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Transforming Aquaculture Sludge into Commercial Fertiliser Products: Economic and Agronomic Validation

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Abstract

Recirculating aquaculture systems (RAS) generate sludge with elevated nutrient concentrations, particularly nitrogen (~57 g·kg^{-1} DM) and phosphorus (~20 g·kg^{-1} DM), representing a potentially valuable secondary raw material for agriculture (van Rijn, 2013). This study evaluated vermicomposting, pellet production, and direct soil application focusing on process parameters, agronomic performance, and economic feasibility. Vermicomposting experiments were conducted using *Eisenia andrei*. Fresh and flocculated sludge contained ammonium levels between 0.01–0.05 %, which caused high earthworm mortality when applied without stabilisation. Pre-composting for seven days combined with mixing sludge with straw significantly reduced ammonia toxicity, improved the C:N ratio, and enhanced substrate structure and aeration. Under stabilised conditions, earthworm survival exceeded 90 %, accompanied by biomass gain and cocoon production. The resulting vermicompost exhibited improved physical properties and increased levels of plant-available nutrients. At market prices of approximately € 56–72 per tonne, the simple payback period for a vermicomposting unit was estimated at 2–3 years, assuming steady sludge input and low external energy demand. Pellet production was assessed to improve material stability and transport efficiency. Dewatered sludge (25 % DM) was mixed 1:1 (w/w) with wood dust to enhance pellet integrity and reduce zinc content from 977 mg·kg^{-1} in raw sludge to 446 mg·kg^{-1} in the final product, meeting regulatory limits. The mixture (43 % DM) was dried to 85–86 % DM prior to pelletisation. Energy analysis identified drying as the dominant cost factor: fully electric drying resulted in production costs of approximately € 0.24–0.36 per kg, while natural gas reduced costs to € 0.07–0.08 per kg, and biomass-based heat to € 0.03–0.05 per kg. Pelletisation itself represented a minor share of total energy demand. The final pellet contained 30.4 g·kg^{-1} N and 10.7 g·kg^{-1} P (DM basis) and complied with heavy-metal thresholds. Agronomic performance was verified in pot trials with lettuce (*Lactuca sativa*), comparing fresh sludge, flocculated sludge, pelletised fertiliser, mineral fertiliser (Control+), and unfertilised control (Control−). Fresh and flocculated sludge treatments at recommended nutrient doses achieved biomass production comparable to or exceeding mineral fertilisation, while a high-dose sludge treatment (25 %) showed low growth due to ammonium toxicity. Overall, the results demonstrate that RAS sludge can be transformed into agronomically effective fertiliser products when ammonia stabilisation, heavy-metal management, and energy-efficient processing are appropriately addressed, supporting circular integration between aquaculture and agriculture.

Keywords: aquaculture, circular bioeconomy, fertilzer, nutrient recovery, sludge

References

van Rijn, J., 2013. Waste treatment in recirculating aquaculture systems. Aquacultural Engineering 53, 49–56.

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