1 Introduction

1.1 Background

Today approximately 93% of the phosphate rock mined is used to produce mineral fertilizers and animal feed. Considering the overwhelming share of fertilizers and animal feed in global phosphate consumption, it is evident that the development of future world phosphate production will be driven by the development of agriculture, which in turn is driven by global population growth and its food requirement. It therefore follows that the use of phosphate - a non renewable natural resource - will increase in the future. Using these assumptions, it can be estimated that current economically exploitable P reserves will be depleted in about 60 to 130 years (Steen, 1998). In the view of this fact, recycling of secondary raw material has to be postulated as a must in sustainable agriculture. Recycling of plant nutrients from sewage sludge (SS) and meat and bone meal (MBM) can contribute to sustainable use of natural resources. In case of phosphate deposits, an efficient recycling of phosphate containing secondary compounds will become increasingly important in the near future (Haneklaus et al., 2000). A principal demand is its reasonable utilization for fertilization purposes. A current idea is to keep the phosphate as concentrated as possible to ensure its recycling in agriculture. This is one of the most important issues of sustainability of future societies.

Every year more than 1.1 million tons of animal meal products (MBM, bone meal [BM], blood meal, feather meal, poultry meal and fat) and about twice this amount of SS (2.3 million tons DM) are produced and disposed of in Germany (Die Deutsche Fleischmehlindustrie, 2004; BMU, 2001; UBA, 2001). The agricultural use of SS was about 40% of total production (UBA, 2001). Among the options to utilize SS are the application on agricultural land, incineration, landfill and forestry. The relative importance of different ways of use or disposal in Germany is summarized in Fig. 1.1.

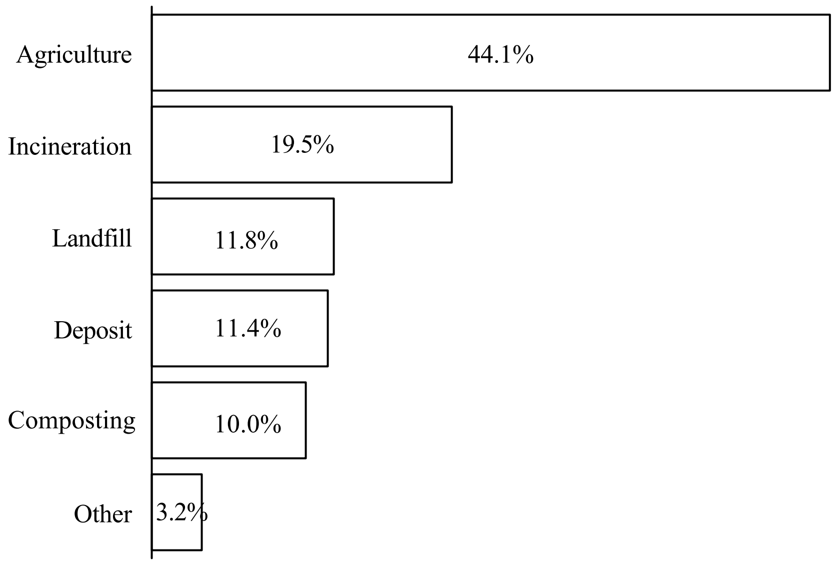

Fig. 1.1: Use of sewage sludge in Germany in the year 1996 (UBA, 2001).

MBM and SS contain considerable amounts of phosphorus (P) and other plant macronutrients which can be applied to soil for better crop production (Schnug et al., 2003a; Schnug et al., 2003b; Rogasik et al., 2003; Düring and Gäth, 2002; Sommers, 1980). The P concentrations in MBM, BM and related products range from 0.1% to 6.1%, the P content of SS amounts to about 1.2% (data according to Die Deutsche Fleischmehlindustrie, 2004; BMU, 2001; UBA, 2001). From this data, a P potential of about 27,000 t per year in the case of SS and of about 24,000 t per year in the case of animal products can be estimated. In comparison, the inorganic P fertilization in Germany is 154,578 t P per year. Thus, 33% could be substituted by waste material (SS, MBM and BM). This underlines the importance of a responsible P recycling.

Recycling of plant nutrients from waste material can contribute to saving of natural resources if both the demands of the soil and of environmental protection are fully satisfied (Haneklaus et al., 2000). However, SS is enriched with heavy metals, such as zinc (Zn), copper (Cu), manganese (Mn), lead (Pb), cadmium (Cd), nickel (Ni) and chromium (Cr), which can be toxic to plants and animals (Anon, 2001; Jarausch-Wehrheim et al., 2001; Fleckenstein et al., 1998; Folle et al., 1995; Taylor et al., 1995). Studies have shown that continuous application of SS on land results in the accumulation of heavy metals at toxic levels for plants (Chang et al., 1983). The heavy metal concentrations are clearly lower in MBM than in SS materials (Tab. 1.1).

Tab. 1.1: Average heavy metal concentrations of sewage sludge (SS) and meat and bone meal (MBM).

Raw material	**Concentration (mg kg^{-1})**					
	Cu	**Zn**	**Mn**	**Pb**	**Cd**	**Ni**
Sewage sludge*	282	2,850	5,688	1,272	60	90
Meat and bone meal**	21	130	22	3.0	0.1	7.6

Sources: *Jarausch-Wehrheim et al. (2001), **Anon (2001) (unpublished).

The Council of the European Communities (CEC, 86/278/EEC) and Germany (AbfKlaerV, 1992) have established and proposed a number of directives related to water, wastes and the environment which regulate the production and disposal of SS.

Secondary raw materials often also contain amounts of organic harmful substances, such as xenobiotics in SS or prions carrying transmissible spongiform encephalopathy (TSE) in MBM. Until the European Union (EU)-ban, MBM contributed up to 57% of the supplementation of P that was needed for pigs and poultry (Rodehutscord et al., 2002). Over the last two decades, the utilization of MBM as animal feed has become a great topic of debating especially due to the bovine spongiform encephalopathy (BSE). BSE is a sub-acute degenerative disease affecting the central nervous system of cattle and belongs to a group of related diseases known as TSE. They are caused by prions that produce spongiform changes in the brain (Prusiner, 1996). Current evidence suggests that the disease was caused by the use of contaminated MBM in concentrated feed for cattle (WHO, 1997; Kimberlin, 1993). Due to the general EU-ban for MBM, alternative usage is needed (Kleinhanss et al., 2000). For this reason it is essential that technologies are established in order to guarantee a safe utilization of SS and MBM on agricultural soils. The investigation of alternative technologies for the disposal of SS and MBM is very important in future (Düring and Gäth, 2002; Hahn, 1999). A promising strategy for solving the demonstrated problems is incineration. Incineration of MBM and SS allows to maintain the nutrient "P" for plant production and to destroy xenobiotics and TSE constituents in these materials at the same time.

However, a basic issue here is the mobility of phosphate in ash substances. These ash substances mostly contain P in the form of apatite, the solubility of which in soil is limited, as is already known from sedimentary rock phosphates. Plant availability of the P added with ashes is of particular interest for an optimal crop production. Therefore, one of the most important problems is the increase of P concentration in the soil solution. One possible strategy to increase the P solubility is an "*In situ*" digestion of the meat/bone meal or sewage sludge ashes (MBMA, BMA and SSA) by applying them together with elemental S (Schnug et al., 2003b; Fan et al., 2002). Similar or more favorable effects may be expected from the combination of a suitable amount of elemental S and *Thiobacillus* inoculation. The principle is to manufacture compound fertilizers containing the rock phosphates and a suitable amount of elemental S to ensure its transformation in soluble forms by means of the sulfuric acid produced in the course of sulfoxidation. The process is enhanced by inoculating the soil with *Thiobacillus*. *Thiobacillus* are characterized by their ability to gain energy from the oxidation of reduced S and iron compounds (Schnug et al., 2003b). "*In situ*" digestion experiment carried out by Fan et al. (2002) showed that the concentration water soluble P in the combining S and rock phosphate (SP) with *Thiobacillus* inoculation treatment increased significantly during laboratory incubation. Thus, there was a significant negative relationship between soil pH and water soluble P content in the inoculated SP treatment.

The implication is that proper recycling of P bound in MBM or SS residues will become a major issue of sustainability of any future agricultural production system.

The major task of the presented research work was the evaluation of agricultural utilization of phosphate from incinerated sewage sludge and meat and bone meal, and the assessment of effects of "*in situ*" digestion on P availability.

1.2 Objectives

The key objectives of this research work were to assess

(i) chemical changes in the element composition of sludges and meat and bone meal through incineration,

(ii) P availability of different waste materials and their ashes,

(iii) changes in micronutrients and heavy metals during incineration of sludges and meat and bone meal,

(iv) the impact of "*in situ*" digestion on nutrient availability.

2 Materials and methods

2.1 Sewage sludge and animal meal

<u>Collection and preparation</u>

Animal meal materials were included as bone meal (BM) and meat and bone meal (MBM). The commercial BM and MBM materials were produced by a rendering plant in Belm-Icker (SNP Icker G.m.b.H. & Co. KG, Engter Str. 101, 49191 Belm-Icker). Sewage sludge (SS) was collected from a waste water treatment plant in Braunschweig (Celler Heerstraße 337, 38112 Brauschweig-Watenbüttel). The SS samples were air-dried and ground to pass a 2-mm sieve. All original materials were analyzed for macro- and micronutrients, heavy metals and pH before controlled incineration (see Tab. 3.1). Original materials were pelleted before the incineration process. Each original material was mixed with cellulose (10%), starch (3%) and water to obtain an optimum pellet condition. The pellet diameter was about 4 cm with a thickness of 2 cm (Fig. 2.1).

Fig. 2.1: Pelleting and incineration processing of original materials.