ECOCYCLES
ISSN 2416-2140

OPEN ACCESS
Scientific journal of the
European Ecocycles Society

Ecocycles, Vol. 11, No. 1, pp. 83-93 (2025)
DOI: 10.19040/ecocycles.v11i1.495

RESEARCH ARTICLE

Exploring the impact of fish effluents as organic fertilisers on the growth and yield of soil-grown bok choy and turnip

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Abstract – Whilst livestock manure is allowed and indeed encouraged as a fertiliser in organic arable crop production in Europe, the use of effluents from aquaculture farms is not permitted under the current European regulatory framework, Council Regulation (EU) 2018/848. In this study, the effects of two types of fish effluents – fish water and fish sludge – from an aquaponic system were tested on the yields of bok choy (*Brassica rapa* subsp. *chinensis*) and turnip (*Brassica rapa* subsp. *rapa*) grown in certified subsoil and compared with the use of composted horse manure as fertiliser. The results for both crops demonstrate a good performance of fish effluents, and especially fish sludge, compared with livestock manure, and this puts into question the continued prohibition of the use of fish effluents in organic agriculture in the European Union. This research provides critical insights into the viability of fish effluents as sustainable fertilisers in organic crop production. The findings advocate for a reconsideration of the current regulatory framework, promoting the integration of aquaponics in organic farming systems, which could enhance resource efficiency and reduce environmental impacts.

Keywords – aquaponics, bok choy, turnip, fish, effluent, organic

Received: October 20, 2024 Accepted: February 18, 2025

1. INTRODUCTION

According to the new Council Regulation (EU) 2018/848 on organic production, plant production rule 1.9.2, which entered into force on 1 January 2022, the use of livestock manure is encouraged:
'The fertility and biological activity of the soil shall be maintained and increased ... by the application of livestock manure or organic matter, both preferably composted, from organic production' (European Commission, 2018).

Where the nutritional needs of plants cannot be met by the measures provided for in rule 1.9.2, only certain fertilisers and soil conditioners derived from non-organic production are allowed to be used, as laid out in Chapter 24 of the Regulation. At the time when the new regulations were published, these were listed in Annex I of Regulation (EC) No 889/2008 (European Commission, 2008). The list does not include waste from aquaculture systems (known as 'fish effluents') and, subsequent to a request for clarification, the European Commission responded that '*fish raw manure is not mentioned in Annex I to Regulation (EC) No 889/2008 therefore its use is at present not allowed in organic production'* (Nathalie Sauze-Vandevyver, pers. comm., 2020). Whilst Annex I to Regulation (EC) No 889/2008 has subsequently been repealed by Annex II to Regulation (EU) 2021/1165 (European Commission, 2021a), the list of authorised fertilisers and soil conditioners essentially remains the same, with only farmyard and poultry named as permitted types of manure from non-organic production.

Fish effluents have been used as fertilisers for a variety of food crops grown in soil, often improving yields; these include tomato (Castro et al., 2006; Gravel et al. 2015; Khater et al., 2015; Mangmang et al., 2015a; Pattillo et al., 2020), chicory (Lenz et al., 2021a), lettuce (Mangmang et al., 2015b; Lenz et al., 2021b), cucumber (Mangmang et al., 2016), cabbage (Elsbaay & Darwesh, 2022), as well as soybean, potato, and onion (Abdelraouf, 2017; Fruscella et al., 2023). Since fish effluents are similar in their chemical composition to livestock manures they are therefore suitable to be used as agricultural fertilisers (Naylor et al., 1999), discharging them, which is routinely done (Montanhini Neto & Ostrensky, 2013), is effectively a waste of a useful resource. This is especially true for fish sludge, which have been found to hold 7–32% of the total nitrogen and 30–84%

of the total phosphorus of the overall effluent (Cripps & Bergheim, 2000). This is in contrast with fish water, filtered aquaculture effluents, which are generally deficient in phosphorus, potassium, calcium and some micronutrients (Delaide et al., 2019), although this can be corrected by increasing the fish stocking density, managing pH levels, and adding supplements such as rock phosphate, potassium sulphate, and calcium chloride (Harika et al., 2024) .

Recycling aquaculture effluents by using them as fertilisers for crop production could provide solutions to several urgent problems by i) reducing the negative impact that fish farm effluent discharge has on the water quality of aquatic ecosystems, such as increasing eutrophication rates (Kledal et al., 2019; Famoofo & Adeniyi, 2020), ii) partially substituting artificial fertilisers, which require substantial amounts of energy (Rahimi et al., 2020), as well as natural resources to be produced (Vaccari, 2009; Scholz et al., 2013) and iii) reducing energy to process and treat the effluents (Tom et al., 2021).

In this study, fish effluents[1] from an aquaponic system were used as fertilisers and compared with composted horse manure for the cultivation of two subspecies of bok choy (*Brassica rapa* subsp. *chinensis*) and turnip (*Brassica rapa* subsp. *rapa*), grown in British certified topsoil. In both experiments, three fertilisation regimes were employed: horse manure (which is permitted in EU organic legislation Commission Regulation (EU) 2018/848), fish water, and aerobically processed fish sludge. Aerobic mineralisation was chosen over anaerobic mineralisation because it generally requires a low level of low-skilled maintenance, the water can be used directly for plant fertilisation, is a faster procedure (Chen et al., 1997), offers a higher total percentage of suspended solids removal and lowered chemical oxygen demand (Delaide et al., 2018), eliminates the possibility of anaerobic secondary metabolites and other substances toxic to plants, reduces strong odours, has lower emissions of greenhouse gases (Zhang et al., 2021), decreases the risk of fertiliser-induced toxicity (Delaide et al., 2021), results in lower nutrient loss and higher nutrient capture (Monsees et al., 2017), and results in better mineralisation performance (Delaide et al., 2018), compared to anaerobic mineralisation. The fertilisation regimes were compared in order to challenge the exclusion of fish effluents in organic production by the EU and the UK. The growth of the two plant subspecies was assessed by measuring the final plant yield.

2. MATERIALS AND METHODS

2.1 Setting

Two experiments were performed, in which bok choy and then turnip were grown sequentially outside in plastic containers in British certified topsoil (BS3882) to provide a suitable standard growing medium that emulates an agricultural soil, and fertilised with either composted horse manure or two types of fish effluents. A control treatment was also employed, consisting of a watering regime with tap water without any fertiliser. Physical analyses of the final plant yields, including weight, width, and height, undertaken at the end of the experiments to assess the effect of the different treatments. The experiments took place on a green roof on the second floor of the Stockwell Street building, University of Greenwich, SE10 9BD in London, UK, between August 2021 and March 2022.

Both bok choy (*Brassica rapa* subsp. *chinensis*), variety 'Hanakan F1' and turnip (*Brassica rapa* subsp. *rapa*), variety Purple Top Milan, were chosen for their widespread cultivation in the south-east of the UK, their popularity, ease of cultivation, fast growth, compact shape, and low space requirements.

2.2 Treatments

All plants were watered from the top, and given either 700 ml of tap water or fish effluents. For the experiment on bok choy, four treatments, with three replicates of each treatment, were devised. In all treatments, plants were grown in BS standard topsoil. For treatment T, the plants were watered with tap water daily. For treatment M, composted horse manure was mixed in the soil before the beginning of the experiment (3 kg in each box, roughly 23% of total volume), and the plants watered with tap water daily. For treatment F, plants watered with fish water daily. For treatment FS, plants were watered with fish water daily, and every third day with aerobically treated fish sludge only. The bok choy was grown in late summer (from August to September, 33 days), when the temperatures were still high and thus daily watering was required, which resulted in the FS treatment for bok choy being fish water two days out of three, with the third day consisting of fish sludge

The exact same regime was devised for turnip, but differed with respect to watering intervals. The turnips were grown in autumn and winter (November to February, 105 days), and thus in much lower temperatures, where daily watering was not required. For this reason, the plants in the experiment on turnip were only watered once every three days across all treatments, and the FSL treatment consisted of only fish sludge. This was done in order to investigate whether a fertilisation regime with only fish sludge was effective or detrimental to the plants, and to see whether any differences in yield would result between a pure fish water fertilisation regime and a pure fish sludge regime.

2.3 Soil Mix Compositions

The soil used was a BS3882 certified peat-free manufactured topsoil blended with quarried sand and 40% compost. The soil was analysed for nutrients and physical

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[1] In this paper, the more generic term 'fish water effluents' or 'fish effluents' refers to both fish water and fish sludge. "Fish water" refers to the filtered fish effluent, while "fish sludge" refers to the unfiltered fish effluent.

and chemical parameters by NRM Labs[2] (Table 1).

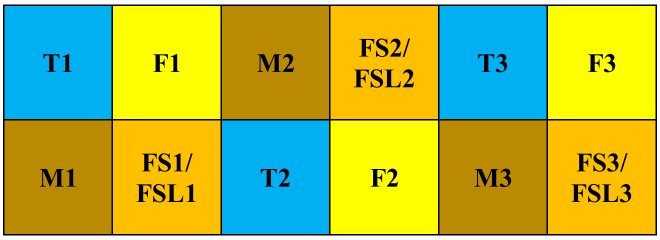
Table 1. Values for pH, elements, and physical parameters of the topsoil used.

Parameter	Values
pH	8.48
P	47.6 mg/l
K	1887.05 mg/l
Mg	213.65 mg/l
Mn	4.51 mg/l
Cu	6.17 mg/l
B	2.6 mg/l
Na	103 mg/l
Zn	18.68 mg/l
Ca	1290 mg/l
Av Fe	69.59 mg/l
NO_3^-	260.8 kg/ha
NH_3	3.88 kg/ha
SMN	265 kg/ha
O.M. LOI	7.94 %
Av SO_4	66.41 mg/l
CEC	18.2 meq/100g
Bulk Density	617 us/cm

2.4 Experimental Design

For both experiments, each plastic growing container (dimensions: length 44 cm, width 30 cm, height 18 cm) containing approximately 13L of soil constituted a single replicate of which there were three for each treatment. For the bok choy experiment each container had six plants, whilst five plants per container were used in the turnip experiment. The boxes were drilled with five 1 cm holes at the bottom to prevent water stagnation, and were placed inside larger plastic trays filled with water in order to prevent slugs from getting inside; drainage was ensured, as the containers were standing on legs at a higher level than the water in the trays underneath. All the boxes were covered with 5 x 7 mm plastic braided mesh to protect the plants from birds and insects. The boxes were arranged in two rows of six boxes each (Figure 1).

The experiment on bok choy started on 11 August and ended on 13 September 2021, lasting a total of 33 days. The experiment on turnip started on 10 October 2021 and ended on 1 March 2022, lasting a total of 142 days. For both experiments, seeds were planted in seedling trays indoors in the same soil as that used for the experiment, one per cell. The seedlings were transferred to the boxes two weeks after sowing. The plants were watered in the morning.



T1	**F1**	**M2**	**FS2/ FSL2**	**T3**	**F3**
M1	**FS1/ FSL1**	**T2**	**F2**	**M3**	**FS3/ FSL3**

Figure 1. Arrangement of the boxes (top view), showing the position of treatment T (tap water) replicates (blue), treatment M (manure) replicates (brown), treatment F (fish water) replicates (yellow), and treatment FS (fish sludge, for bok choy) and FSL (fish sludge, for turnip) replicates (orange).

2.5 Watering and Fertilisation Sources

Tap water, fish water, and fish sludge were the three water types in the experiments. 'Tap water' was potable water from the University system supplied by Thames Water; 'fish water' was filtered fish water, extracted from the degassing tank after passing all the filtration units and prior to entering the hydroponic tanks; and 'fish sludge' was unfiltered fish water, where the effluents that still contains solids (mainly fish excrement and uneaten food), were extracted from the bottom of the primary settlement filtration tank, prior to it being passed to the secondary filtration units. Before being used, the bottom waste was extracted and placed in an aerobic reactor comprising a container, an AquaForte V60 air blower, and a diffuser to enhance aerobic conversion of the waste into useful nutrients.

The two fish effluent types were taken from the University of Greenwich aquaponic system, stocked with approximately 350 Nile tilapia (*Oreochromis niloticus*) coupled with a floating raft vegetable growing system, with ornamental gourds, turmeric, cape gooseberry and mint in a 36 m^2 glasshouse. The tilapia ranged between 100–500 g in weight and were fed twice a day with Aller Aqua Primo 6mm sinking pellet feed[3], for a total of 500 g of feed per day. The methods employed for water and soil analyses are listed in Appendix A. The composition of the tap water was obtained from Thames Water[4], and the composition of the two fish waters was analysed (Table 2). The nutrient values of the composted horse manure that was used for Treatment M are described in Table 3. The main nutrients for plant growth were analysed in g/m^2 for the two experiments (Table 4).

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[2] Address: Coopers Bridge, Braziers Ln, Winkfield Row, Bracknell RG42 6NS. Website: https://cawood.co.uk/nrm/.

[3] Feed composition: 37% crude protein, 12% crude fat, 32.5% nitrogen-free extracts, 7% ash, 3.5% fibre, 1% phosphorus, 19.6MJ gross energy, 16MJ digestible energy.

[4] Water parameters from the London postcode where the experiment took place obtained from https://www.thameswater.co.uk/.

Table 2. Parameters of the tap water and the two fish effluents used, analysed by NRM Labs. Values reporting a "-" signify that that measurement was not undertaken.

Parameter	Tap Water	Fish Water	Fish Sludge
pH	7.60*	6.7	5.8
$CaCO_3$	323 mg/l	-	-
Conductivity (20°C)	594 (μS/cm)	791	1020
Turbidity	<0.09 FTU	-	-
NH_4^+	0.12 mg/l	-	-
NO_3^-	27.2 mg/l	44.3	69.6
NO_{3}-/NO_2^-	0.55 mg/l	-	-
NO_2^-	0.013 mg/l	-	-
Hardness	244 mg/l	-	-
Fe	3.6 μg/l	-	-
Mg	4.3 mg/l	12.33 mg/l	18.34 mg/l
Alkalinity	-	36 mg/l	13 mg/l
SO_4^{2-}	-	161.8 mg/l	204.4 mg/l
B	-	0.01 mg/l	0.03 mg/l
Na	-	44.0 mg/l	50.5 mg/l
Cl^-	-	59.2 mg/l	69.8 mg/l
P	-	4.4 mg/l	12.8 mg/l
K	-	1.5 mg/l	3.5 mg/l
Ca	-	112.6 mg/l	136.4 mg/l
CO_3	-	< 10 mg/l	< 10 mg/l
TDS	-	553.7 mg/l	714 mg/l

*pH measured consistently at the University of Greenwich shows a value of approximately 8.40.

Table 3. Composted horse manure nutrient values, analysed by NRM Labs.

Measurements	Values	Amount (kg) per fresh tonne
pH	8.56	-
Total N	0.71% w/w	3.96
NH_4^+	<10 mg/kg	<0.01
NO_3^-	155 mg/kg	0.09
P	0.23 % w/w	2.94
K	0.70 % w/w	4.67
Mg	0.26 % w/w	2.40
Ca	20.75 mg/kg	730.60
SO_4	0.15 % w/w	2.13
Cu	35.0 mg/kg	0.02
Zn	116 mg/kg	0.06
Na	0.05 % w/w	22.31
Dry matter	55.8%	558.00

At the end of the experiments, each plant was measured for weight, width (maximum horizontal distance between two leaf ends, only for bok choy), height (maximum distance from stem base to highest leaf), number of leaves (only for bok choy), weight of leaves (only for turnip), and taproot weight (only for turnip).

Table 4. Soil main macronutrients found in treatments F (fish water), FS/FSL (fish water and fish sludge for bok choy; only fish sludge for turnip), and M (manure) over the whole duration of the two experiments, analysed by NRM Labs.

Parameters	Treatment T (g/m^2)		Treatment F (g/m^2)		Treatment FS/FSL (g/m^2)		Treatment M (g/m^2)
	bok choy	turnip	bok choy	turnip	bok choy	turnip	bok choy & turnip
NO_3^-	4.76	6.83	7.75	11.2	9.23	17.47	2.05
P	-	-	0.77	1.1	1.26	3.21	66.82
K	-	-	0.26	0.38	0.38	0.88	106.14
Mg	0.75	1.08	2.16	3.09	2.51	4.60	54.55
SO_4^{2-}	-	-	28.32	40.61	30.8	51.30	48.41
Na	-	-	7.7	11.04	8.08	12.68	507.05
Ca	-	-	19.71	28.26	21.09	34.24	16604.55

2.6 Statistical Analysis

The R statistical software (R Core Team, 2021) was used to analyse the plant yield data, and 1-way ANOVA and Tukey HSD tests were performed to identify statistical differences across treatments. 1-way ANOVA was performed to assess treatment effects and when such effects were significant, post-hoc pairwise comparisons were calculated using a Tukey HSD test. No random factors were considered, and the fixed factors were the treatments; the response was a function of the treatments. Each plant or plant part was measured, and the average was used in the ANOVA model. The standard errors were calculated from the analysis of variance residuals.

3. RESULTS AND DISCUSSION

3.1 Bok Choy

At the end of the experiment, four trays of plants on one side of the set-up had been damaged by pests, most likely by the caterpillars of cabbage white butterflies (*Pieris rapae*) which had been observed on the premises throughout the duration of the experiment, trying to enter the protective mesh. The four trays corresponded to one replicate each, therefore the results were confined to only two replicates per treatment instead of three.

A significant difference in size and weight was observed between treatments, with plants fertilised with fish effluents exhibiting the largest sizes (Figure 2). Yield data are also reported (Table 5).

Table 5. Means with standard errors for weight, width, height, and leaf number across treatments in bok choy.

Treatment	Weight (g)	Width (cm)	Height (cm)	Leaf number
T (tap water)	10.65 ± 0.81	5.45 ± 0.26	14.36 ± 0.48	7.45 ± 0.24
M (horse manure)	20.05 ± 2.19	6.22 ± 0.26	15.62 ± 0.75	7.95 ± 0.43
F (fish water)	50.05 ± 6.46	8.73 ± 0.53	18.87 ± 0.69	8.15 ± 0.43
FS (fish sludge)	65.55 ± 6.89	9.95 ± 0.40	20.05 ± 0.64	8.90 ± 0.58
p-value	<0.001	<0.001	<0.001	0.1481

In all measurements, the residues of the model were found to be normal, no outliers were identified, and no mistakes in the data were identified. All treatments were found to have a significant effect ($p<0.05$) in all yield measurements except for leaf number. The same pattern observed across all measurements, with treatment FS performing the best, followed by treatment F, then by treatment M, and finally by treatment T (Figure 3). In all measurements, no significant difference between F and FS was found.

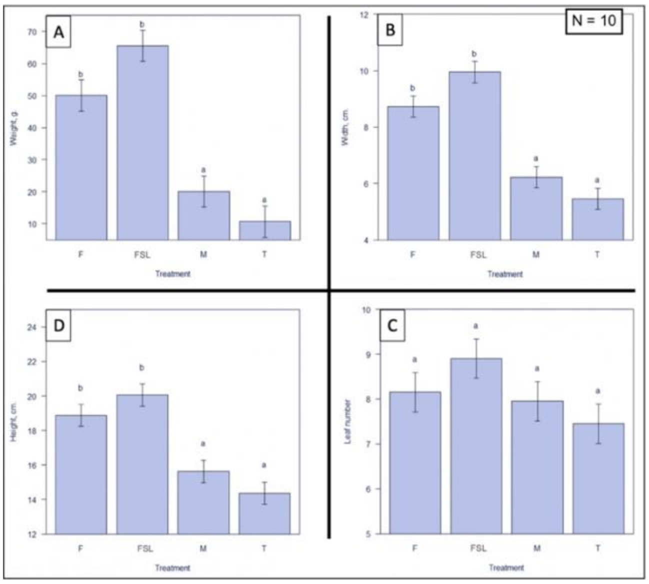

Figure 3. Tukey HSD multiple comparison test bar chart for plant weight (A), plant width (B), leaf number (C), and plant height (D) of bok choy, with the error bars representing the pooled standard error. Treatments: F – fish water; FS – fish water and fish sludge; M – manure; T – tap water. Different letters correspond to significant differences in means. Sample number (n) in the top right corner.

In all measurements, the data distribution was found to be normal, no outliers were identified, and no mistakes in the data were identified. In all yield analyses, the trend was, from highest to lowest value: treatment FS > treatment F > treatment M > treatment T. In all measurements, the two fish effluent treatments (FS and F) performed better than the horse manure treatment.

3.2 Turnip

All plants grew (Figure 4), with only two mortalities (one plant from replicate F3 and one from replicate FSL3), which occurred for unknown reasons. During the last two weeks of the experiment all plants bolted and formed flowers which were much taller than the rest of the plant, thus plant height measurements were taken from the base of the stem to the top of the flower stock.

Figure 4. Final yield at the end of the turnip experiment, with the mesh removed.

A clear difference in size was observed between treatments, with plants fertilised with the fish effluents exhibiting the largest sizes (Figure 5). Yield data are also reported below (Table 6).

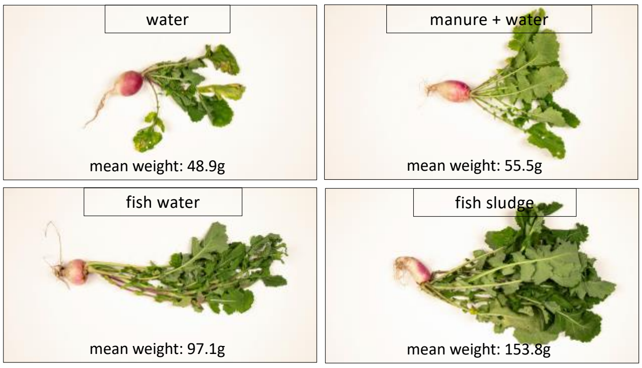

Figure 5. Comparison of randomly selected turnip plants, one per treatment, showing the differences in size and mean weight.

Table 6. Means and standard error for height, total weight, taproot weight, and leaf weight across treatments in turnip.

Treatment	Height (cm)	Total weight (g)	Taproot weight (g)	Leaf weight (g)
T	37.75 ± 2.96	48.94 ± 5.13	20.23 ± 4.25	28.72 ± 2.73
M	37.08 ± 2.24	55.53 ± 7.71	18.83 ± 5.00	36.69 ± 4.17
F	47.71 ± 1.71	97.06 ± 9.03	24.99 ± 5.96	72.07 ± 4.39
FSL	47.41 ± 1.92	153.79 ± 14.90	26.99 ± 4.77	126.81 ± 12.08
p-value	0.001	<0.001	0.623	<0.001

In all measurements, the residues of the model were found to be normal, no outliers were identified, and no mistakes in the data were identified. The treatments were found to have a significant effect (p<0.05) in all yield measurements except for taproot weight. The same pattern observed across all measurements, with treatment FS performing the best, followed by treatment F, then by treatment M, and finally by treatment T (Figure 6). In all measurements, no significant difference between F and FSL was found.

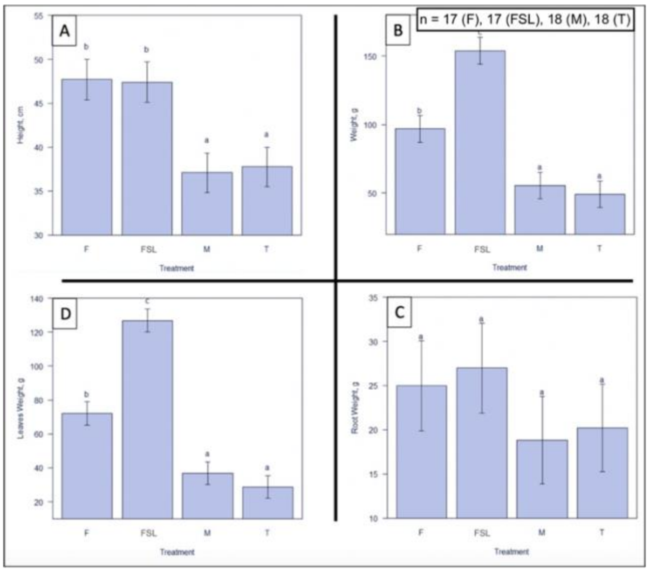

Figure 6. Tukey HSD multiple comparison test bar chart for plant height (A), plant weight (B), taproot weight (C), and leaf weight (D) of turnip, with the error bars representing the pooled standard error. Treatments: F – fish water; FSL – fish sludge; M – manure; T – tap water. Different letters correspond to significant differences in means. Sample size (n) in the top right corner.

In all measurements, the data distribution was found to be normal, no outliers were identified, and no mistakes in the data were identified. In all measurements, the fish effluent treatments (F and FSL) performed the best.

4. DISCUSSION

For both bok choy and turnip, the results obtained are in line with other studies on the subject. In an experiment conducted by Palada et al. (1995), bok choy was fertilised with fish effluents (fish water and fish sludge) from tilapia culture tanks, two to three times per week. The fish effluent treatments resulted in a significant net increase in yield, with the fish effluents with no solid removal performing better than the fish effluents where solids had been removed. Although not utterly comparable with the present study because of different growing conditions, in a study by Limbu et al. (2017) bok choy plants were irrigated with pond water from African sharptooth catfish (*Clarias gariepinus*) and Nile tilapia polyculture at a density of 3 fish/1.25 m^3 or 2.4 fish per 1 m^3 (the ponds were also fertilised with cattle manure at a rate of 280 kg/ha per week), resulting in a 1.8 times yield increase compared with those irrigated with stream water. Cerozi et al. (2022) compared the growth of turnip fertilised with fish water from a recirculating aquaculture system stocked with blue tilapia (*Oreochromis aureus*) with plants irrigated with only tap water. Whilst the study found no significant difference in the biomass of the crops in each treatment, the authors concluded that the results were probably skewed by the fact that the soil used in the experiment was relatively nutrient-rich, although they do not state its nutrient concentration.

The results of the experiments from this study greatly exceeded such yield increases, with the plants from the fish water (F) and the fish water combined with fish sludge (FS) producing yields 4.7 and 6.2 times higher than the ones fertilised with tap water (T), although the stream water used in the study by Limbu et al. (2017) most likely contained nutrients for plant growth as well, thereby reducing the nutritional gap between the two treatments, and the fish stocking density of the ponds was much lower than that in the University of Greenwich aquaponic system. Both studies, however, show the effectiveness of fish effluents as fertilisers for improving the yields of bok choy. Furthermore, Cerozi et al. (2022) compared the growth of bok choy fertilised with fish water from a recirculating aquaculture system stocked with blue tilapia (*Oreochromis aureus*) with plants irrigated with only tap water, and the study found no significant difference in the biomass of the crops in each treatment. The authors conclude that the results were probably skewed by the fact that the soil used in the experiment was relatively nutrient-rich, although they do not state its nutrient concentration.

By prohibiting the use of fish effluents as fertilisers, the EU organic regulations misalign with key EU policies and strategies. At the heart of the European Commission's policy agenda is the European Green Deal. Under the Green Deal's Farm to Fork Strategy and the EU Biodiversity Strategy for 2030, the European Commission has set a target of at least 25% of the EU's agricultural land to be under organic farming by 2030 (European Commission, 2021b). This ambition will however require thorough consideration of how to guarantee a sustainable supply of nutrients to organic farms in the future. Whilst organic farms with livestock are able to reuse nutrients using their livestock, organically produced feed often comes from the redistribution of nutrients from stockless feed-producing farms to livestock farms, thus not representing a net import of nutrients (Reimer et al., 2023). The origin of the official list which defines which non-organic fertilisers are permitted in organic farming dates back to 1974, and its contents reflect the common fertilisation practice on central European organic farms at that time (Løes & Adler, 2019). If the organic sector in Europe is to expand in a sustainable fashion and meet the European Commission's target, the list of permitted fertilisers needs to be updated with an increased range of nutrient sources tailored to organic stockless farms, including fish effluents.

Despite the fact that Commission Regulation (EU) 2018/848 (article 6c) advocates '*the recycling of waste and by-products of plant and animal origin as input in plant and livestock production*', the limited range of permitted manures from non-organic production (i.e. only farmyard and poultry manure) is at odds with another bastion of the European Green Deal, the Circular Economy Action Plan, which focuses on sustainable resource use, including circular approaches to nutrients and water in food production. A key element is the Integrated Nutrient Management Action Plan (INMAP), which aims to reduce the use of chemical and mineral fertilisers by at least 20%, and to reduce by 50% the loss of nutrients (mainly nitrogen and phosphorus) by encouraging their re-use, thus increasing the efficiency of the nutrient cycle and, in turn, improving food security, protecting human health, and preserving ecosystems (European Commission, 2023). By excluding the use of fish effluents as fertilisers, it can be argued that the EU organic regulations do not fully support a circular approach to sustainable agriculture which seeks to maximise nutrient recycling. The European Commission acknowledges that land-based recirculating aquaculture systems are likely to become more common in the future due to their clear benefits, which include low water use (European Commission, 2021c). If the waste-to-value opportunity provided by fish effluents from these systems is not recognised by allowing their use in organic agriculture, this will inevitably lead to their discharge into the environment, thereby increasing pollution of waterways and further moving nutrients from the land into the sea and /or requiring significant funds to treat these effluents.

5. CONCLUSION

The bok choy and turnip experiments indicate, as previous researchers have that fish effluents are effective fertilisers. The results obtained in the experiment on bok choy substantiated most of the research done by previous authors on this crop (Palada et al., 1995; Limbu et al., 2017; Cerozi et al., 2022). The results also confirm the previous outcomes of Fruscella et al. (2023) where onions similarly performed well with fish effluents. The results from these experiments confirm the effectiveness of fish effluents as fertilisers, and highlight the need for the EU to rethink their exclusion in organic production in the EU. This is particularly necessary in the light of EU and UK policies to expand organic production and in the general need to source organic nutrients, rather than inorganic ones, which have no relevance in the circular economy and where supplies are threatened through wars, and threats to the supply chains.

Despite the positive outcomes observed with fish effluents in promoting the growth of bok choy and turnip, it is important to acknowledge potential nutrient limitations associated with their use. Fish effluents typically vary in nutrient composition depending on several factors, including the species of fish, feeding practices, and management of the aquaculture system (Zhanga et al., 2021). Key nutrients such as nitrogen, phosphorus, and potassium, while present in beneficial quantities, may still be insufficient to meet the optimal growth requirements of all crops (Eck et al., 2019; Lobanov et al., 2021). Additionally, the ratios of these nutrients can influence plant health and yield, potentially leading to deficiencies in micronutrients that are critical for specific crop performance (Fruscella et al., 2023; Kankia et al., 2023). Future studies should aim to characterise the nutrient profiles of these effluents more comprehensively and assess their long-term impacts on soil health and crop nutrition.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Stephen Young from the University of Greenwich for the help provided in the statistical analyses.

APPENDIX

The following are the methods employed by NRM Labs to analyse the substrate and fish effluent samples.

Substrate – ammonium nitrate-extractable calcium and sodium

Samples were air-dried at or below 30 °C and sieved to 2 mm. Calcium and sodium were extracted by shaking the samples with M ammonium nitrate at 20 °C for 30 minutes. After filtration, the calcium concentration in the extract was quantified via Atomic Absorption Spectrophotometry.

Substrate – available sulphate

Samples were air-dried at or below 30 °C, sieved to 2 mm, and extracted under controlled conditions with a phosphate buffer (ratio 1:2). The filtered extract was then analysed by Inductively Coupled Plasma Emission Spectroscopy.

Substrate – DTPA-extractable manganese, iron, copper, and zinc

Samples were air-dried at or below 30 °C and passed through a 2 mm mesh. Zinc, manganese, iron, and copper were extracted at 20 °C using a DTPA solution in a 1:2 ratio. Under these conditions, the metal ions achieved equilibrium with the chelating agent. A pH of 7.3 enabled DTPA to extract iron alongside the other metals.

Substrate – hot water-soluble boron

Samples were air-dried at or below 30 °C, sieved through 2 mm, and subjected to hot water extraction to assess boron availability. The boron concentration in the resultant extract was measured using ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy).

Substrate – organic matter content by loss on ignition at 430 °C

Samples were air-dried at or below 30 °C, passed through a 2 mm sieve, and combusted at 430 °C. The loss in mass due to combustion was reported as the organic matter content (in %) on a dry matter basis.

Substrate – mineral nitrogen (available N)

Samples were chopped, thoroughly mixed, and a portion was shaken with 2 M KCl to extract mineral-N fractions. A dry matter determination was also performed. If mineralisable N was required, a separate portion was incubated anaerobically at 40 °C in water for one week to induce nitrogen mineralisation, followed by KCl extraction. Once in solution, nitrate-N, nitrite-N, and ammonium-N were measured colourimetrically.

- Nitrate-N and nitrite-N: These were determined based on a diazo compound formed by reaction of nitrite with sulphanilamide, which was then coupled with N-1-naphthylethylenediamine dihydrochloride to produce a red azo dye (measured at 540 nm). In channel one, nitrate was fully reduced to nitrite by cadmium metal in an open tubular cadmium reactor (OTCR), enabling measurement of total oxidised nitrogen (TON) as nitrite plus reduced nitrate. In channel two, only nitrite was measured; nitrate-N was calculated by subtracting nitrite from TON.
- Ammonium-N: In channel three, ammonium reacted with alkaline hypochlorite and phenol to yield indophenol blue, with sodium nitroprusside acting as a catalyst. The absorbance was measured at 640 nm. A combined potassium sodium tartrate/sodium citrate reagent was added to prevent precipitation of calcium and magnesium hydroxides.

Substrate – pH and lime requirement

Samples were air-dried at or below 30 °C and sieved to 2 mm. pH was assessed potentiometrically in a suspension formed by mixing the samples with water in a 1:2.5 ratio. Because temperature affects pH, measurements were conducted under controlled thermal conditions.

Substrate – Olsen's extractable phosphorus

Samples were air-dried at or below 30 °C and sieved to 2 mm. The available phosphorus was extracted by shaking the samples at 20 °C with 0.5 M sodium bicarbonate for 30 minutes. The phosphorus concentration in the extract was determined by flow injection analysis/colourimetry, where acid ammonium molybdate formed the phosphomolybdate ion. Reduction with ascorbic acid produced a blue complex, measured at 880 nm. Calibration was carried out using commercial phosphate standards traceable to SI units.

Substrate – ammonium nitrate-extractable potassium and magnesium

Potassium and magnesium were extracted by shaking the samples with 1 M ammonium nitrate at 20 °C for 30 minutes. After filtration, their concentrations in the extract were measured by Atomic Absorption Spectrometry, with calibration based on commercial standards traceable to SI units.

Fish effluent – nitrate nitrogen

Nitrate-N was determined colourimetrically from the formation of a diazo compound between nitrite and sulphanilamide, which subsequently coupled with N-1-naphthylethylenediamine dihydrochloride to produce a red azo dye, measured at 540 nm. In channel one, nitrate was completely reduced to nitrite by cadmium metal in an open tubular cadmium reactor (OTCR), permitting the measurement of total oxidised nitrogen (TON) as the sum of nitrite and reduced nitrate. In channel two, only nitrite was measured; hence, nitrate-N was derived by subtracting the nitrite concentration from the TON.

Fish effluent – dissolved elements

Particulate matter was removed by filtration, and the filtrate was analysed for selected elements using either Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) or Inductively Coupled Plasma Emission Spectroscopy (ICP-OES). The choice of technique depended on the element in question and the required Limit of Detection, with ICP-MS enabling lower detection limits.

Fish effluent – electrical conductivity

The conductivity of the solution was measured with an EC meter, standardised to 25 °C.

Fish effluent – pH

pH was measured potentiometrically under temperature-controlled conditions to account for temperature effects on the measurement.

Fish effluent – total dissolved solids

Samples were filtered through glass fibre paper to remove suspended solids. A known volume of the filtrate was dried at 180 °C, and the resulting residue was weighed to determine the total dissolved solids.

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