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Garlic (*Allium sativum*) Production Using Aquaculture Effluent and Nitrophosphoric Fertilization

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Abstract. **The effluent from aquaculture activities contains essential elements that can be used in agriculture. In this study, the effluent from tilapia (*Oreochromis niloticus*) production was used to fertilize garlic with four nitrophosphoric treatments: 1) no fertilization, 2) 40–20, 3) 80–40, and 4) 160–80 ($kg \cdot ha^{-1}$ of N and P_2O_5, respectively). Treatment 3 resulted in the highest yield and better plant nitrogen levels. The effluent from tilapia aquaculture is a significant source of nitrogen and phosphorus. Hence, it is crucial to calculate the fertilization precisely based on the contributions of the soil and the effluent. However, the effluent did not provide significant levels of K, Mg, Fe, Cu, Mn, and Zn, which were adequately provided by the soil. The effluent did contain elevated levels of Ca and S due to the original water contents.**

Aquaculture, which involves the cultivation of fish, shellfish, and other aquatic species, has seen significant growth worldwide in recent decades. Production has increased from just over 60 million tons in 1970 to almost 180 million tons in 2020 (Food and Agriculture Organization 2022), and it is projected to grow by 57% by 2050 (Boyd et al. 2022). This growth is driven by the increasing demand for high-quality animal protein due to the increase in the global population, as well as the limitations of wild fish capture.

One of the most commonly used aquaculture systems is tank-based cultivation without water recirculation, where 5% to 10% of the effluent must be removed daily to maintain water quality and prevent adverse effects on the fish. These tank effluents contain organic and inorganic substances from uneaten feed and fish waste, which can be beneficial in agricultural production. Various studies have shown that such effluents contain essential plant elements (N, P, K, S, Ca, Mg, Fe, Cu, Mn, and Zn) as well as organic matter, contributing to improved yields (Puccinelli et al. 2023).

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The development of integrated agricultural production models worldwide aims to enhance the efficient use of natural resources and increase food diversity. An example of this is the integration of aquaculture production with the cultivation of horticultural species.

However, there is a lack of research on the irrigation of garlic (*Allium sativum*) using effluents from aquaculture production and nitrophosphoric fertilization. To address this gap, a trial was conducted with the following objectives: 1) to evaluate the yield and nitrogen status in the garlic plants and 2) to determine the contribution of nutrients from tilapia (*Oreochromis niloticus*) effluents during a garlic cultivation cycle.

Materials and Methods

The aquaculture production unit comprised a geomembrane tank with a central drainage measuring 6 m in diameter with a capacity of 30,000 L. The species being cultured was gray tilapia (*Oreochromis niloticus*), which were 3 months old at the start of the trial and had an average weight of 200 g. The fish were fed with Nutripec fattening food from the Purina® brand, which contains 28% protein. The stocking density was 40 fish per cubic meter. The daily feeding amount equated to 2% of the total fish biomass per tank.

Water quality parameters were maintained as follows: pH levels were kept between 7 and 7.5, electrical conductivity (EC) between 0.8 and 1 $dS \cdot m^{-1}$, dissolved oxygen between 4 and 6 $mg \cdot L^{-1}$, ammonia $N\text{-}NH_3$ levels were maintained at less than 0.1 $mg \cdot L^{-1}$, water hardness was kept below 100 $mg \cdot L^{-1}$ as $CaCO_3$, and water temperature fluctuated between 15 and 22 °C. Water exchanges were performed every 3 to 5 d, with volumes ranging from 20% to 50% of the tank, depending on the water quality.

The original water had the following average concentrations of each nutrient ($mg \cdot L^{-1}$): 2, 0, 4, 45, 6, 32, 0.001, 0.01, 0.001, and 0.001 of $N\text{-}NO^{-}_{3}$, P, K, Ca, Mg, $S\text{-}SO^{-2}_{4}$, Fe, Cu, Mn, and Zn, respectively. The effluents used in irrigation had the following average concentrations of each nutrient ($mg \cdot L^{-1}$): 13, 15.5, 4, 50, 6, 40, 0.01, 0.12, 0.01, and 0.2 of $N\text{-}NO^{-}_{3}$, P, K, Ca, Mg, $S\text{-}SO^{-2}_{4}$, Fe, Cu, Mn, and Zn, respectively.

The crop plot measured 1000 m^2 and had the following soil characteristics: sandy clay loam texture, pH 7.5, EC 1.5 $dS \cdot m^{-1}$, organic matter 1.1%, apparent density 1.46 $g \cdot cm^{-3}$. The phytonutrients present were 20 $kg \cdot ha^{-1}$ of $N\text{-}NO^{-}_{3}$, 80 $kg \cdot ha^{-1}$ of P_2O_5, 1800 $kg \cdot ha^{-1}$ of K_2O, 5670 $kg \cdot ha^{-1}$ of Ca, 420 $kg \cdot ha^{-1}$ of Mg, 147 $kg \cdot ha^{-1}$ of $S\text{-}SO^{-}_{4}$, 0.5 $kg \cdot ha^{-1}$ of Fe, 1 $kg \cdot ha^{-1}$ of Cu, 21 $kg \cdot ha^{-1}$ of Mn, and 4.2 $kg \cdot ha^{-1}$ of Zn.

The garlic variety used was a landrace type planted at a density of 350,000 plants/ha. Fertilization treatments included T1) no fertilization, T2) 40–20, T3) 80–40, and T4) 160–80 ($kg \cdot ha^{-1}$ of N and P_2O_5, respectively). Urea and diammonium phosphate (DAP) were used as sources of N and P in the fertilizers applied. In all treatments, water with aquaculture effluents was used equally. The irrigation was done using 6000 caliber tape with 20-cm drippers and 1 L/h emitter flow and 120 mesh filter. Soil moisture was maintained between field capacity and 30% reduction in usable moisture. The total irrigation amount was 400 mm.

The experimental design used was a randomized block design with four repetitions. The experimental unit had an area of 60 m^2. The study variables included the following:

1. Yield components: agronomic yield, fresh bulb weight, bulb diameter, number of cloves per bulb, and average clove weight.
2. Nutritional status of N in the plant, which was measured 30 d before harvest [chlorophyll, nitrogen balance index (NBI), flavonoids, and anthocyanins] using a Dualex® portable equipment.
3. Nutrient contributions from the effluent during the crop cycle, including N, P, K, Ca, Mg, S, Fe, Cu, Mn, and Zn. $N\text{-}NO^{-}_{3}$ was measured using a Laquatwin® ionometer and the other elements were measured using atomic absorption. The analysis of variance and comparison of means (Tukey test at ≤ 0.05) was performed using the SAS version 9.0 program.

Table 1. Results of yield components and nitrogen status in garlic plants with aquaculture effluent irrigation and nitrophosphoric fertilization.

	Yield components					N status in the plant			
Tr	Yield	BW	BD	GCB	CW	Chl.	NBI	Flav.	Ant.
1	5,758 b	16.45 b	12.0 a	20 ab	0.82 a	40.00 a	25.25 ab	1.60 a	0.093 a
2	5,600 b	16.00 b	12.0 a	23 a	0.70 b	39.00 a	26.30 ab	1.44 b	0.080 b
3	6,405 a	18.30 a	12.4 a	22 a	0.83 a	41.71 a	29.68 a	1.43 b	0.078 b
4	5,075 b	14.50 b	11.5 b	20 ab	0.73 b	41.30 a	29.36 a	1.38 b	0.078 b

Yield = $kg \cdot ha^{-1}$. Tr = treatment; BW = bulb weight (g); BD = bulb diameter (cm); GCB = garlic cloves per bulb; CW = cloves weight (g); Chl. = chlorophyll Dualex® ($\mu g \cdot cm^{-2}$); NBI = nitrogen balance index Dualex®; Flav. = flavonoids index Dualex®; Ant. = anthocianins index Dualex®. Different lowercase letters in a column denote significant differences among the treatments ($P \leq 0.05$).

Results and Discussion

The highest yield, 6405 $kg \cdot ha^{-1}$, was achieved with treatment 3 (80–40–00), which also showed the best values for yield components such as bulb weight, bulb diameter, number of teeth per bulb, and clove weight. This outcome is attributed to the improved nitrogen status in the plants under this treatment, as indicated by higher chlorophyll and NBI contents, along with lower levels of flavonoids and anthocyanins. These factors may have contributed to better photosynthesis performance (Table 1).

Treatment 3 had 150 kg of nitrogen per hectare (N/ha) available, resulting from contributions from the soil, effluent, and fertilizer (Fig. 1A). The effluent contributed 52 $kg \cdot ha^{-1}$ of nitrogen, accounting for 34.6% of the total available nitrogen. This is a significant amount and demonstrates substantial savings of this nutrient. It is worth noting that the effluent's $N\text{-}NO^{-}_{3}$ corresponds to the combined contributions from the original water source, unconsumed food, and fish feces, minus losses in the aquaculture system process and retained material in solid sedimentation filters.

The yields and nitrogen status of plants in treatments 1, 2, and 4 were similar despite differences in the amount of nitrogen provided (Table 1). This may be because of the use of a native variety in the trial, which typically has lower yields and requires fewer nutrients compared with improved varieties.

In Fig. 1B, it is shown that the effluent contributed 64 kg of P_2O_5 per hectare, which is slightly more than half of the recommended amount for garlic cultivation in the region (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias 2021). This result is important for saving phosphorus fertilizer, but it also serves as a warning not to overdo the application of this element, as it may lead to nutritional problems due to possible antagonism with iron and zinc (Sánchez-Rodríguez et al. 2017).

Figure 1C and D indicated that the macro and micronutrients contributed by the effluent are minimal compared with what the soil provides. These elements are typically present in low concentrations in aquaculture effluents because fish require little of them and are provided with minimal food in their diet (Yep and Zheng 2019). The high levels of calcium and sulfur in the effluent were attributed to the water's natural composition, which accounted for 90% and 80% of these elements, respectively.

Conclusions

The aquaculture effluent from tilapia (*O. niloticus*) is a major source of nitrogen and phosphorus. Therefore, fertilization with these elements needs to be accurately quantified based on the contributions of the soil and the effluent. The effluent did not contribute significant amounts of potassium (K), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) because these were provided adequately by the soil. Calcium (Ca) and sulfur (S) levels were high in the effluent due to the original water contents.

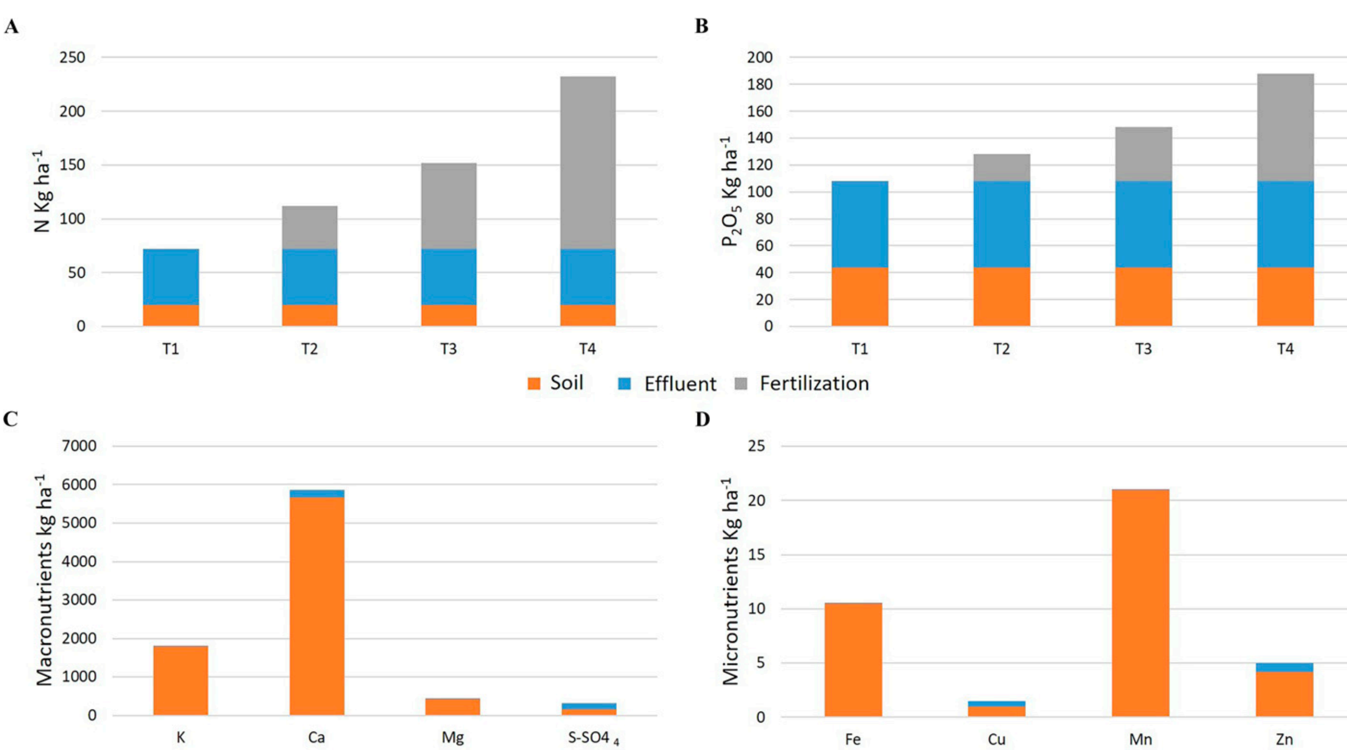

Fig. 1. Results of the contribution of nutrients to the garlic crop by source: (**A**) $N\text{-}NO^{-}_{3}$ contribution, (**B**) P_2O_5 contribution, (**C**) macronutrients contribution, and (**D**) micronutrient contribution.

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