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Sustainable Production of Tomato Using Fish Effluents Improved Plant Growth, Yield Components, and Yield in Northern Senegal

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Abstract: Aquaculture and agriculture integration is essential for maximizing water and land productivity in arid and semi-arid regions. Thus, the increase in global water scarcity and the dual use of water for crop and fish production has the potential to optimize water use, dispose of aquaculture wastes, provide additional nutrients to crops, and reduce inorganic fertilizer usage, thus maximizing farm productivity. This greenhouse study was conducted to determine the effects of fish effluents on the growth, yield parameters, and yield of tomatoes (*Solanum lycopersicum* L.). The experiment was carried out in a randomized complete block design with six replications. The 13 treatments consisted of three irrigation water types (river water—control, *Nile tilapia—Oreochromis niloticus*, African sharptooth catfish—*Clarias gariepinus*), four fertilizers (chicken manure, cow manure, sheep manure; recommended rate of NPK—280 kg ha^{-1} of 10-10-20), and six mixed treatments with fish effluent and 50% of the applied rate of manure alone. Results showed that irrigation with *C. gariepinus* effluent increased the stem diameter by 21%, the number of flowers by 88%, the fruit number by 50%, the fruit diameter by 24%, the mean fruit weight by 34%, and total fruit weight of tomato by 96% compared to NPK treatments. These effects were more evident when *C. gariepinus* was mixed with poultry, cow, and sheep manures, which resulted in significantly greater values than recommended rates of NPK. The higher productivity observed from the combined use of *C. gariepinus* and manure treatments (133% increase, on average) compared to NPK treatments was related to the continuous supply of nutrients and the increase of yield parameters. Therefore, the combined use of *C. gariepinus* effluent and manure can be a viable alternative for smallholder farmers, for whom inorganic fertilizers are often neither affordable nor available.

Keywords: *Solanum lycopersicum*; *Clarias gariepinus*; *Oreochromis niloticus*; aquaculture and agriculture integration; yield; Senegal

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1. Introduction

The rational use of water in agriculture is of paramount importance as the world's freshwater resources are under increasing threat. It is estimated that 70% and 80% of the world's freshwater is used for crop irrigation, while water use conflicts are expected to increase in arid and semi-arid regions due to recurrent droughts, severe water scarcity, and acute food insecurity [1]. In addition, ever-increasing population growth, coupled with the intensification of economic activities to supply their needs, has led to increased competition for limited water resources. Efficient approaches to maximize farm production without increasing water consumption are crucial to sustainable agriculture and mitigating the mentioned vulnerabilities [2–4]. Among these approaches, the integration of aquaculture and agriculture using fish effluents offers on-farm synergy between fish farming and crop production. The technique simultaneously enables the efficient use of scarce water resources, with an increase in soil fertility and a concomitant reduction of fertilizer use and groundwater contamination, consequently increasing farm sustainability and productivity [5,6] (Figure 1).

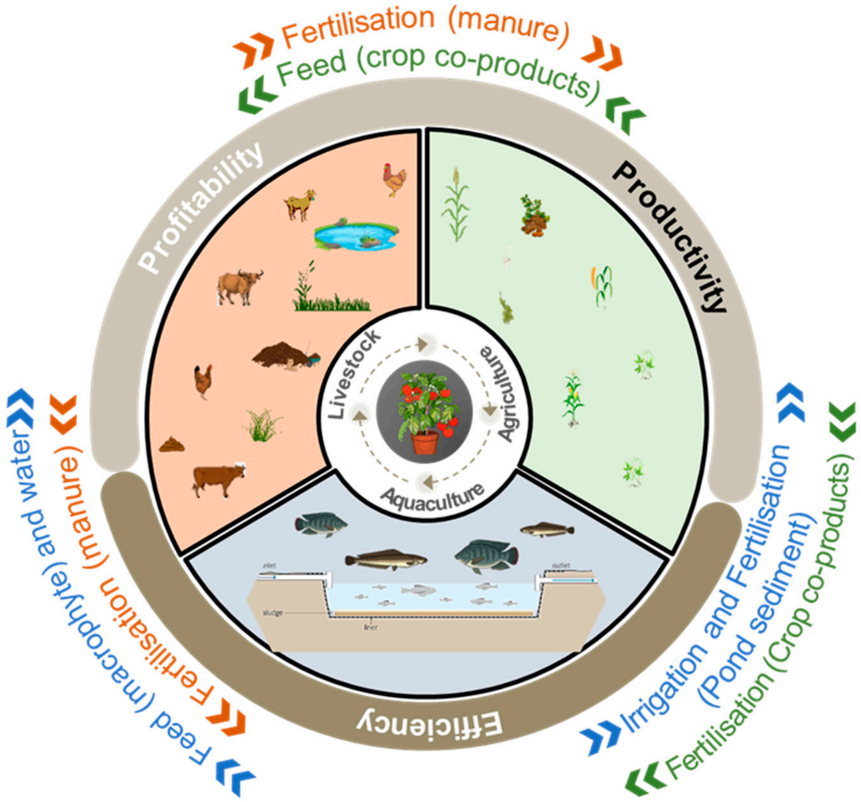

Figure 1. Potential benefits from the integration of aquaculture, livestock, and agriculture.

Fish effluents are defined as nutrient-rich water that contains both inorganic and organic nutrients with the potential to replace chemical fertilizers under an aquaculture–agriculture integrated system [6]. Research has shown that most nutrients needed for plant growth can be found in fish feed [7]. Specifically, 50% of the fertilizer applied to summer crops and 100% of the fertilizer applied to winter crops can be substituted, respectively, by irrigation with fish farm effluents [8]. The nutrients in fish effluents are either directly excreted by fish or produced by microbial breakdown of organic wastes and are often available in water-soluble form for plant uptake [9]. Shpigel and Neori [10] noted a nitrogen use efficiency lower than 10–50% for fish and a 70–80% waste conversion of the mineral resources entering the water by nutrients. Boyd and Tucker [11] later reported that only 25% to 30% of the nitrogen input to an aquaculture production system is assimilated in the final fish biomass. As for phosphorus, Holby and Hall [12] recorded a phosphorus uptake lower than 15–40% for fish, while about 70% of the phosphorus is excreted as waste into the water. More recently, Isitekhale and Adamu [13] reported that only 25% of N and 20% of P of fish feed is recovered in harvested fish, the rest being accumulated in farm effluent.

With the increase in worldwide aquaculture production, fish farming has the potential to generate significant amounts of effluents that can be used throughout the year for crop irrigation, particularly in drought-prone regions [14]. Studies have shown that multiple species such as tomatoes [15], lettuces (*Lactuca sativa* L.) [16], bean (*Phaseolus vulgaris*) plants [17], potato (*Solanum tuberosum* L.), soybean (*Glycine max* (L.) Merr.) and onion (*Allium cepa* L.) [18], fava bean (*Vicia faba* L.), lupine (*Lupinus perennis* L.), soybean, and sunflower (*Helianthus annus* L.) [8] can be grown throughout the year using fish effluents. In addition, the long-term performance of an integrated aquaculture–agriculture system is better than that of a non-integrated system, hence representing a relevant strategy for farmers to adapt to market and climate changes [19]. The resilience of a farming system is increased when cultivated crops are irrigated with fish effluents under a fish and crops integrated farm type, making this system less risky particularly for smallholder farmers with limited resources [20]. Moreover, the prices of inorganic fertilizers have steadily increased over the past few decades, making them expensive or unavailable to smallholder farmers [21]. From an environmental standpoint, incorporating fish effluents can enhance soil chemical properties, such as nitrogen, available phosphorus, water-soluble potassium, calcium, and magnesium [22,23], and reduce discharge to the environment [24,25]. The resulting benefits include a buildup of soil organic matter layers and an increase in crop yields.

Previous studies have demonstrated that crop irrigation with fish effluents increased water use efficiency and soil fertility, which resulted in enhanced plant growth and overall productivity [5,6,14]. Zhang et al. [26] reported efficient water usage and better environmental conditions year-round from the recirculation of fish wastewater discharges compared to the static control pond in an integrated recirculating aquaculture system. A study conducted by Abdul-Rahman et al. [27] revealed that irrigation with tilapia effluents increased maize (*Zea mays* L.) yield (7.07 kg/m^2), water use efficiency (1.94 kg/m^3), and water productivity (0.51 USD/m^3) as compared to yield (4.21 kg/m^2), water use efficiency (1.16 kg/m^3), and water productivity (0.30 USD/m^3) of maize irrigated with well water at planting, demonstrating the feasibility of integrating aquaculture and agriculture in semi-arid regions. Castro et al. [15] observed a significant increase in tomato fruit number and production in the first three harvesting periods following irrigation with fish effluent water compared to well water. Mariscal-Lagarda et al. [9] reported that the yield of tomatoes irrigated with shrimp effluent (33.3 kg per 45 plants) was 30% higher than plants that received groundwater but were comparable to plants that watered with nutritive solution (35.7 kg). Zohry et al. [28] irrigated fava bean and chickpea (*Cicer arietinum* L.) with fish farm effluent and recorded an 11 and 29% yield increase, respectively, compared to Nile water. Another study conducted by Danaher et al. [29] demonstrated that substrates incorporated with 10% aquaculture effluent could be an alternative to inorganic fertilizer in tomato production and could also improve the physical and chemical parameters of soil quality. In terms of economics, studies showed that net income benefits of up to 60% can be achieved when fish is integrated with rice (*Oryza sativa* L.) and some vegetables as a result of both savings in fertilizers and increased plant productivity [30,31].

Tomato is one of the most widely grown crops worldwide, with an annual production of 189.1 million tons in 2021 [32]. The tomato fruit, used for fresh consumption or processing, has a high nutritional value, a high quantity of soluble solids, and good market acceptance, all of which ensure rapid economic returns for farmers. It is grown in many countries and a variety of climates, including relatively cold regions, due to the development of indoor cultivation. In Senegal, tomato is an economically important vegetable crop. The total harvested area in 2021 was 9447 ha for a total production of 155 050 tons [32]. In Senegal, tomatoes, mainly grown in the Niayes area and the Senegal River valley (North of Senegal), are very demanding in terms of fertilization (inorganic and/or organic) to ensure good plant growth and development. In the semi-arid region of Northern Senegal, testing of effective water and fertilizer use in agricultural systems is required. In other regions, previous studies have predominantly investigated the effects of fish farm effluents compared to river water or chemical fertilizers [5,6,14,17,27,33,34], but only a few on the combined use of fish effluents and manure [15]. Furthermore, most studies have focused solely on *Nile tilapia* [5,6,15,17,23,27,33] but not on both *Nile tilapia* and African sharptooth catfish. In Senegal, these two species are major fish products and are extensively used for food and feed supplements. To the best of our knowledge, no research in Senegal has investigated the potential of replacing chemical fertilizers with fish effluents in tomato production using an integrated aquaculture and agriculture system. The objective of this study is to investigate the effects of African sharptooth catfish (*Clarias gariepinus*) and *Nile tilapia* (*Oreochromis niloticus*) effluents when combined with organic manure on the growth, yield parameters, and yield of tomatoes compared to the recommended rate of mineral fertilizers.

2. Materials and Methods

2.1. Soil and Manure Description

A greenhouse experiment was carried out at the farm of the Faculty of Agronomy, Aquaculture and Food Technology of Gaston Berger University, Saint-Louis Senegal (16°03′19.0″ N 16°25′39.0″ W). The soils, which have been under permanent fallow with predominantly sandy loam soils (Table 1), are classified as Eutric regosols, weakly developed and commonly dry soils. They have high base saturation in the subsoil, low water holding capacity, high permeability, and are very sensitive to drought [35]. The climate of the area is of the Sudano-Sahelian type and is marked by two seasons: a longer dry season (November—June) and a shorter rainy season (July—October). The study area is characterized by an average annual rainfall of 450 mm with a mean maximum temperature of 37 °C and a mean minimum temperature of 16 °C.

Table 1. Physical and chemical properties of soil and animal manure.

Parameters	Soil	Poultry Manure †	Cattle Manure †	Sheep Manure †
Clay (%)	8.25	–	–	–
Sand (%)	75.00	–	–	–
Silt (%)	16.75	–	–	–
BD	1.526	–	–	–
FC (cm^3 water/cm^3 soil)	0.156	–	–	–
pH (1/2.5)	8.23	7.24	7.12	7.62
EC (1/2.5) (mS cm^{-1})	0.269	6.530	3.340	6.470
C (%)	0.793	7.890	5.897	10.257
N (%)	0.124	4.006	1.766	2.861
C:N	6.395	1.970	3.339	3.585
OM (%)	1.364	–	–	–
Available P (mg kg^{-1})	34.740	–	–	–
Exchangeable Ca (cmol kg^{-1})	2.625	6.00	6.00	3.75
Exchangeable Mg (cmol kg^{-1})	0.75	3.75	1.125	3.75
Exchangeable Na (cmol kg^{-1})	0.155	0.155	0.0525	0.15
Exchangeable K (cmol kg^{-1})	0.0728	0.0686	0.0224	0.0476

BD: Bulk density; FC: Field capacity; EC: Electrical conductivity; † pH and EC cattle, sheep manure (1:5) materials: deionized water mixture on a volumetric basis).

2.2. Experimental Design and Treatments

The experimental pots were laid out in a randomized complete block design (RCBD) with six replicates per treatment. Tomato seeds (F1 KIARA) used in this experiment were obtained from the Faculty of Agronomy, Aquaculture, and Food Technology of Gaston Berger University. Tomato Kiara is a determinate and early maturing variety with excellent tolerance to tomato yellow leaf curl virus (TYLCV) and is adapted for hot and dry seasons. This hybrid is particularly interesting for both the local market and for transformation because of its high dry matter rate. The treatments consisted of three irrigation water types (river water—control, *Oreochromis niloticus*, *Clarias gariepinus*), four fertilizers (chicken manure, cow manure, sheep manure, NPK), and six mixed treatments with effluent and 50% of the applied rate of manure alone. Before plant transplanting, the manure amendments (poultry manure, cow manure, and sheep manure) were equilibrated in 3.5 kg pots for a week at 80% of field capacity. Sowing was carried out manually at a rate of three seeds per pot at Gaston Berger University's greenhouse. Two weeks after seed germination, seedlings were thinned to one plant per pot. A standardized gravimetric approach of daily pot weighing (twice a day) was followed to gradually attain 80%. The management practices were similar in all treatments throughout the growth cycle except for the irrigation water types, animal manure, and fertilizer treatments.

2.3. Soil Sampling and Analysis

Soil analyses were performed using randomly selected soil samples from fields at a depth of 20 cm, and composite soil samples were air-dried in a dust-free glasshouse before being sieved to pass a 5-mm particle size diameter. The soil samples' physical and chemical characteristics (Table 1) were examined at the National Center for Agronomic Research-Senegalese Institute of Agricultural Research (CNRA-ISRA) in Bambey (Senegal). Soil texture was determined by measuring the fine fractions (clays and silts) by sedimentation and the coarse fractions (coarse, medium, and fine sands) by sieving on standardized screens. Field capacity and soil bulk density were determined as described by Gupta and Larson [36] and Chopart [37], respectively. Soil pH and electrical conductivity (EC) were determined as indicated by Mathieu et al. [38], while soil total C, total N, and available P were determined using Walkley and Black [39], Olsen [40], and Kjeldahl [41] modified methods, respectively. The SOM was calculated using the formula SOM = carbon content × 1.72 (with 1.72 being the stable coefficient of cultivated soils) [42].

Plastic pots were filled with 2.750 kg soil on which the corresponding nutrient source was uniformly applied and incorporated at approximately 15 cm in each pot as per fertilization treatment. Each plastic pot was lined with a polythene bag to prevent loss of soil. Animal manure was collected from farms near the faculty's farm and was applied 1 week before planting. The inorganic recommended rate of 280 kg/ha of NPK 10-10-20 was applied in two inputs—50% or 140 kg/ha at 7 days after emergence (DAE) and 50% (140 kg/ha) at 40 DAE. The fish effluents used in this experiment came from fishponds in which the African sharptooth catfish and *Nile tilapia* were stocked at a density of 10 fish/m^2. The fish were fed three times a day with commercial diets such as Gouessant and Aquaban. The chemical properties of the water and effluents are presented in Table 2.

Table 2. Chemical composition of river water, *Clarias gariepinus*, and *Oreochromis niloticus* effluents used for tomato irrigation.

Parameters	**River Water**	***Clarias gariepinus***	***Oreochromis niloticus***
pH (1/2.5)	6.35	6.32	6.07
CE (1/2.5) (µs cm^{-1})	8.41	29.2	16.19
Exchangeable Ca (cmol kg^{-1})	0.525	0.6	0.375
Exchangeable Mg (cmol kg^{-1})	0.15	0.3	0.375
Exchangeable Na (cmol kg^{-1})	0.105	0.195	0.1725
Exchangeable K (cmol kg^{-1})	0.0098	0.021	0.0238

2.4. Agronomic Parameters and Economic Indicators

SPAD-502 chlorophyll meter readings on the third leaf from the top were taken at sowing, during vegetative growth, at flowering, during fruit formation, and at maturity stages to help determine foliar chlorophyll concentration differences between fertilization treatments. Plant height, stem diameter, number of ramifications, and flowers were determined at maturity. After these measurements, tomato fruit were hand-harvested weekly until all mature fruit were collected from the plants. Fruit number plant^{-1}, fruit diameter, and mean fruit weight plant^{-1} were recorded at harvest. Fruit weight plant^{-1} was calculated by weighing all counted fruit from each plant.

2.5. Statistical Analyses

The collected parameters were statistically analyzed using SAS JMP Pro version 15.0.0 statistical software (SAS Institute Inc., Carey, NC, USA). Analysis of variance (ANOVA) [43] was used to determine the significant effects of fertilization treatments on plant growth, yield, yield components, and SPAD values. Fisher's protected least significant difference at a 5% level of probability was used for mean separation when significant differences were found among treatments.

3. Results and Discussion

3.1. Plant Growth

A significant difference ($p < 0.05$) between fertilization treatments was observed in tomato stem diameter, number of ramifications, and flowers but not in plant height (Table 3). The results revealed that plants irrigated with *C. gariepinus* effluent had a significantly higher stem diameter (6.67 cm) than tomatoes watered with river water (4.33 cm) but had comparable value to tomatoes fertilized with the recommended dose of inorganic fertilizers (5.50 cm). The combination of *C. gariepinus* + 50% sheep manure had the highest number of ramifications and flowers, recording an average of 7.33 and 14.67, respectively (Table 3). This treatment is followed by plants watered with *C. gariepinus* + 50% poultry (7.00) and cattle (6.33) manure, while the control recorded the lowest number of ramifications with 1.33. As for the number of flowers, NPK-fertilized tomatoes had the lowest values (5.67), while the best-performing treatment was followed by *O. niloticus* + 50% sheep manure (11.00) and *C. gariepinus* (10.67) (Table 3).

Table 3. Effect of fertilization treatments on stem diameter, plant height, number of ramifications, and flowers of tomato.

No.	Treatments	Stem Diameter (cm)	Plant Height (cm)	Number of Ramifications	Number of Flowers
T1	River water—Control	4.33 ^{†,de,††}	56.67 ^{a}	4.00 ^{cde}	9.67 ^{bcd}
T2	*C. gariepinus* effluent	6.67 ^{a}	53.67 ^{a}	5.00 ^{abcd}	10.67 ^{ab}
T3	*O. niloticus* effluent	5.33 ^{abcde}	54.33 ^{a}	1.33 ^{e}	7.00 ^{bcd}
T4	Recommended NPK	5.50 ^{abcde}	54.67 ^{a}	5.00 ^{abcd}	5.67 ^{d}
T5	Cattle manure	5.50 ^{abcde}	52.33 ^{a}	3.67 ^{cde}	5.67 ^{d}
T6	Poultry manure	4.67 ^{cde}	48.67 ^{a}	2.67 ^{de}	6.00 ^{cd}
T7	Sheep manure	4.00 ^{e}	44.67 ^{a}	3.33 ^{de}	6.00 ^{cd}
T8	*C. gariepinus* + Cattle manure	5.67 ^{abcd}	50.67 ^{a}	6.33 ^{abc}	10.00 ^{bc}
T9	*C. gariepinus* + Poultry manure	6.00 ^{abc}	49.00 ^{a}	7.00 ^{ab}	9.00 ^{bcd}
T10	*C. gariepinus* + Sheep manure	6.33 ^{ab}	56.00 ^{a}	7.33 ^{a}	14.67 ^{a}
T11	*O. niloticus* + Cattle manure	5.67 ^{abcd}	58.67 ^{a}	3.33 ^{de}	7.33 ^{bcd}
T12	*O. niloticus* + Poultry manure	5.00 ^{bcde}	54.00 ^{a}	4.33 ^{bcd}	8.67 ^{bcd}
T13	*O. niloticus* + Sheep manure	5.00 ^{bcde}	53.67 ^{a}	3.33 ^{de}	11.00 ^{ab}

† Each value is the mean of six replicates. †† Means within column, followed by different letters, are significantly different (Fisher's protected LSD, $p = 0.05$).

On average, plants watered with only *C. gariepinus* or mixed with 50% manure recorded similar or higher plant growth than the recommended dose of inorganic fertilizers but always greater value than control plants. These results are similar to those reported by Hailu and Wakjira [44], who compared the potential of *Nile tilapia* wastewater and chemical fertilizer on tomato productivity. They found no significant difference between wastewater and inorganic fertilizer treatments for plant height (60.63 vs. 58.50 cm), plant size (girth) (5.13 vs. 5.00 cm), lateral branch number/plant (5.25 vs. 5.13), and the number of flower/plant (30.75 vs. 29.88). In another study, irrigation of maize with fish effluent resulted in significantly higher plant height (262.3 cm), number of leaves per plant (17.8), and plant weight (884.0) than height (213.9 cm), number of leaves per plant (16.4), and weight (526.2) of plants irrigated with well water [27]. A field study evaluating the effect of fish farming effluent application on maize and bean plants revealed contrasting results on crop development and growth. They found that irrigation with fish farming effluent significantly influenced the height and diameter of maize, but no significant differences were found for bean plants compared to the control treatment. The stimulating effect of fish effluents on plant growth might be related to their higher nutrient content levels [14,15,27]. Segura et al. [45] indicated that effluents can provide significant amounts of N, P, and K to tomatoes and increase their nutrient use efficiency. These findings demonstrated that fish water effluents are a viable source of irrigation water and nutrients for tomato production.

3.2. Yield Components

The effects of fertilization treatments on fruit number, fruit diameter, and mean fruit weight of tomatoes were evaluated, and findings are presented in Figures 2–4. Results show that fruit number was significantly ($p < 0.05$) influenced by treatments. Tomato plants irrigated with *C. gariepinus* effluent + 50% cattle manure and poultry manure had a significantly higher number of fruit with 9.00 and 8.33, respectively, than other treatments, as shown in Figure 2. These numbers were significantly greater than that observed in control plants and plants fertilized with inorganic fertilizers with, respectively, 3.67 and 4.00 fruits. In addition, the combination of *C. gariepinus effluent* + 50% cattle manure and poultry manure produced more fruit than each treatment taken individually. As shown in Figure 2, the lowest value (2.00) was noted with plants watered with *O. niloticus* effluent. For fruit diameter, results indicate that the combination of *O. niloticus* and 50% cattle manure had a significantly ($p < 0.05$) higher value with 3.34 cm compared to other treatments, particularly with plants receiving inorganic fertilizers which recorded the lowest value (2.56 cm) (Figure 3). As reported in previous studies, fish effluents have been shown to enhance the yield components of various crops [8,15–18,23]. In line with our study, an increase in fruit number was also observed by Segura et al. [15] for tomatoes watered with fish effluents compared to plants irrigated with well water. These results could suggest that nutrient content in fish effluent is responsible for the enhancement in tomato fruit number. Therefore, Khater et al. [46] investigated the extent to which nutrient content in effluent fish farms is sufficient to support tomato plants and found that nutrient consumption increased with increasing the flow rate. As a result, the tomato fruit number increased from 14.12 to 16.85 as the effluent flow rate increased from 4.0 to 6.0 L h^{-1}.

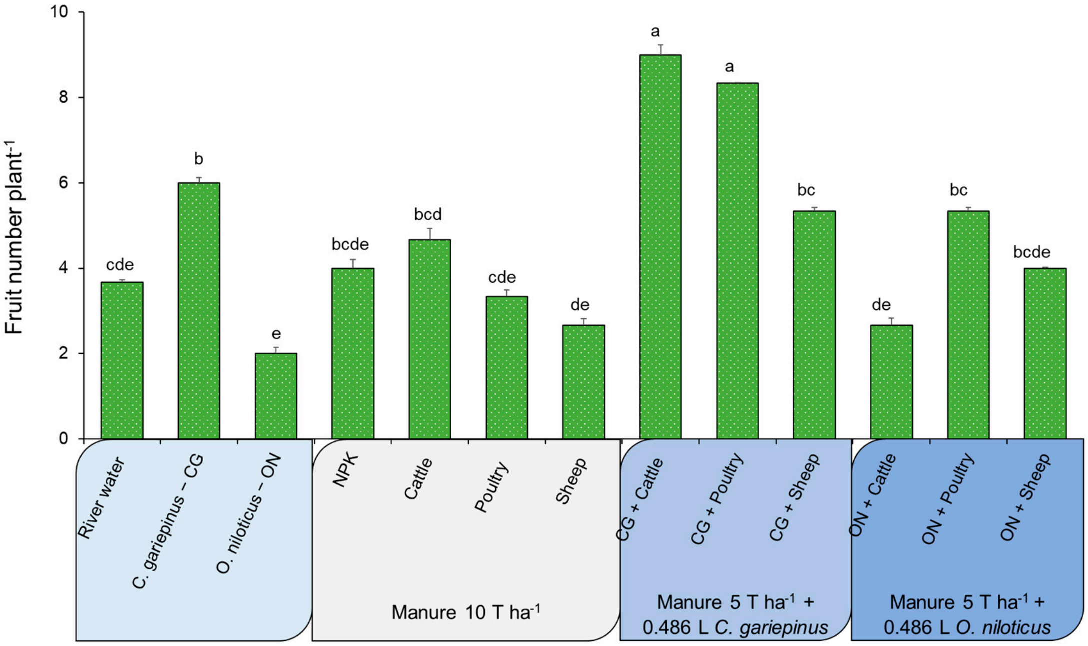

Figure 2. Effect of fertilization treatments on fruit number per plant of tomato. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error bars represent the standard error of the mean (n = 78).

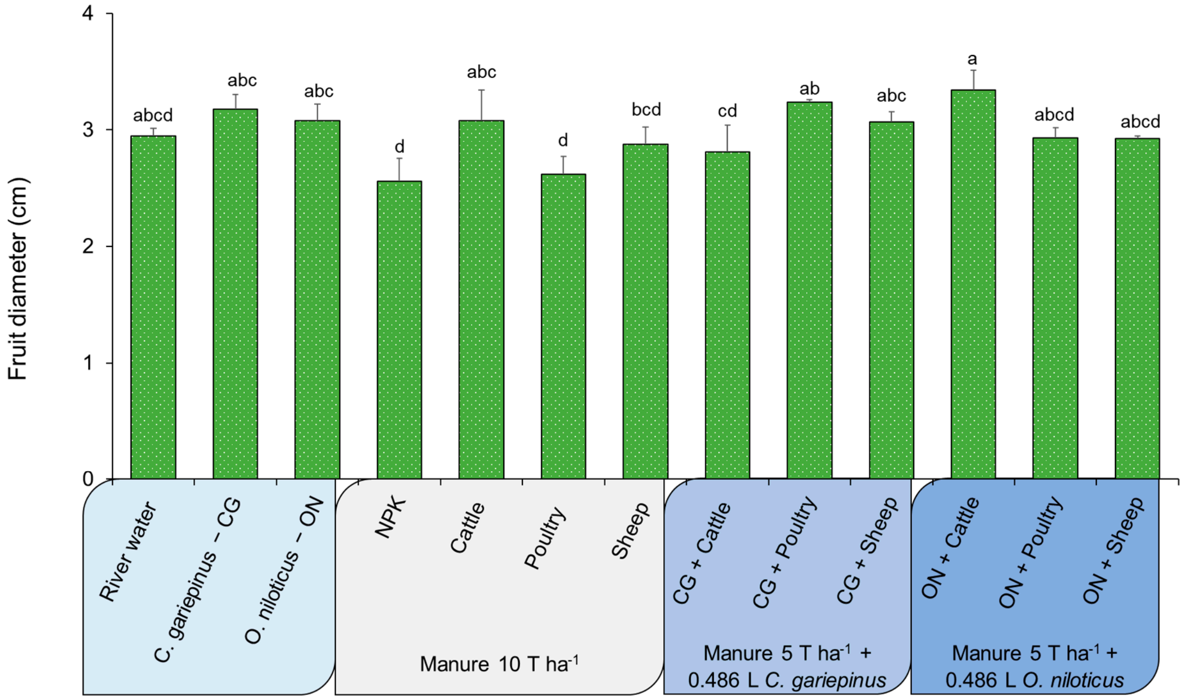

Figure 3. Effect of fertilization treatments on fruit diameter of tomato. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error bars represent the standard error of the mean ($n = 78$).

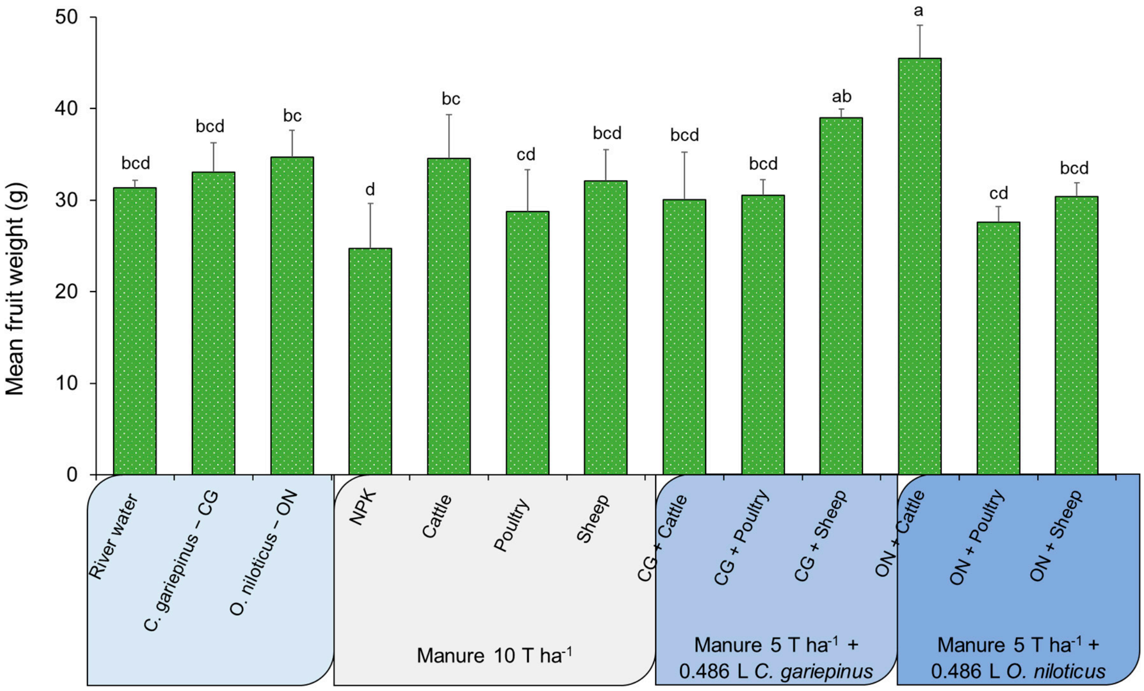

Figure 4. Effect of fertilization treatments on mean fruit weight of tomato. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error bars represent the standard error of the mean ($n = 78$).

Similar to fruit diameter, the combination of *O. niloticus* and 50% cattle manure recorded a significantly ($p < 0.05$) higher mean fruit weight (45.46 g) than other treatments (Figure 4). This is significantly greater than values observed with plants irrigated with river water (31.33 g). Inorganic fertilization decreased the mean fruit weight (24.71 g) of tomatoes and recorded the lowest value compared to other treatments (Figure 4). When taken individually, plants irrigated with *O. niloticus* or amended with cattle manure had significantly lower mean fruit weights of 34.72 g and 34.58 g, respectively, than their combination. In the present study, treatments that recorded the highest fruit number had the lowest mean fruit weight. This is similar to results obtained by Castro et al. [15], who attributed the reduction in fruit mean weight to a deficiency in fertilizer. They argued that although fish effluent treatments produced a greater number of fruit at the beginning of their crop cycle, they did not produce enough nutrients to sustain fruit mean weight.

3.3. Fruit Weight

Regarding the fruit weight of the tomato, Figure 5 shows that *C. gariepinus* effluent and 50% poultry manure had a significantly ($p < 0.05$) higher weight (251.33 g.plant^{-1}) compared to other treatments. The results show that this treatment is followed by *C. gariepinus* effluent + 50% cattle manure (220.15 g.plant^{-1}) and *C. gariepinus* effluent + 50% sheep manure (220.15 g.plant^{-1}), though not statistically different. Application of *C. gariepinus* effluent (191.67 g.plant^{-1}) and poultry manure (86.23 g.plant^{-1}) individually both recorded significantly lower values than their mixed treatment (Figure 5). The figure also shows that the lowest value was observed in plants watered with *O. niloticus* (66.67 g.plant^{-1}), which was not significantly different from plants receiving inorganic fertilizers (97.33 g.plant^{-1}).

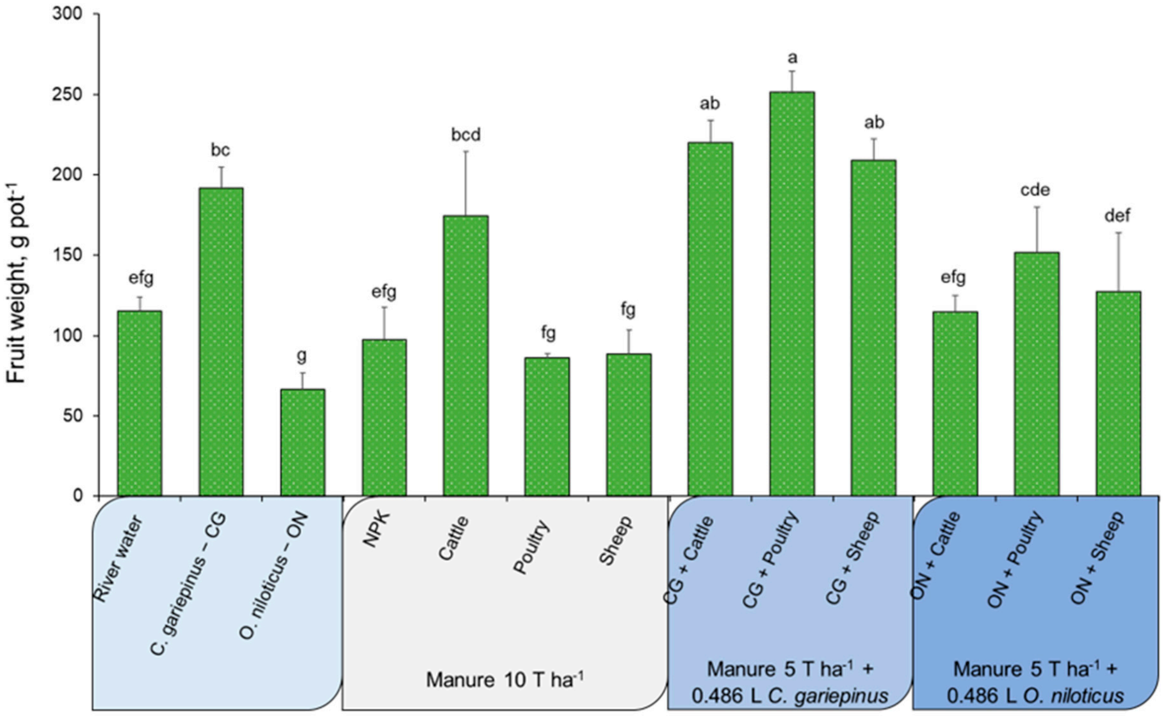

Figure 5. Effect of fertilization treatments on fruit weight of tomato. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error bars represent the standard error of the mean (n = 78).

Although watering tomato plants with *C. gariepinus* effluent and 50% manure decreased the mean fruit weight (Figure 4), the recorded increase in fruit number (Figure 2) was sufficient to enhance fruit production (Figure 5). Similar trends were observed by Castro et al. [15] when they irrigated cherry tomatoes with fish effluent compared to well water. They attributed the increase in fruit weight to the nutrient content of fish effluents. In the present study, the nutrients present in the *C. gariepinus* effluent and manure could also have contributed as plant fertilizer following microbial transformation during the tomato cycle. In addition, the potential of organic amendments such as effluents to provide small amounts of nutrients to crops throughout their cycle could lead to a more efficient absorption of nutrients by plants, much like a fertigation system [21,27]. Other benefits of using fish effluents include the suppression of soil-borne diseases, demonstrating the potential of fish effluents to improve nutrient concentrations, and promoting plant growth while increasing soil suppressiveness [47]. From an economic perspective, the use of fish effluents can reduce the reliance on chemical fertilizers for crop production as similar yields were observed in comparison to conventional fertilization methods, making this practice a potentially viable option for producers [48]. The results of our study also show that the use of *C. gariepinus* effluent or its combination with manure significantly increased tomato growth and production, while *O. niloticus* effluent recorded the lowest values. The observed differences in fruit weight between plants watered with *C. gariepinus* and *O. niloticus* effluents can be attributed to the morphological, histological, and chemical differences in the gastrointestinal tracts of fish species [49]. These latter authors further stated that the differences between these fish species might be due to species-specific nutritional physiology and diet composition which can influence their rates of nutrient and mineral absorption as well as excretion.

3.4. SPAD Values

Leaf chlorophyll content can be influenced by several factors, such as growth stage and fertilization treatments. SPAD-502 chlorophyll meter readings were collected on tomato plants at sowing, during vegetative growth, at flowering, during fruit formation, and at maturity stages (Figure 6). Average SPAD values ranged from 31.67 during the vegetative growth stage to 34.00 at the onset of maturity and subsequently dropped to 31.74 at complete maturity (Figure 6). Results show that leaf chlorophyll content was significantly different between treatments during vegetative growth, at flowering, during fruit formation, and at beginning maturity. At vegetative (37.5) and flowering (36.27) stages, poultry manure recorded the highest SPAD values for tomato (Figure 6B,C), while the lowest values were recorded by *O. niloticus* effluent combined with 50% cattle manure (24.63) and 50% cattle manure (19.7). At the fruit formation stage, plants watered with *C. gariepinus* had the highest (41.93) SPAD values. The combination of *C. gariepinus* and 50% cattle and poultry manure gave significantly higher values than other treatments at the beginning of maturity with, respectively, 49.47 and 48.43 (Figure 6E).

Chlorophyll content is one of the indicators that can be used to assess the health status of plants. Therefore, measuring the amount of chlorophyll in plant leaves provides a more precise picture of the changes induced by natural and human stressors, as these factors have an impact on the quantity of chlorophyll. Research has also shown that there is a strong positive relationship between chlorophyll content in the leaves and the plant nitrogen concentration [50]. However, few studies have attempted to elucidate the effect of fish effluents on crop SPAD values. Results from this study showed that organic amendments such as fish effluents or manure significantly increased the SPAD values of tomatoes. Kolozsvári et al. [51] also reported that the SPAD of willow (*Salix alba* L.) irrigated with fish effluent water was greater than the values of plants receiving surface water. Changes in SPAD values between fertilization treatments can be attributed to the quality of irrigation water and manure, particularly the higher N concentrations.

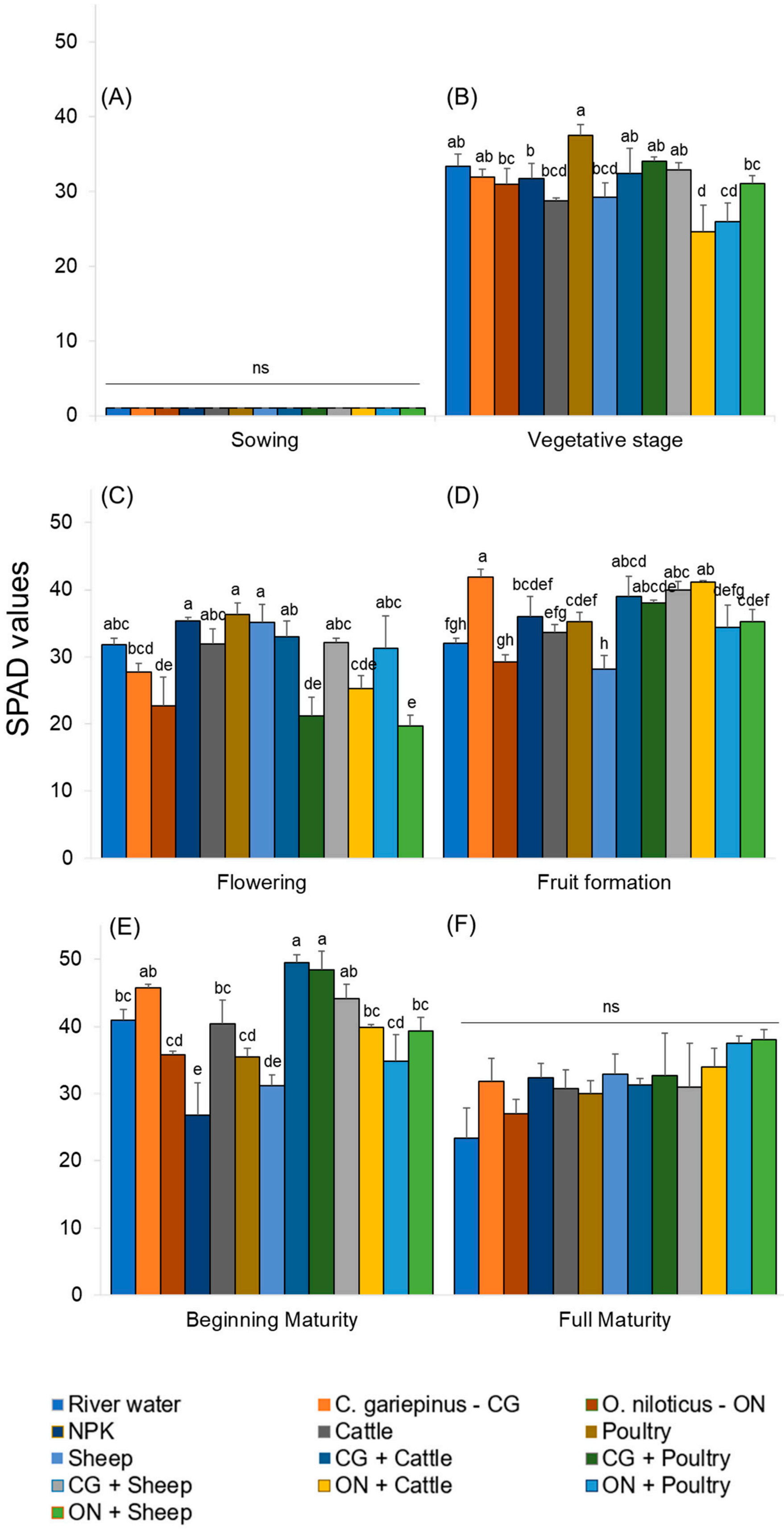

Figure 6. Effect of fertilization treatments on SPAD values of tomato. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD, and error

bars represent the standard error of the mean (n = 78). (**A**) = sowing, (**B**) = vegetative stage, (**C**) = flowering, (**D**) = fruit formation, (**E**) = beginning maturity, (**F**) = full maturity. ns: non-significant.

4. Conclusions

Water usage efficiency and food production will have to increase as water stress in semi-arid countries worsens. Integrating aquaculture and agriculture using fish effluents is one method of reaching this objective. Fish effluents are known as a potential source of nutrients for crops due to their high concentration in macro- and micronutrients. In addition, the recycling of wastewater from aquaculture farming systems could represent an essential part of water demand management while reducing environmental pollution and the overall cost of production. Our findings suggest that irrigating tomato plants with a mixture of *C. gariepinus* effluent and a 50% applied rate of manure alone can greatly increase stem diameter, number of ramifications, fruit number, mean and total fruit weight compared to the recommended rate of inorganic fertilizers. Although not measured, the combination of fish farm effluent from *C. gariepinus* and manure potentially provided a balanced and extended supply of nutrients throughout the crop growth period, resulting in enhanced plant growth. This study highlighted that fish effluent, particularly *C. gariepinus*, significantly enhanced plant growth and yield compared to the conventional rate of mineral fertilizer. Therefore, the use of fish effluents may be useful as a water source for irrigation in agriculture, particularly in regions with water shortages and low access to affordable chemical fertilizers. However, further studies are required to examine the impact of fish effluents on tomato production on a bigger scale and over multiple seasons to assess the long-term effects of fish effluent applications. Although not reported in previous studies, nitrogen leaching and potential contamination of groundwater need to be evaluated [23]. Additionally, the economic viability of this integrated system must be assessed to support its adoption among smallholder farmers.

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