Available online at www.sciencedirect.com
ScienceDirect
Europ. J. Agronomy 26 (2007) 257–265
European Journal of Agronomy
www.elsevier.com/locate/eja

Heavy metal transfer from composted macroalgae to crops

Maria Greger[a,*], Torleif Malm[b], Lena Kautsky[a]

[a] Department of Botany, Stockholm University, S-109 61 Stockholm, Sweden
[b] Department of Biology and Environmental Science, Kalmar University, S-391 83 Kalmar, Sweden

Received 15 March 2005; received in revised form 19 September 2006; accepted 19 October 2006

Abstract

Marine macroalgal compost may be used as fertiliser in agriculture and horticulture. However, macroalgae may accumulate heavy metals, thereby rendering compost made from it unsuitable for food crop production. Our aim was to determine whether the edible parts of crop plants grown in various macroalgal composts contain elevated concentrations of heavy metals. Compost of seaweed beach-cast containing up to 85% red macroalgae and experimentally produced red and brown-algal (*Fucus serratus*) composts, respectively, were used in cultivating vegetables. The vegetables produced were compared with ones cultivated in composted horse manure and in soil in terms of transfer of cadmium (Cd), and in some cases also of copper (Cu), lead (Pb), and mercury (Hg) from the different substrates to the edible parts of the plants. Effects of the composted material on biomass production and seed germination were also examined. Concentrations of Cu, Hg, and Pb were not elevated in either of the composts or in the crop plants compared with limit values for cultivated plants and soil. However, the concentration of Cd in the composts and crop plants was greater than the limit values for arable soil and cultivated plants, respectively. Furthermore, more Cd was transferred to the plants grown in red-algal than in brown-algal (*F. serratus*) compost, despite the fact that the brown-algal (*F. serratus*) compost had a higher Cd concentration. The Cd concentrations in lettuce and oats cultivated in the seaweed composts exceeded official EU limit values, while the concentrations in root vegetables and leguminous plants were lower than the limit values. Cultivation in composted red macroalgae increased the biomass production of all vegetables except beans, compared with cultivation in the other substrates. However, the germination frequency was lower for seed sown in composted red and brown algae than for seed sown in soil. We conclude that although cultivation of food crops directly in composted macroalgae (specifically, composted red algae) would enhance yields, it is not recommended. Instead, macroalgal compost could be used in smaller amounts on agricultural soils as a valuable nutrient source for non-food crop cultivation.

Keywords: Cadmium; Crop plant; *Fucus*; Heavy metal; Macroalgal compost; Red alga

1. Introduction

The use of marine macroalgae as fertiliser in crop production has a long tradition in coastal areas all over the world (Stephenson, 1968). Over 250 years ago, von Linné (1745) had already reported the extensive agricultural use of the perennial brown macroalgae, *Fucus vesiculosus* L., on the large Swedish island of Öland, in the Baltic Sea. Seaweed cast continued to be so valuable to farmers, even in the early 1900s, that the authorities had to regulate its use (Weibull, 1919). In many countries, seaweed and beach-cast are still used in both agriculture and horticulture (Verkleij, 1992; Zodape, 2001). The positive effect of these substances on crop growth is even greater than would be expected from the nutrients they supply, and this effect may be caused by growth hormones in the macroalgae (Crouch and Vanstaden, 1991, 1992, 1993). Besides supplying nutrients, using composted macroalgae improves the soil structure by increasing the humus content (Haslam and Hopkins, 1996).

To the best of our knowledge, no data have been presented concerning possible heavy metal contamination occurring by fertilizing the soil with macroalgae, although it is well documented that heavy metals, which bind to the polysaccharides in the cell walls of algae (Zolotukhina and Gavrilenko, 1991), can be accumulated by macroalgae. Red algae in particular may concentrate heavy metals by a factor of 10^4 from seawater, which commonly has a very low heavy metal concentration (Wahbeh and Mahasneh, 1985). The accumulation of heavy metals by macroalgae depends on both the total surrounding metal concentrations and the availability of the metals, which increases with decreasing seawater salinity. This has been suggested by,

* Corresponding author. Tel.: +46 8 161210; fax: +46 8 162268.
E-mail address: maria.greger@botan.su.se (M. Greger).

1161-0301/$ – see front matter
doi:10.1016/j.eja.2006.10.003

for example, Steinhagen-Schneider (1981) as a reason for the 10-times-higher cadmium concentration in *F. vesiculosus* growing in the brackish central Baltic Sea (∼7‰ salinity) than in the North Sea (∼30‰ salinity).

Eutrophication of the Baltic Sea has led to an increase in the growth of filamentous macroalgal species over the past 60 years, while the amount of *F. vesiculosus*, traditionally used as an agricultural fertiliser in south-eastern Sweden, has declined (Cedervall and Elmgren, 1990). In shallow water in the archipelagos, brown filamentous macroalgae of the genera *Pilayella* and *Ectocarpus* are today abundant (Lotze et al., 2000; Vahteri et al., 2000), while the macroalgal community along the open coasts mainly consists of red macroalgal species of the genera *Polysiphonia*, *Ceramium*, and *Rhodomela* (Wallentinus, 1979). In late summer and autumn, large quantities of these filamentous macroalgae become detached from the substrate, accumulating along the open coasts and as drifting mats in shallows among archipelagos in the area (Norkko and Bonsdorff, 1996a,b; Norkko, 1998). According to Malm et al. (2004), up to 6900 tonnes fresh weight of beach-cast per km of shoreline per year is found on the island of Öland in Sweden. Removing the macroalgae from the beaches may, however, result in a waste disposal problem on land. It would thus be of both economic and environmental interest to use the beach-cast as fertiliser, partly replacing the use of commercial fertilisers in coastal areas (Jöborn et al., 2001).

This research investigated the concentrations of cadmium (Cd), copper (Cu), mercury (Hg), and lead (Pb) in macroalgal beach-cast from the Baltic Sea, on the island of Öland, and in compost made from red and brown algae, and determined the transfer of these metals into food crops. The investigation was performed in four steps. First, the concentrations of Cd, Cu, Pb, and Hg were analysed in algae collected from four different types of fresh beach-casts along the east coast of the island of Öland in the Baltic Sea. In the second step, the transfer of Cd, Cu, Pb, and Hg from composted beach-cast to crops was determined in a greenhouse experiment. Since we found that only the Cd concentrations and the transfer of Cd to crops exceeded the threshold values for arable soil and cultivated plants established by national and European authorities the third and forth steps only examined Cd. In the third step, beach-cast and manure were compared in terms of Cd concentrations and transfer of Cd to various crops in field cultivation. In the fourth step, the objective was to compare various substrates in terms of Cd concentrations and the transfer of Cd to crops; the substrates were composted red filamentous algae, composted brown seaweed (*Fucus serratus* L.), and soil. This experiment was performed in a greenhouse.

2. Materials and methods

2.1. Species composition of beach-cast

The species composition of the beach-cast at Böda, situated on the east coast of Öland, Sweden (N57″13′52 E17″05′47), was estimated in September 1999. Beach-cast from three other sites – northern, central, and southern – 70 km apart on the east coast of Öland, were also analysed. At each site, 1-kg samples were collected along 500 m of shoreline at five sites approximately 100 m apart, 0.5 m above the water line. The samples were sorted by species, and the biomass of the dominant species was determined by measuring the fresh weight. The proportions of the two filamentous red macroalgal species present in the beach-cast, i.e. *Polysiphonia fucoides* (Hudson) Greville and *Rhodomela confervoides* (Hudson) P.C. Silva, were estimated by sorting 100 g (FW) of filamentous macroalgal biomass from each sampling site, using a stereomicroscope. From these data, the proportion of each species as a percentage (fresh weight per m^2) of the beach-cast was calculated. The sorted beach-cast material was used in analysing the Cd, Cu, Pb, and Hg concentrations in each species.

2.2. Plant cultivation in beach-cast compost

2.2.1. Greenhouse experiment (experiment one)

The sandy beaches at Böda have been cleaned of beach-cast regularly over the past 20 years by owners of waterfront property. The material has been dumped in large piles in the forest close to shore, where it has been left to decay. Five kilograms of this composted algal material was collected from the bottoms of four different 3-year-old piles. From photographs and from interviews with workers responsible for the beach cleaning, the initial composition of the composted material in all piles was estimated to be over 90% filamentous red algae. Four boxes (0.1 m × 0.3 m × 0.5 m) were filled with 15 dm^3 of these composted materials, each box containing compost from a single compost pile. As controls, four similar boxes were filled with commercially available compost, Weibulls ekologiska plantjord, from Svalöf-Weibull AB (Sweden). The parameters of both substrates in terms of pH, organic content, nutrients (NPK), salinity, and water-extractable anion concentration are presented in Table 1.

Twenty oat plants (*Avena sativa* L. cv. Kattgräs) and 20 pea plants (*Pisum sativum* L. cv. De Grace, low) were grown from seed in each of the four composts produced from the beach-casts and in each of the four soil samples. The cultivation was done in a greenhouse (set for 22 °C, RH ≈ 70%) equipped with supplementary high-pressure 230V, 240 W sodium lamps (Kema Europa, Amsterdam, The Netherlands), giving a photon flux density of 500 $\mu mol\ m^{-2}\ s^{-1}$ for 12 h of each 24-h cycle. The plants were harvested after approximately 2 months of growth, by which time the ears and pods had developed. After harvest, the aboveground plant material and growth substrate were analysed for Hg, Pb, Cu, and Cd as well as organic matter content.

2.2.2. Field experiment (experiment two)

A field experiment was performed in Böda in summer 2000. The same beach-cast compost (from Böda) as was used in the greenhouse experiment was used in this experiment. The material was spread out forming a square 10 m^2 and 0.5 m thick. As a standard of reference for the beach-cast compost, an equally large square of composted horse manure (comprising barley straw and horse faeces in equal proportions) was also used (for substrate parameters, see Table 1). The two squares were each