Evaluation of the properties of waste from African catfish (Clarias Gariepinus B.) farming in the context of using it for agricultural purposes

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Abstract. Development of modern aquaculture involves increasing the share of production in closed systems with water recirculation. In such facilities, waste with a considerable content of the solid fraction and a high concentration of biogenic elements is generated in the process of water treatment. According to present legislation, such waste cannot be used as fertilizers, which is contradictory to the idea of sustainability and rationalization of the use of environmental resources. The aim of this paper was to assess the chemical composition of African catfish farming waste in the context of the possibility of using it for fertilization purposes. The assumed goal was achieved by studying the waste generated at a water treatment facility that uses the method of active microscreens in an African catfish farm. 10 samples of waste (which, in raw form, is transported to the local wastewater treatment plant) were collected for the research. The content of dry matter, macroelements, microelements and heavy metals was determined in the studied waste. Dry matter content was determined by weight method, nitrogen and carbon content – by elemental analysis method, whereas the content of the other macroelements and trace elements was determined using the ICP-OES method. Results of the conducted research point to high concentrations of nitrogen and phosphorus. These are the main elements which decide on the fertilizing value of the studied material. Nitrogen content was approximately 5.354%, whereas phosphorus content – 3.436% calculated on dry matter. The content of other macroelements and trace elements was at a level observed in natural fertilizers. Heavy metals content did not disqualify the studied material from being used for fertilization purposes. Results of the conducted research indicate unambiguously that the studied material should be used for fertilization. Directing this waste to wastewater treatment plants is not well-founded from the economic and environmental point of view. The issue of proper management of waste generated in aquacultures with water recirculation should be regulated at the legislative level to reduce the amount of biogens dispersed in the environment and to improve the efficiency of production of aquaculture animals.
1. Introduction

Development of local aquaculture is a strategic part of the European Union policy regarding food production due to the great and continually increasing demand in the Commonwealth countries for fish and seafood. The European Union is the largest market for imported fish and seafood in the world. Development of local aquaculture allows for partial independence from external markets [1]. Import of aquaculture products creates an additional risk of non-compliance with EU regulations regarding the safety of products and production technology [2,3]. The products of aquaculture belong to a group of increased risk associated with their chemical and biological contamination. For that reason, in all countries of the Commonwealth, all aquacultures are subjected to regular official controls. Not without significance is also the assurance of a minimum environmental impact as a response to the requirements of the increasing number of consumers [4]. Activities in the field of fish farming and farming of other aquaculture animals are connected with generation of large amounts of waste consisting of excreta from these animals and fodder leftovers. This waste poses a risk to both the aquaculture animals habitat and to the surrounding ecosystems on which a unit of aquaculture exerts direct effect. Such waste is a source of biogens and trace elements, which can be the cause of intensification of eutrophication processes [5]. The considerable amount of organic matter constitutes a medium for the growth of microorganisms, which poses a microbiological risk. The considerable amount of organic sediments generated in the area of aquaculture leads to oxygen deficit and intensification of anaerobic decomposition of organic matter, which results in emission of toxic gases such as methane, hydrogen sulfide or ammonia. Amount of created suspension (calculated on dry matter) under conditions of intensive fish fattening is at a level of approximately 40% of the mass of introduced fodder [6,7] state that production of 1000 kg rainbow trout causes emission of approximately 250 kg suspension, approximately 8.7 kg phosphorus and 50.2 kg nitrogen into the environment. On the other hand, Chen et al. [6] state that fattening of African catfish increases the amount of phosphorus emitted into the environment over two-fold, which is associated with increased concentration of production in a unit of water volume. The above-mentioned bibliographic data show that more than 60% phosphorus emitted into the environment from aquaculture is present in undissolved form. On the other hand, nitrogen (in approximately 70% of the total amount) is emitted into the environment in the form of water-soluble compounds. Intensification of aquaculture production leads to an increase in concentration of post-production waste on small areas, leading to partial or total imbalance in homeostasis of local ecosystems. Aquaculture production organized in such a way has a negative and multifaceted impact on the natural environment. Reducing organic matter emission from production of aquatic animals to natural water bodies is one of the most important aspects of development of rational aquaculture [8, 9]. Waste produced in the farming process can be utilized within an expanded ecosystem that is based on polyculture. It is based on controlled growth of specific microorganisms and introduction of organisms from various levels of the trophic chain [10,11]. Such practices are the best solution, but systems based on polyculture have specific efficiency and, at a considerable concentration of production and generation of large amounts of waste, lose the water treatment ability. In the case of open water aquacultures, a very common practice is to combine fish farming with farming of crustaceans which utilize fodder leftovers and fish excreta [12]. Waste from aquaculture production constitutes the solid fraction and the liquid fraction. Solid waste should be processed, whereas liquid waste which is generated during water recirculation is usually directed (along with the municipal wastewater stream) to a treatment plant. Due to a high content of biogenic elements, such wastewaster should not be discharged into aquatic environment as it can pose a risk of eutrophication. Progress in water treatment technology leads to generation of waste with a high content of solid fraction and a high concentration of elements. On one hand, this poses a greater risk to the environment, but the high concentration of elements, particularly biogenic ones, provides a possibility of using the waste in question in agriculture. Waste that is generated during aquaculture production has been classified in the second group of the "European Waste Catalogue and Hazardous Waste List" and placed in the category of waste from agriculture, horticulture, forestry, hunting, fishery and food waste. In some states of North America, e.g. in West Virginia, this waste is
classified to the group of industrial waste [13]. For that reason, waste generated in aquaculture cannot be used for fertilization or improvement of soil fertility. It would be possible to use such waste in agriculture after processing it by methane fermentation. According to Polish legislation, biomass after methane fermentation is regarded as waste. Regulation of the Minister of Environment on waste catalogue [14] specifies that the waste is coded as 19 06 06 – digestate from anaerobic treatment of animal and vegetable waste. According to the Regulation of the Minister of Environment [15], recovery of the digestate using the R10 method is possible by distributing it over land in order to assist cultivation. However, fermentation of the waste in question would be economically unjustified due to high costs of building and maintaining a methane fermentation facility. African catfish farms in Poland are usually small, therefore the amount of waste generated in them does not provide economic justification for creating facilities for processing such waste. The only effective method of managing the waste in question is to use it in its raw form in agriculture.

The aim of this paper was to assess the chemical composition of African catfish farming waste in the context of the possibility of using it for fertilization purposes.

2. Materials and methods
To achieve the pursued objective, a precise analysis of the chemical composition of waste generated at an African catfish (Clarias gariepinus B) farming facility was conducted. Waste from a farm located in Warmińsko-Mazurskie province was used in the research. The average production output is approximately 100 t fish per year. African catfish farming is carried out in the studied farm in a closed cycle system with water recirculation. Used water is purified using the method of microscreens and treated by biofiltration. Microscreens are moving mechanical screens in which an entire volume of water is filtered through a material with different permeability, and sediments are continuously flushed from the drum. Such a material (with a high degree of hydration) is referred to as production waste. Processes taking place in biofilters lead to oxidation of ammonia and to a decrease in phosphate content in water. As a result of filtration on microscreens, most of slurry from animal excreta and fodder leftovers is removed from water. Quality of water after recirculation makes it possible to maintain animal well-being. After treatment, reaction of water as well as ammonia content in water are determined. Currently, generated waste is transferred to a wastewater treatment plant where it undergoes the treatment process. Waste formed on biofilters is combined with waste from microscreens. The introduced system allows for complete recirculation of process water. 10 laboratory samples (1 kg each) were collected for research from a reservoir with the capacity of about 10 m³, which functions as a storage reservoir for this waste. The laboratory sample consisted of five increments collected using a scoop at various depths in the reservoir. Samples were collected March, May, July, September and November 2015. The laboratory samples of the waste were dried at 65°C, homogenized and subjected to dry mineralization in an open system. Then they were mineralized in a muffle furnace at 450°C and digested in nitric acid solution. The analytical sample was 3 g dry matter. Concentration of the studied elements in the obtained solutions was determined by atomic emission spectrometry, on an Optima 7600 manufactured by PerkinElmer. Wavelengths that were used for determining the concentration of the studied elements as well as the detection limits for the methods are provided in table 1. Nitrogen and organic carbon content was determined by elemental analysis method, using Elementar vario MAX cube elemental analyzer. The correctness of analyses of the studied elements was verified using certified reference material IEA-V-10. Table 1 shows results of analyses of the reference material and an estimated value of recovery based on analyses conducted in 4 replications. The content of dry matter, organic carbon, nitrogen, and of other macroelements (Ca, P, Na, K, and Mg) was determined in the samples of the waste in question. Moreover, the content of trace elements was determined Cu, Zn, Fe, Mn, Cr, Ni, Pb, Cd, Sr, B and Ba.
Table 1. Parameters of analysis method.

| Parameters | Wavelengths [nm] | Limit detection [mg·dm⁻³] | Content in certificated material [mg·kg⁻¹] | Measured [mg·kg⁻¹] | Recovery [%] |
|------------|------------------|---------------------------|------------------------------------------|-------------------|-------------|
| Mg         | 285.208          | 0.0016                    | 1360                                     | 1414.4            | 104         |
| P          | 213.617          | 0.076                     | 2300                                     | 2231              | 97          |
| Ca         | 317.933          | 0.01                      | 21600                                    | 22896             | 106         |
| Na         | 589.592          | 0.069                     | 500                                      | 485               | 97          |
| K          | 766.490          | -                         | 21000                                    | 19740             | 94          |
| Cd         | 228.802          | 0.0027                    | 0.03                                     | 0.0315            | 105         |
| Cr         | 267.707          | 0.0071                    | 6.5                                      | 6.76              | 104         |
| Cu         | 327.393          | 0.0097                    | 9.4                                      | 10.058            | 107         |
| Fe         | 238.204          | 0.0046                    | 185                                      | 179.45            | 97          |
| Mn         | 257.608          | 0.0014                    | 47                                       | 46.53             | 99          |
| Ni         | 231.604          | 0.015                     | 4                                        | 3.84              | 96          |
| Pb         | 220.353          | 0.042                     | 1.6                                      | 1.696             | 106         |
| Zn         | 206.200          | 0.0059                    | 24                                       | 23.52             | 98          |

3. Results and discussion

Aquaculture has been the fastest growing branch associated with food production in recent years. This is associated with increasing demand for aquaculture products and constantly decreasing production capabilities of natural water bodies [16]. Moreover, fish and seafood from fishery can have a higher concentration of xenobiotics, which is associated with the source of food [17]. Owing to the fact that aquaculture production has an adverse impact on the water environment (which is very sensitive to pollutants), the development of this branch of economy is associated with the development of pro-environmental technologies. One of the most important trends in the development of aquaculture is intensification of production, which leads to an increase in quantity of product when using a specific amount of water, fodder and energy. Using fodder which has high digestibility and a balanced composition of nutrients leads to acceleration of the production of fish biomass and to reduction of the amount of waste generated [18]. In terms of the environmental impact, increasing the number of aquatic animals as well as intensification of the fattening process are beneficial. The issue associated with animal well-being and with aquaculture fulfilling its non-production functions (such as recreational, landscape, retention functions or the function of a habitat for wild animals) can be a problem in such technological solutions [19]. Waste associated with fish farming is comprised of excreta from these animals and fodder leftovers. According to law, it cannot be regarded as fertilizer and used for soil fertilization [15]. Therefore, there is an increasing problem of management of waste generated on aquaculture farms, particularly when production organization is based on water recirculation. This is exemplified by African catfish (Clarias gariepinus B.) farming. For business reasons, production of this fish species in Poland is increasing. That is why the amount of waste accompanying this production will be also increasing. One of the greatest achievements in aquaculture is the technology of production with water recirculation. Such a production system allows to organize fish farming in places isolated from natural water bodies. This way the amount of pollutants that enter the environment as well as the influence of kept species on the surrounding ecosystems are limited. Moreover, in systems with water recirculation it is possible to rigorously control water properties, which translates into fish health and use of fodder [20].

The studies waste had a watery consistency with black color and a low intensity smell. Dry matter content in it ranged from 6.236 to 8.110% (table 2). A slight difference was observed in the dry matter content in individual samples. Hydration of water recirculation waste is determined by efficiency of the system. Results obtained in our research are indicative of properly selected infrastructure and proper optimization of the process. Production of 1 t fish biomass is accompanied by generation of 15
t waste. The use of microscreens and biological beds with a microbial inoculum for water treatment in the recirculation system is the most effective, but at the same time the most costly, method. Alternative water treatment methods that use natural mechanisms of water self-purification in sedimentation tanks can be as effective. However, in the case of fish farming requiring water heating this would entail heat losses [21].

Nitrogen is an important element in animal metabolism. Specificity of the biogeochemical cycle of nitrogen is the reason why it occurs in large amounts in both fodder and excrements. Farming of aquaculture animals leads to emission of considerable amounts of this element into the aquatic environment. Most nitrogen compounds which are present in fish excreta are very quickly transformed into soluble forms, which makes it difficult to remove it using mechanical methods [22]. Elevated amounts of ammonia in water lead to disturbances in fish physiology, growth limitation and a decreased capacity to use fodder. In extreme cases, fish poisoning may take place. African catfish tolerates elevated ammonia content in water, but under intensive production with recirculation it is necessary to remove ammonia from biofilters [23]. The mean nitrogen content in the studied waste was 5.35% DM and ranged between 4.860 and 6.202% DM. The determined amounts are higher than those in literature data regarding the content of this element in fish excreta. Naylor et al. [24] report nitrogen content in rainbow trout excreta at a level of approximately 3% DM. Salazar and Saldana [25] observed similar amounts of nitrogen in salmon excreta. Nitrogen content in post-production waste determined in our research is much higher than it is usually observed in natural fertilizers of various origin (table 2). Using this type of fertilizers should therefore be linked with controlling the amount of nitrogen introduced into the soil ecosystem. The limit for this element in the case of organic fertilization is 170 kg N · ha⁻¹ · year⁻¹ [26]. According to law, the maximum dose of studied waste could amount to approximately 45 t raw waste. Moreover, nitrogen present in fish excreta is assimilated by plants better than natural fertilizers, which, at large doses of this material, can pose a risk to both natural ecosystems and to the quality of plant products [27, 19].

In terms of the impact of aquaculture on the environment, phosphorus poses the greatest risk. It is the element most responsible for intensification of eutrophication processes. Its biogeochemical cycle is not connected with the atmosphere, that is why the entire charge of this element is accumulated in individual parts of the aquatic ecosystem. The mean phosphorus content in the studied waste from water treatment with the use of microscreens was 3.436% DM and ranged from 2.856 to 3.980% (table 2). Phosphorus content observed by D’Orbcastel et al. [28] in waste from rainbow trout farming was at a level similar to that obtained in our research. Nitrogen content observed by these authors was at a level of approximately 4% DM. Salazar and Saldana [25] observed slightly lower content of this element in salmon excreta.

The studied waste from African catfish farming was found to have high content of potassium, magnesium, calcium and sodium. The average content of these elements for all of the studied samples was, respectively, 0.164%, 0.390%, 5.669% and 0.188%. Slightly smaller amounts of macroelements, compared with the results obtained in our research, were found in excreta of salmons farmed in cages [25]. The studied waste contains more than twice the amount of calcium and phosphorus compared with the amounts of these elements that are usually found in natural fertilizers (table 2). Sodium content was at a level similar to that found in natural fertilizers, whereas potassium content was several times lower [29, 30]. Many authors draw attention to the possibility of using solid waste from aquaculture for crop fertilization. Castro et al. [31] conducted a study on the possibility of utilizing used water from aquaculture for irrigation of tomatoes. These authors observed a positive effect of irrigating with water from tilapia farming on yielding of these plants. Ghaly et al. [32] obtained similar results. Boyd et al. [33] evaluated the usability of bottom sediments generated in ponds which are used for tilapia farming. Potassium content recorded by these authors was almost ten times higher, whereas nitrogen and phosphorus content was almost ten times lower compared with the results obtained in our research. These authors draw attention to high availability of macroelements present in fish excreta. A similarly positive effect of sediments from farming ponds on yielding of sward was observed by Haque et al. [34] under aquaculture production combined with dairy production. Used water from
marine aquacultures or organic waste are successfully used for fertilization of halophilic plants or for production of substrates used in cultivation of these plants [35].

Sustainable development of aquaculture is based on using animals from different levels of the trophic chain in order to optimize the use of food (both from natural resources and introduced into the aquatic environment in the form of fodder). The idea of Integrated Multi-Trophic Aquaculture (IMTA) is the foundation for development of present day aquaculture. Its goal is waste-free production, thereby reducing its negative environmental impact. Fish farming in the recirculation system gives no possibility of implementing IMTA in classical perspective due to very specific farming conditions (a very large number of animals) and strict parameters of the environment where animals live.

Incorporation of terrestrial plants into a production system will allow to re-use biogenic elements, which was also pointed out by Turcios and Papenbrock [36]. Illera-Vives et al. [37] draw attention to a high fertilizing potential of waste from fish production in the context of using it for fertilization of organic crops. Fertilization of organic crops with the use of waste from fish production is in compliance with general and specific principles of organic farming. Organic fertilizers, due to varied composition and origin, are an important source of microelements in agroecosystems. When such fertilizers are used regularly, it is very rare to observe a microelement deficiency in cultivated plants. That is why plant production based on rational management of environmental resources should be connected with organic fertilization. All certified primary production quality systems such as Integrated production, GLOBAL G.A.P. or Sai platform, put emphasis on the management of soil organic matter, which is associated, among other things, with the use of organic fertilizers. When assessing the applicability of different materials for use as organic fertilizers or plant growth enhancers, both the microelement content and the content of heavy metals should be taken into account. Microelements are plant nutrients, whereas heavy metals can have an adverse impact on the growth and development of plants. Trace elements which occur in excessive amounts in the environment are accumulated in plant tissues, posing a risk to organisms at subsequent levels of the trophic chain [38].

The studied waste was found to have high iron content. The mean content of this element in all the samples was 0.643% and varied from 0.586 to 0.709% DM (table 2). Iron concentrations in fish farming waste determined in our research are several times higher than generally found in natural fertilizers, which allows the waste in question to be regarded as a valuable source of this microelement. Mean concentrations of boron, barium, cobalt, copper, lithium, manganese and zinc amounted to, respectively, 48.65, 2.785, 0.202, 21.30, 0.211, 44.51 and 121.6 mg ∙ kg⁻¹ DM. The content of microelements determined in the studied waste was generally at a similar level to that observed in natural fertilizers [29,30]. Lithium content in the studied material was several times lower than that observed in natural fertilizers. The studied material contained large amounts of boron, zinc and molybdenum. The content of these elements determined in the waste is observed in natural fertilizers rich in these elements. The content of heavy metals in organic fertilizers is an important criterion of their quality. Concentration of heavy metals does not disqualify the studied materials as fertilizers or soil conditioners. Concentration of cadmium, chromium, nickel and lead was, respectively, 0.164, 1.722, 1.511 and 0.198 mg ∙ kg⁻¹. These values are many times lower than the content of heavy metals allowed in organic fertilizers [39]. One of the most important problems associated with the use of waste materials for crop fertilization is the risk of lack of repeatability of chemical composition of the product. The results of the conducted research point out to a little variation in chemical composition of waste coming from treatment of water from recirculation in aquaculture. The relative coefficient of variation for the studied parameters varied from 7.131% in the case of iron concentration to 40.44% in the case of lead content in it. Variation of the content of elements determined in the waste from African catfish farming, collected in different periods of farming, is much lower than generally found in natural and organic fertilizers. The results of the conducted research indicate unambiguously that waste from water treatment in systems with water recirculation can be a valuable source of nutrients. Despite the fact that this waste contains considerable amounts of organic matter and macromolecules, at present the only legally permitted form
of its management is to transfer it to treatment plants. Such an approach is improper in terms of rationalization of managing biogenic elements and soil organic matter, and also in terms of rationalization of energy consumption. At a dose of 10 Mg of the studied waste, almost 40 kg N, over 50 kg P\(_2\)O\(_5\) and approximately 60 kg Ca will be introduced to soil. In addition, over 4 kg iron and approximately 80 g zinc will be introduced. However, using the studied waste for fertilization or improvement of soil fertility may cause technological problems associated with its application. Physical properties and the risk of odors being emitted during application can be a problem, which was highlighted by Ghaly et al. [32]. The risk of microbiological contamination, which may be a result of storing waste before application, is also an unresolved matter. Before water recirculation waste is permitted for use as fertilizers or soil conditioners, thorough tests connected with its storage and the impact on soil and plant environment should be conducted. Under conditions of insufficient organic fertilization of soils, particularly in areas with a small number of animals, the possibility of using aquaculture waste for fertilization purposes appears to be sound from the environmental point of view and economically substantiated. The matter of the trend in managing water recirculation waste should be resolved at the legislative level.

**Table 2.** Element content in waste generated during the treatment of the water from the rearing of the African catfish

| Parameters | Unit | min   | max   | average | %\(^a\) | Literature\(^b\) dung |
|------------|------|-------|-------|---------|--------|-------------------------|
| SM         |      | 6.236 | 8.110 | 6.988   | 11.59  |                         |
| N general  | %    | 4.859 | 6.202 | 5.354   | 9.750  | 2-3                     |
| P          |      | 2.856 | 3.980 | 3.436   | 13.12  | 6-15                    |
| K          |      | 0.124 | 0.214 | 0.164   | 21.60  | 12-20                   |
| Mg         |      | 0.276 | 0.390 | 0.335   | 11.12  | 4-12                    |
| Ca         |      | 5.389 | 6.925 | 5.920   | 8.999  | 10-30                   |
| Na         |      | 0.084 | 0.165 | 0.118   | 24.41  | 1-4                     |
| Fe         |      | 0.586 | 0.709 | 0.643   | 7.131  | 0.19-0.25               |
| B          |      | 40.11 | 60.12 | 48.65   | 14.39  | 25-80                   |
| Ba         |      | 2.165 | 3.420 | 2.785   | 17.34  | 1-14                    |
| Cd         |      | 0.125 | 0.243 | 0.164   | 25.48  | 0.52                    |
| Co         |      | 0.153 | 0.277 | 0.202   | 26.40  | 0.5-2.5                 |
| Cr         |      | 1.112 | 2.495 | 1.722   | 33.18  | 2-8                     |
| Cu         | mg·kg\(^{-1}\) | 11.26 | 19.56 | 15.11   | 21.30  | 15-185                  |
| Li         | mg·kg\(^{-1}\) | 0.173 | 0.262 | 0.211   | 15.77  | 10-25                   |
| Mn         | mg·kg\(^{-1}\) | 38.45 | 51.56 | 44.51   | 11.53  | 20-180                  |
| Ni         |      | 1.096 | 2.065 | 1.511   | 27.75  | 2.8-9.2                 |
| Pb         |      | 0.108 | 0.311 | 0.198   | 40.44  | 11.1-35                 |
| Sr         |      | 14.96 | 25.62 | 19.73   | 22.06  | 14-56                   |
| Zn         |      | 91.25 | 156.9 | 121.6   | 21.05  | 54-194                  |
| As         |      | 8.445 | 12.56 | 10.43   | 15.44  | 1-8                     |
| Mo         |      | 22.25 | 29.89 | 26.72   | 11.01  | 3-12                    |
| Se         |      | 1.985 | 2.824 | 2.328   | 12.89  | -                       |

\(^a\)relative standard departure

\(^b\) data from literature (32,33)
4. Conclusion
1) The studied waste was found to have high concentrations of nitrogen and phosphorus. These are the main elements which decide on the fertilizing value of the studied material. Nitrogen content was approximately 5.354% N, whereas phosphorus content – 3.436% P_2O_5.
2) The content of other macroelements and trace elements was at a level observed in natural fertilizers in different regions of the world.
3) Chemical composition of the studied waste collected at different times was found to be constant.
4) Maximum permissible heavy metal content in natural fertilizers was not exceeded in the studied waste.
5) From the point of view of chemical composition, the studied waste from fish farming should be used for fertilization. Transferring this waste, along with municipal wastewater, to a treatment plant is a part of inefficient waste management. Therefore, the issue of proper management of waste from water treatment in aquaculture facilities with water recirculation should be regulated at the legislative level.

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