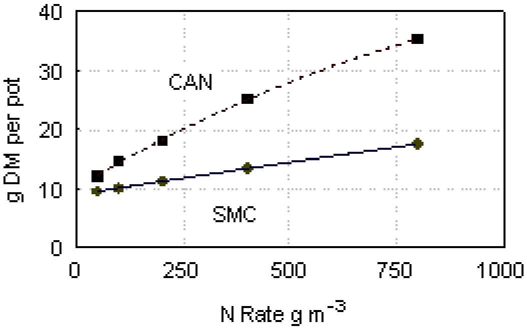

Figure 10 : Comparison of SMC and CAN as N sources for growth of grass.

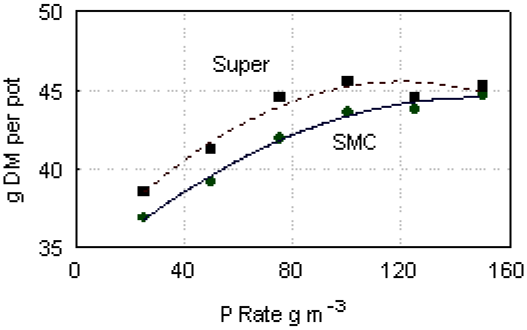

Figure 11 : Comparison of SMC and superphosphate as P sources for growth of grass.

There was a nearly linear response to the addition of N either as SMC or CAN (Figure 10). However there was a very obvious difference in the response to the two N sources. Over the rates of N applied, the rate of grass dry matter (DM) production per gram of N applied was 15.2 for CAN and 5.3 for SMC. CAN is therefore a more efficient source of N. The difference between the two fertilisers was more marked when the N retrieval rates were compared. In the CAN treatments 75% of the N applied as CAN was retrieved in the harvested shoot samples while this dropped to 12% in the case of SMC. Particularly in the early harvests the CAN treatments had much higher N concentrations in the leaf.

The yield response curves to the addition of P were similar for SMC and superphosphate with the superphosphate treatments only just out yielding the SMC treatments (Figure 11). The proportion of P retrieved in the harvested leaf samples where superphosphate was the P source was 50%. In the case of SMC this was 29%. As in the N experiment this was accounted for by the superphosphate treatments having higher leaf P concentrations in the early harvests.

It was concluded that SMC, while not as efficient as superphosphate, was an effective source of P. While it makes some contribution to N nutrition, it would need to be supplemented by another source of N for optimum results.

Effect of SMC on glasshouse tomatoes

The objective of this experiment was to assess the suitability, under Irish conditions, of SMC for use as a soil amendment and nutrient source in protected cropping by its effect on the yield and quality of truss tomatoes and also its effect on soil structure and fertility.

SMC was applied at 0, 50, 100 and 200 t ha^{-1} and rotavated into the top 20cm of glasshouse soil in April. Tomato plants cv. Triton were planted, and the plants were given a standard feed (175 mg l^{-1} N, 293 mg l^{-1} K) from June 12 until the end of cropping. Six fruit were allowed to develop on each truss and whole trusses were harvested. Fruit was harvested and recorded twice weekly from July 28 to October 21. Fruit quality parameters, i.e. % soluble solids, titrateable acidity, electrical conductivity (EC) and K content, were measured by sampling 6 fruit per plot on a single picking. When cropping was complete undisturbed soil cores were taken using stainless steel sample rings (100cl volume) which were used to carryout a physical analysis using a sandbox apparatus.

The addition of SMC reduced the soil bulk density and increased the measured organic matter content (Table 7). SMC also increased the total pore space and improved the water holding capacity without any negative effects on aeration. The beneficial effect of SMC on soil structure was also evident in the ease with which the soil with the higher levels of SMC could be worked when taking samples.

Table 7: The effects of SMC on soil physical properties.

SMC Rate (t/ha)	Organic matter (%)	Bulk density (kg/l)	Pore space (%)	Content at pF 1 (%)	
				Water	Air
0	14.3	1.06	51.1	46.5	4.6
50	15.2	0.94	55.0	48.7	6.3
100	16.2	0.92	56.6	50.5	6.1
200	17.1	0.79	60.3	53.7	6.6

The addition of SMC had a positive effect on the fruit quality parameters, significantly increasing titrateable acidity and K levels (Table 8). These properties are closely associated with good flavour in tomatoes. The improvement in fruit quality was probably primarily due to the higher levels of K in the soil which has been well documented to improve fruit quality. In this experiment, levels of K were as high as 1140 mg l^{-1} at the high application rates of SMC. This is a level where yields might be expected to be depressed due to high salt levels. In this experiment however, that effect was possibly mitigated by improved soil structure and water holding capacity. There was no significant effect on fruit yield or on fruit size as measured by average weight.

Table 8: Effect of SMC on fruit quality and yield.

SMC rate (t/ha)	Soluble solids %	Titrateable acidity*	EC (mS/m)	K (mg/kg)	Mean fruit wt.(g)	Fruit yield (kg/ m^2)
0	5.5	7.8	653	2,267	85	11.8
50	5.5	8.0	665	2,333	84	11.8
100	5.6	7.9	673	2,333	87	11.8
200	5.6	9.2	703	2,467	84	11.9

** meq. per 100g fruit puree*

SMC gave positive results as a soil amendment for tomatoes. Its high available K content resulted in an improvement in fruit flavour parameters. It had no negative effects on fruit production and it improved soil structure.

Effect of SMC on greenhouse lettuce

Concern has been expressed about the use of organic manures in greenhouse cultivation about the possibility of high nitrate level occurring in leafy crops such as lettuce due to continued nitrification taking place particularly in autumn and early winter when soil temperatures under glass are still relatively high. To test whether this might be a residual problem like this with SMC a crop of lettuce was grown after the tomato crop.

After removal of the tomato crop the soil was carefully rotavated, flooded to reduce conductivity and to return the soil to field capacity and a dressing of 35 g/m^2 of calcium ammonium nitrate was raked in. Lettuce seedlings, cv. Wendel, in peat blocks were planted ion November 27. Soil samples were taken for analysis and the results are shown in Table 9. SMC had no significant effect on nitrate N level in the soil but was still increasing the electrical conductivity (EC) and the P and K levels.

Table 9 : Effect of SMC soil nutrient levels (mg/l) at the start of the lettuce experiment

SMC rate (t/ha)	pH	EC (mS/m)	NO_3-N	P	K
0	7.6	73	69	161	197

SMC rate (t/ha)	pH	EC (mS/m)	NO_3-N	P	K
50	7.6	88	88	185	273
100	7.4	129	112	216	385
200	7.3	130	88	299	421

The lettuce was harvested on March 12, the fresh weight was recorded and samples were analysed for nitrate content and other mineral constituents. These results are shown in Table 10. SMC did not affect the lettuce head weight, nitrate content or total N content. The nitrate levels were below the EU limit of 4,500 mg/kg for this time of the year. SMC increased the P level in the lettuce but not the K.

Table 10 : Effect of SMC on lettuce head weight, nitrate level and mineral composition.

SMC rate (t/ha)	Lettuce head weight (g)	Nitrate (mg/kg fresh)	N (g/kg DM)	P (g/kg DM)	K (g/kg DM)
0	210	3,328	47.6	4.4	88.9
50	211	3,554	47.0	4.7	93.3
100	204	3,547	47.5	5.3	93.3
200	214	3,388	46.6	5.9	92.5

The results indicate that build up of nitrate levels in soil due to mineralisation and nitrification and consequent high uptake of nitrate by the crop is unlikely to be a problem with SMC even at the high rates used in these experiments. From this point of view SMC is a suitable amendment for greenhouse soils.

SMC as an organic manure for potatoes

Potatoes with their high nutrient demand and an area of 26,000 ha in 1999 are a potential target crop for utilising SMC. This experiment was set up to assess the suitability of SMC for use as a soil amendment and nutrient source for potato production and studied its effects on the yield, quality and nutrient uptake of the crop.

The trial was located at Kinsealy on a moderately well-drained Grey Brown Podzolic of clay loam texture. Five rates of SMC were applied, 0, 8, 16, 32, and 64 t/ha, to plots measuring 4.5 x 10.5 m. Each plot was split into 3 subplots receiving 0, 75 or 150 kg N/ha as calcium ammonium nitrate (CAN). Because of the wet conditions in the spring of 1988 the SMC could not be applied until May 12. It was rotavated into the top 20 cm of soil. Potatoes, cv. Record, were planted on May 13. The CAN was applied in a single application on May 27. Plant and tuber samples were taken on August 5-10. The plots were harvested on October 8-21, graded into three sizes 10-45, 45-80 and 80mm+ and the yields recorded.

Sub-samples were taken and the percentage dry matter determined. Samples were retained for nutrient analysis.

Due to the late planting date and consequent short growing season, overall yields were low. Increasing SMC rate significantly increased plant and tuber dry matter yields in the intermediate harvest and increased tuber fresh and dry weight yields in the final harvest. Increasing the rate of N had a similar effect. The effects of both SMC and fertiliser N can clearly be seen in Figure 12 where tuber yield (45-80 mm) is plotted against SMC rate at the 3 N rates, (0, 75 and 150 kg N ha^{-1}). Applying SMC increased the yield irrespective of the level of CAN applied.

It is possible that the yield response was due to the nutrients supplied by the SMC. Applying SMC at 64 t/ha increased the soil P level from 13 to 35 mg/l and the K level from 125 to 210 mg/l. SMC increased plant weight and also plant uptake of N, P and K. However no symptoms of nutrient deficiency were noted except for that of N where no CAN was applied. Levels of P and K in the plant tissue were not in the deficiency range.

Historically soils at Kinsealy show no response to P once soil levels are adequate but a response to K might be expected.

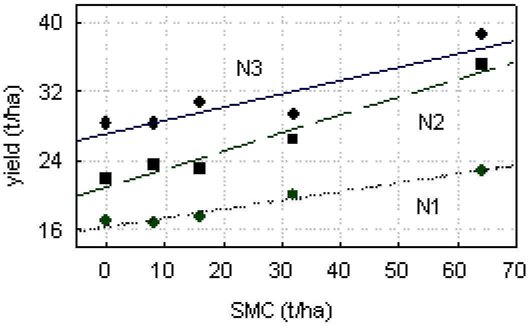

Figure 12 : Effect of SMC on yield of potatoes (45-80 mm) at three levels of nitrogen, 0 (N1), 75 (N2) and 150 (N3) kg/ha.

It is also possible that the addition of organic matter to the soil in the SMC had a beneficial effect on soil structure and micro-biological activity which in turn increased growth and nutrient uptake.

Addition of SMC, especially at the high rate, increased tuber dry matter production, and increased the concentration of N and K in the tubers but reduced the dry matter content. It is concluded that SMC is a suitable organic manure for potato production. It increased plant growth and nutrient uptake and increased tuber production at all levels of fertiliser N.

Effect of SMC on winter and spring wheat.

The object of these experiments was to assess the suitability of SMC for use as a soil amendment and N nutrient source in winter and spring wheat production by studying its effects on the yield, quality and N uptake of the crop. Wheat was selected because its straw is one of the primary raw materials used in the production of mushroom compost and so the use of SMC on wheat would be a convenient way to re-cycle the nutrients.

The experiments were located at Lyons Research Farm on a clay loam soil which was known not to give a response to P and K application for cereals. Experiment one was grown as a second winter wheat crop after a 3 year grass lay. The trial was set out as a split-plot design with 4 replications of 8 x 15 m plots receiving the following 5 rates of SMC, 0, 8, 16, 32, and 64 t/ha. Each plot was split into 3 sub-plots receiving the following 3 rates of N fertiliser, 0, 80 and 160 kg/ha as calcium ammonium nitrate (CAN). The SMC was ploughed into the top 20cm of soil on November 1, 1997 and winter wheat cv. Brigadier was sown on November 3. The CAN was applied in 2 applications in March and April. The plots were harvested on September 17, 1998 and the grain yield and percent lodging recorded. Straw and grain N levels were determined and hence the total shoot N uptake.

It had been intended to grow a second winter wheat crop using the same plots but because of poor weather in autumn, 1998 it was not possible to sow the winter wheat. Consequently the second application of SMC made to the plots on October 13 was ploughed in on March 16, 1999 and spring wheat cv. Baldus was sown on March 19. This crop was harvested on September 6, 1999 and measurements were made as for the first crop. For this crop, the N rates which were applied were 0, 60 and 120 kg N per ha applied in April and May.

The addition of SMC gave a significant linear increase in grain yield in both experiments (Figures 13 and 14). In experiment 1, increasing rates of SMC significantly increased grain protein content, and therefore grain N %, grain N uptake and total shoot N uptake (Table 11).

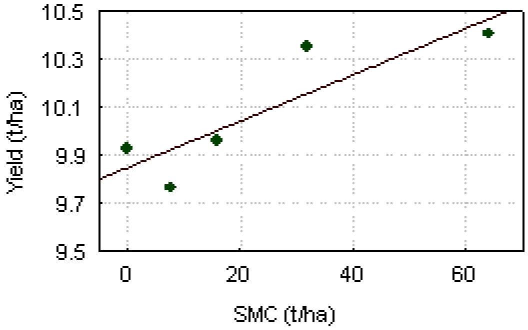

Figure 13 : Effect of SMC addition on the yield of winter wheat in 1997/98 (Experiment 1).

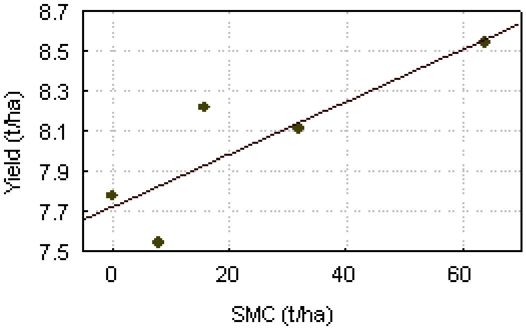

Figure 14 : Effect of SMC addition on the yield of spring wheat in 1999 (Experiment 2).

The increase in total shoot N uptake of 26.3 kg/ha between the lowest and highest rates of SMC is relatively small in comparison to the 525 kg/ha total N added in the SMC. This indicates that SMC is an inefficient source of N with only 5% of added SMC-N being retrieved by the crop and with the SMC only supplying 12% of the total N removed by the crop. The chemical fertiliser was more efficient at supplying N with 40% of added fertiliser N being retrieved by the crop. Similar results in relation to N uptake were obtained in experiment 2.

Table 11 : Effects of SMC on wheat yield, lodging and N uptake.

SMC Rate (t/ha)	Yield (t/ha)	Lodging (%)	Straw N (%)	Straw N (kg/h)	Grain protein (%)	Grain N (kg/ha)	Total shoot N (kg/ha)
0	9.93	15.0	0.78	66.2	8.92	131.2	197.2
8	9.84	16.7	0.80	66.3	8.80	128.4	194.6
16	9.96	24.2	0.85	72.9	9.12	134.6	207.5
32	10.35	22.5	0.78	68.0	9.06	138.9	206.9
64	10.40	36.7	0.87	77.8	9.47	145.7	223.5

The addition of inorganic N in the form of CAN increased yield significantly in both experiments. Figure 15 shows the yield response to SMC at the three levels of N in experiment 2. There is an obvious difference between the N levels. There was an interaction between SMC and the rate of CAN with the effect of SMC being greater at the zero rate of N.

The only negative effect of applying SMC was an increase in lodging which is shown for experiment 1 in Table 9. Most of this was due to severe lodging at the highest SMC level, which was further increased by a delay of 4 weeks in harvesting due to wet weather. However this trend was also noted in experiment 2.

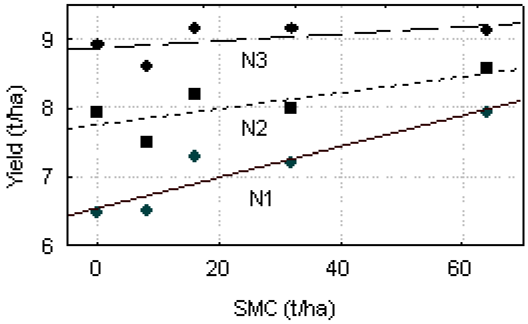

Figure 15 : Yield response of spring wheat in 1999 (Experiment 2) to SMC at three levels of N, 0 (N1), 60 (N2) and 120 (N3) kg/ha.

In general, SMC gave favourable results with positive effects on grain yield in both crops. Viewing SMC strictly as an N source, these results agree with those of the greenhouse experiment with grass on the availability of N in SMC. SMC is an inefficient source of N and will require supplementary fertiliser N to obtain optimum results. The rate at which the remaining N from the SMC becomes available over a period of years will require further study. The only negative effect that was recorded was an increase in lodging at high SMC levels.

Effect of SMC on soil nutrient levels

Samples of soil from the treated plots were taken for nutrient analysis during the field experiments in order to study the effect of SMC on mineral levels in the soil. Soil cores were taken to a depth of 1 m which were then sub-divided into either three or four segments. The segments were analysed separately. This was done in order to study whether SMC was affecting nutrient levels lower down in the soil profile.

The effect of SMC applied at a rate of 64 t/ha in the field potato experiment on soil nutrient levels is shown in Table 12. The SMC was applied in May, rotavated into the top 15 cm and the samples were taken in July. Each 1 m core was divided into three segments. In this experiment, SMC had no effect on nitrate N levels, the P level in the top 33 cm was increased markedly but there was no effect below this. K levels in the top 33 cm were similarly raised and increased at depths below this were not significant.

Table 12 : Effect of SMC on nutrient levels in soil at three depths in the potato experiment.

Rate of SMC (t/ha)	Depth (cm)	NO_3-N	P	K
0	0-33	9	13	109
0	33-66	0	2	11
0	66-99	3	11	9
64	0-33	9	33	169
64	33-66	3	3	20
64	66-99	4	12	25

During the second year of the wheat experiments, soil samples were taken in April and September, 1999 from the control plots (no SMC) and those receiving the heaviest rate of SMC (64 t/ha). As the SMC was applied to each crop, the plots receiving SMC had been given two applications, one before the winter wheat crop in October 1997 and the other before the spring wheat crop in April 1999. Cores were taken to a 1 m depth and they were divided into four segments. The effect of SMC on nitrate N and P levels at four depths, averaged for the two sampling dates, is illustrated in Figures 16 and 17.

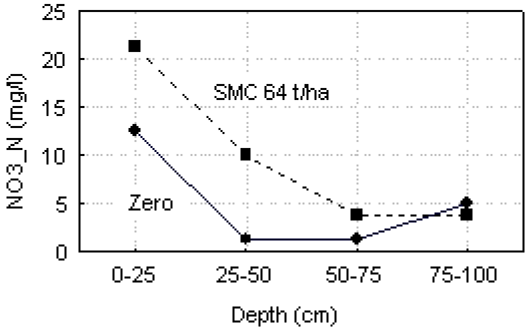

Figure 16 : Effect of SMC on nitrate N levels at four soil depths.

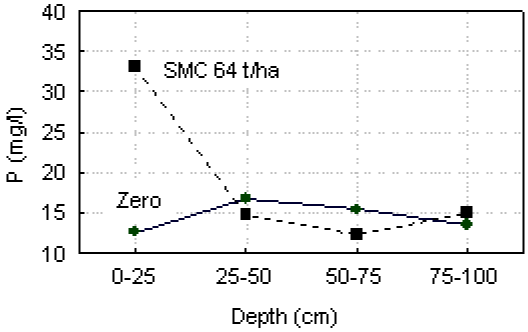

Figure 17 : Effect of SMC on P levels at four soil depths.

SMC increased the level of nitrate N in the top 50 cm of soil but not below this. The level of P in the top 25 cm was increased markedly by the application of SMC but there was no increase in P levels at lower depths in the soil profile.

Conclusions

Logistical

- Management of SMC in environmentally sustainable ways is difficult due to both the characteristics of SMC itself and the nature of the mushroom industry.
- Hemp bags showed some promise as biodegradable bags but they appeared to increase the incidence of *Trichoderma* and were more expensive than polyethylene.

- Under Irish conditions, it would be necessary to cover SMC in order to dry it naturally. Use of forced air would shorten the drying time considerably.
- SMC has a low energy value *ca.* 9 MJ/kg DM. Use of SMC as an alternative fuel may be feasible in the cement manufacturing industry, but full scale testing would be required to demonstrate this.
- Utilising SMC on the land is the most environmentally sensible management option that is immediately available to the mushroom industry.
- This end use, and other uses, would be facilitated by a co-ordinated SMC handling scheme at the core of which is one or more centralised SMC handling depots.
- For a producer with four standard mushroom tunnels, the annual costs of a co-ordinated SMC management scheme could be little different than the unmanaged approach currently in use.
- The capital costs of a centralised SMC depot would likely have to be subsidised for a co-ordinated scheme based on centralised SMC handling to operate successfully.

Agronomic

- Virtually all of the K in SMC is water soluble and therefore available to plants. Most of the N and P is not water soluble.
- When compared with CAN as a source of N for grass in a pot experiment, SMC produced approximately one third the amount of dry matter as did CAN for each gram of N added.
- When tested as a source of P, the dry matter production of grass per gram of P added as SMC was almost as much as when superphosphate was used.
- SMC added to soil increased the organic matter content, total pore space and water holding capacity of the soil.
- On greenhouse tomatoes, SMC improved fruit quality parameters associated with good flavour without reducing fruit yield.
- Use of SMC as a soil amendment in greenhouses did not give rise to high nitrate problems in lettuce.
- SMC increased potato yield in a field experiment even where a base dressing of N was applied. SMC increased plant and tuber uptake of N, P and K.
- In a two year experiment with winter wheat followed by spring wheat, SMC gave a significant linear increase in yield in both crops. The addition of inorganic N in the form of CAN increased yield significantly. This result agrees with the pot experiment indicating that SMC requires supplementary fertiliser N to obtain optimum results.
- Application of SMC to field soil increased the soil test levels for P and K in the top 25 cm of soil. Samples taken lower in the soil profile did not show increased levels.
- Our results indicate that SMC, with an appropriate nutrient management regime, can be used with benefit in field and greenhouse crop production.

Recommendations

- All members of the mushroom industry have a part to play in the future success of any SMC management strategy, therefore a co-ordinated, industry-led solution is likely to be more successful than the individualised approach that has been used in the past.
- The industry should move forward with establishing centralised SMC handling facilities to enable the efficient collection, temporary storage, further processing and transportation of SMC to end users.
- The landscape and horticultural markets must be surveyed to publicise SMC and its merits and to more clearly ascertain the quantities of SMC both these industries would use.
- Comprehensive nation-wide data on nutrient levels, particularly P, in soils is needed to accurately locate areas where organic products, such as SMC, can be used as fertilisers.
- An education and awareness campaign should be conducted amongst farmers, in areas removed from mushroom production, to introduce them to the benefits of SMC and ways to effectively utilise this material.

Acknowledgements

We acknowledge V. Howard, D. Byrne and E. de H. Guajardo for their contribution on the study of biodegradable bags and the potential of SMC for use as an alternative fuel. W. P. Staunton and T. Cormican were also very helpful in the examination of biodegradable bags. We wish to thank M. J. Mahon and P. A. Walshe for skilled technical assistance. We also acknowledge the helpful participation of the mushroom industry. This project was part funded by European Union Structural Funds and the Department of Agriculture, Food and Rural Development Research Stimulus Fund.

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