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Article

Nutrient Solution from Aqueous Extracts as an Alternative to Fertigation in Hydroponic

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Abstract: The reintegration of agro-waste into the same agriculture site fulfils the objective of the European Bio-Economy Strategy: to reduce transport costs, waste volume, and the need for mineral fertilizers. One of the fundamental principles in sustainable agriculture is the recycling of crop residues through composting or vermicomposting. From this process, it is possible to obtain organic matter for the production of aqueous extracts (tea) that can be used as a source of nutrients in fertigation as an alternative to mineral fertilizers. The objective of this research was to evaluate the use of an aerated or non-aerated aqueous extract as a recirculating nutrient solution in a hydroponic culture (NFT) of lettuce. For this, the test method was compared to hydroponic cultivation with a conventional nutrient solution. The conventional nutrient solution contained minerals or synthetic fertilizers and the aqueous extracts of vermicompost from vegetal residues of horticultural crops. The evolution of the chemical composition of the nutrient solutions during cultivation was analyzed, obtaining adequate concentrations of NO_3^-, K^+, and Ca^{2+} and taking possible imbalances in nutrients such as P-$H_2PO_4^-$ into consideration. Plants fertigated with an organic and aerated nutrient solution obtained good yields and improvements in quality by having six times less N-NO_3^- in edible leaves compared to plants exposed to the mineral treatment. The preparation of aqueous extracts as a source of nutrients opens the door to circular agriculture to make processes in intensive production systems more efficient.

Keywords: organic agriculture; vermicompost; *Lactuca sativa* L.; circular economy; organic fertilizer; ammonification; nitrification; N-mineralization; nutrient film technique

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1. Introduction

Hydroponics and/or soil-less cultivation is a technique that grows roots out of the soil in a container with a substrate or in a nutrient solution. It is a very widespread technique that is used for the production of vegetables under protected conditions that has made it possible to increase the yields and quality of fruits [1]. Hydroponic systems for the production of horticultural species require the use of soluble, mineral, and/or synthetic fertilizers, which, when dissolved in water, ensure the availability of nutrients [2,3]. In hydroponic systems without a substrate, the chemical characteristics of the nutrient solution take on special importance and must contain all of the nutrients at appropriate and balanced concentrations. These systems are sensitive to imbalances in the nutrient solution due to their low or almost no buffering capacity [4].

New regulations limit the use of mineral or synthetic fertilizers to reduce the environmental impact of agricultural systems [5]. In this sense, as an alternative to synthetic fertilizers, it is necessary to resort to the use of organic matter from the composting and/or vermicomposting of plant and/or animal waste [6,7]. However, supplementing nutrients by the application of nutrient solutions via fertigation is relatively simple when using mineral or synthetic fertilizers, but it is more challenging in systems where only organic nutrient materials are used [8,9].

We have compost or vermicompost teas (aqueous extracts) that have been shown to promote plant health and increase the yield and quality of fruits, aromatic plants, and flowers because they contain beneficial microorganisms that promote the absorption of essential nutrients in the form of ions [9,10]. Additionally, they are used as organic fertilizers because they contain high microbial loads (plant growth promotion microorganisms, PGPM) that increase the solubility of nutritional elements and promote plant growth [8,11,12].

However, although aqueous extracts have a high microbial load and a high concentration of nutritional elements [9], in general, they are not balanced as nutrient solutions for fertigation [3], and a large number of nutritional elements are in their organic forms and are not available to plants [13–15]. Recent work carried out by our research team [9,12,16] shows that it is possible to find a more or less balanced nutrient solution for horticultural crops based on modifications in the preparation process of the aqueous extract depending on the type of organic matter used for preparation. According to the results, it is possible to solubilize and/or mineralize the nutrients present in organic forms in the aqueous extracts during the production process [9] and use them as a nutrient solution for soilless crops in containers [8,12,16].

In hydroponic crops that do not use a substrate for root growth, continuous recirculation of the nutrient solution and strict control of the ion and O_2 concentrations in it is necessary. In hydroponic systems without a substrate, the use of organic extracts becomes more complex since it is difficult to guarantee that the nutrient solution will provide nutrients in an ionic and balanced form to allow the correct development of the crop. It is also difficult to ensure that there are high levels of O_2 in the solution, since aerobic bacteria and fungi consume most of the oxygen during their metabolic processes. Therefore, it is necessary to ensure that the supply of oxygen is greater to maintain aerobic conditions and avoid the appearance of substances such as valeric, butyric acid, and phenolic compounds, which can be harmful to crops and beneficial to microorganisms [10]. The aeration process of the aqueous extracts generates favorable conditions for the proliferation and activity of microorganisms that are naturally present in the organic matter and the mineralization of the organic matter [8].

To determine the effectiveness of the use of aqueous extracts as organic nutrient solutions in hydroponics and to analyze the response of a crop commonly used in soil-less cultivation, lettuce, a test was carried out in a hydroponic system (NFT—nutrient film technique). The NFT system was developed in the 1960s and was primarily intended for the production of high-quality vegetables in greenhouses [17]. The NFT cultivation system is a hydroponic technique that uses a thin film of nutrient solution to deliver nutrients to plants. A very shallow stream of water containing the dissolved nutrients is recirculated past the bare roots [18]. Figure 1 shows a scheme of the system. The nutrient solution is stored in a tank (C), from where it is recirculated to the crop, and the characteristics of the nutrient solution are controlled (EC, pH, ion concentrations, and O_2). The amount consumed by the crop is completed from another tank (A), where the concentrated nutrient solution is stored. In the tank (C), where the nutrient solution is used to irrigate the crop or in the stock tank (A), it is possible to incorporate a pump that allows the nutrient solution to be aerated, helping to maintain higher O_2 concentrations.

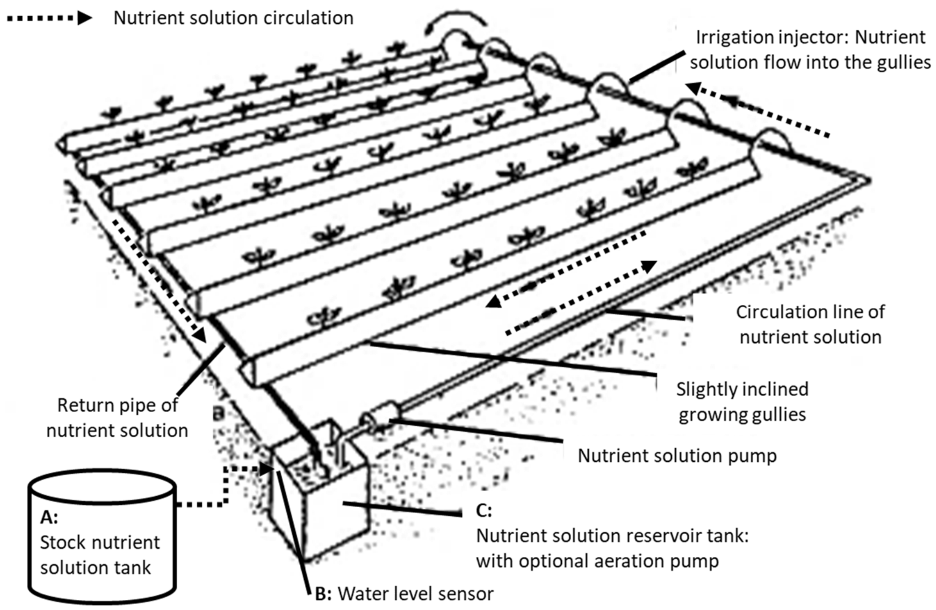

Figure 1. Nutrient film technique. Hydroponic system: The nutrient solution is pumped up to the top of the gullies. The solution passes down the gullies in a thin film and is recirculated to the reservoir tank (C) with an optional submersible pump to increase aeration. A: Stock nutrient solution tank used to refill the nutrient solution tank (C). C: Recirculation tank where it is possible to control the EC, pH, and ion and O_2 concentrations in the nutrient solution during crop growth (adapted from Cooper [17]).

Starting from the hypothesis that it is possible to achieve a sufficiently balanced nutrient solution from aqueous extracts according to the results of [9] and that improving aeration in the organic nutrient solution during cultivation will improve the concentration of nutrients in assimilable forms, it follows that production will not be affected.

The objective of this work was to evaluate the use of aerated or non-aerated aqueous extracts as recirculating nutrient solutions in a hydroponic culture (NFT) of lettuce. For this, it was compared with hydroponic cultivation with a conventional nutrient solution. This work evaluated the variation of nutrient content in the hydroponic cultivation system and the yield and quality responses of the lettuce crop.

2. Materials and Methods

2.1. Culture Establishment and Experiment Description

The experiment was established in a multi-tunnel polycarbonate greenhouse located at the University of Almería (Southeast Spain). The lettuce used was of the Trocadero type (cv. Rex-Rijk Zwaan) at a planting density of 30 plants m^{-2}. The plants were transplanted to the hydroponic system (NFT—nutrient film technique).

Three treatments were established depending on the nutrient solution used (Table 1).

Table 1. Chemical compositions of the nutrient solutions (initial nutrient solution and that used to refill that consumed by the crop) used in growing lettuce in a hydroponic–NFT system. Ion concentration (mmol L^{-1}), pH, EC (dS m^{-1}), and O_2 concentration (mg L^{-1}).

Treatment [1]	NO_3^-	$H_2PO_4^-$	Cl^-	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	pH	EC	O_2
T0	12	2.0	6.1	2.1	5.0	4.8	2.0	5.0	6.50	2.5	6.95
T1/T2	7.9	0.5	6.7	0.2	4.2	3.3	1.2	6.3	8.25	2.1	7.67

[1] T0, conventional nutrient solution; T1 aqueous extract with supplementary aeration in a recirculation tank; T2, aqueous extract without supplementary aeration in a recirculation tank.

Photographs of the experiment are included in Figure 2. Photograph (a) shows the materials used to make the aqueous extract, the vermicompost of vegetable waste from the horticultural crops, and (b) the 500 L tank used in the greenhouse for the preparation of the aerated aqueous extracts for 12–16 days to be used as an initial nutrient solution and filler for treatments T1 and T2. Additionally, there is a photograph of the NFT cultivation table (one per repetition and three tables per treatment) with the recirculation tank with a submersible pump inside to push the irrigation solution to the top of the cultivation channels (c). In (d), there is a photograph of the recirculation tank (100 L) with an extra submersible pump for supplementary aeration of the irrigation solution of treatment T1. Additionally, there are two photographs of the NFT cultivation table with three channels planted (seven plants per channel and three rows per table: 21 plants per table and repetition. In (e) are the seedlings, and in (f) are the plants used for harvest. The experiment used nine NFT growing tables, one growing table (21 plants per table) per repetition and three per treatment. The recirculation tank was topped up every one or two days and refreshed with nutrient solution to maintain the level at 100 L, and a sample was collected to monitor the EC, pH, and ion concentrations. The water consumption that occurs throughout the crop was replaced, but since it is a short cycle, it was not necessary to make a complete change.

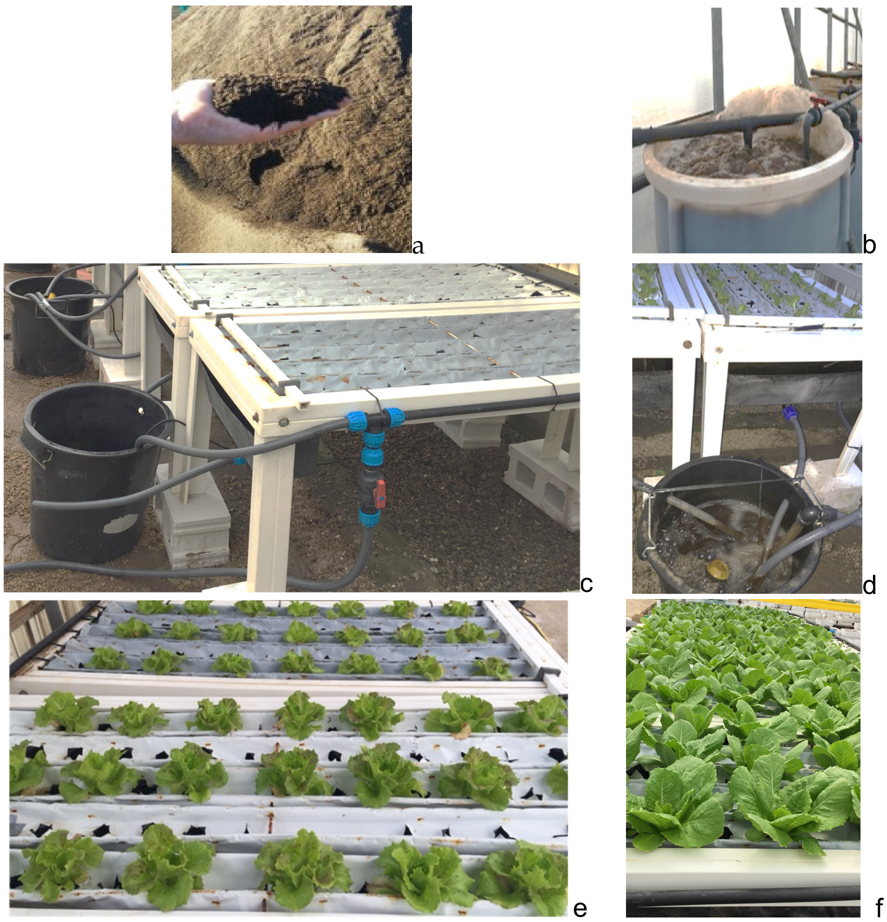

Figure 2. (**a**) Vermicompost of vegetable waste of the horticultural crops used to prepare the aqueous extracts. (**b**) Greenhouse preparation of aerated aqueous extract for 12–16 days to later be used as an initial nutrient solution and to fill the T1 and T2 recirculation tanks. (**c**) NFT cultivation tables with the details of the recirculation tank with a submersible pump inside to irrigate the solution to the top of the channels. (**d**) Details of the recirculation tank with an extra submersible pump for supplementary aeration of the irrigation solution (T1). (**e**) Growing table with three growing channels with seven plants each (3 × 7: 21 plants per table) and detail of the seedlings. (**f**) Plants in the canals for harvest.

The harvest of lettuce was carried out when the plants reached commercial size: this occurred at 35 days from transplantation (DAT) in T0, while in T1 and T2, harvest occurred at 50 DAT.

2.2. Characterization of the Nutrient Solution

For the treatment used as a control (T0), a mineral nutrient solution [19] was prepared with the following fertilizers: $CaNO_3$, NPK with a 15–5–30 balance, and chelated microelements (microstep®® complex). The pH was adjusted in the tank to 6.5 with HNO_3. This same solution was used as a solution to fill the tank during the crop growth.

For the preparation of the aqueous extract used as a nutrient solution, we proceeded according to the method published by [16]. According to [16], vermicompost from horticultural waste was dissolved in water until reaching an electrical conductivity (EC) of 2.0 dS m^{-1}. Then, it was aerated for 12–16 days before being used as a nutrient solution in T1 and T2 (b; Figure 2). It was aerated by recirculation with a submersible pump with a flow rate of 6500 L h^{-1} in a 500 L tank. For T1 and T2, no acid was applied to the nutrient solution, so the pH remained at alkaline values. This same solution was used as a solution to fill the tank during cultivation.

Table 1 includes the initial chemical concentrations (ion composition), pH, EC, and O_2 concentrations of the nutrient solutions used for the hydroponic cultivation of lettuce. These nutrient solutions were the nutritional source throughout the production cycle. It is also the composition of the nutrient solution used to fill the tank and supply the plants' consumption. This operation was carried out every 1 or 2 days, not allowing it to go below 50 L. The water consumption that occurs throughout the crop is replaced, but since it is a short cycle, it is not necessary to make a complete change. The water consumption of each treatment is different, and therefore, the changes in concentration in the irrigation solution according to treatments are included.

To characterize the chemical compositions of the aqueous extracts (T1 and T2) and the conventional solution (T0), the pH and ionic concentration (NO_3^-, NH_4^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and Na^+) were analyzed using the selective electrode potentiometry technique (Imacimus-NT Sensor, Spain). The concentration of phosphates (P-$H_2PO_4^-$) was determined by the spectrophotometric analysis method based on the colorimetry of molybdenum blue obtained for P extraction in an aqueous medium [20] modified by [21]. The oxygen concentration in the nutrient solutions was determined using a portable Crison model Oxi45+ oximeter. The EC was determined with a Tec-Hu TE52 conductivity meter.

We used vermicompost of compost made from vegetable waste from horticultural crops from greenhouses in SE Spain whose average characteristics, according to the manufacturer (Tecomsa S.L. (Almería-Spain)), are as follows: organic matter: 32%; N: 2%; humic acids: 7.40%; fulvic acids: 11.10%; humic extract: 17.5%; Phosphoric anhydride: 1.30%; humidity: 39%; pH: 8; organic carbon: 18.6%; granulometry: 90% > 25 mm.

2.3. Nutritional Characteristics of the Crop: Analysis of the Cell Petiole Extract of or Sap

With a press, the juice from the petioles of the leaves (cell petiole extract—ECP) was obtained. By analyzing the ionic composition of the ECP, we can determine the nutritional status of the crop [22]. To conduct the ionic analysis of the ECP, a random and representative sample of fully developed young leaves was obtained. The petiole was separated and crushed with a press to obtain the greatest amount of extract and was analyzed by the potentiometry method with an ion-selective electrode (Imacimus, NTsensor, Spain), obtaining the concentrations of the ions NO_3-, NH_4^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and Na^+. The phosphate content (P-$H_2PO_4^-$) was analyzed by the same colorimetry method as that carried out for the nutrient solution [20], modified by [21].

2.4. Yield and Leaf Nitrate Content

As a determining parameter of the quality of leafy vegetables, the nitrate content was determined once harvested. The nitrate content in leaves was analyzed with the method described by [23]. The complex formed by the nitration of salicylic acid under highly acidic conditions absorbs maximally at 410 nm in basic (pH > 12) solutions. The absorbance of the chromophore is directly proportional to the amount of nitrate, N, present.

Another important factor is the percentage of dry matter in the leaves and roots, which is why the aerial and root parts of a representative sample of each treatment group were weighed (three plants per repetition). Subsequently, the samples were placed in a forced-air oven at a temperature of 600 °C for 72 h to eliminate the water content present in the plant tissues and determine the percentage of dry matter.

The average fruit weight was also quantified using a sample of 12 lettuces (three per repetition) when the plants reached commercial size. They were weighed with an analytical scale with a precision of ±0.01 g. With the average weight of the commercial fruit (W) and according to the density of the plants (d), the commercial production was calculated (kg m^{-2}) (W (kg $fruit^{-1}$) × d (plant m^{-2})), based on the average weight of the biomass of the samples.

2.5. Statistical Analysis of the Results

The procedure chosen for the analysis of the evaluated parameters was the analysis of variance (ANOVA) at a confidence level of 95.0%. This was followed by multiple range tests to determine the degree of significance using Fisher's least significant difference (LSD) at $p \leq 0.05$.

3. Results and Discussion

3.1. Nutrient Solution for Lettuce Cultivation in an NFT System

Periodic analyses of the nutrient solution were carried out to evaluate the variation in the concentrations of nutrient ions during crop development. Table 2 shows the results obtained in each of the treatments structured over three fortnights with the average data for each period.

The highest concentrations of N-NO_3^- in the nutrient solution were achieved in the treatment with mineral fertilization (T0) throughout the crop (Table 2) with values close to 10 mmol L^{-1}, followed by the organic treatment with greater aeration (T1) with statistically significant differences. Among the organic treatments, T1 stands out, as it had a statistically significant mean concentration of N-NO_3^- that was greater than 27% compared to T2 (Table 2). The determining factor for the concentration of nitrates between organic treatments (T1 and T2) was the aeration system of the nutrient solution present in T1. Aeration generates a higher concentration of oxygen dissolved in the solution, helping to accelerate microbial activity for the mineralization of organic nitrogen to forms that are assimilable by the plant (nitrate) [9,10]. It also responds to the increase in aerobic fermentation that favors increases in the microbial populations present in vermicompost teas, allowing greater mineralization of organic matter [24]. Furthermore, the agitation that accompanies aeration leads to the increased solubility of minerals in water [25].

The higher concentration of N-NO_3^- in the organic solution is also justified by the fixation of atmospheric N_2 that passes into the ammoniacal form and is subsequently converted to NO_2^- and finally to NO_3^- by the actions of nitrosomonas and nitrobacter bacteria [26]. Previously conducted studies state that the aqueous extract of vermicompost tea contains high populations of N-fixing bacteria that reach populations of 12 CFU mL^{-1} (log10) after 12 days of aeration [9].

Goto et al. [27] indicated that at an O_2 concentration of 2 mg L^{-1}, the growth rate of nitrifying bacteria significantly decreases, therefore indicating that the minimum need for dissolved O_2 to promote nitrification processes is 4.5 mg L^{-1}. In our experiment, all three treatments maintained oxygen concentrations above 6 mg L^{-1}. T1 stands out by showing significant statistical differences (LSD 95%) with concentrations greater than 7 mg L^{-1}, and it is evident that aeration favors the mineralization of extracts made with organic materials.

The concentration of N-NH_4^+ was very similar during fortnights 1 and 2 (Table 2), without significant differences between the treatment groups. However, in the third fortnight, the concentrations in T1 and T2 decreased, both having significantly different (LSD 95%) ammonium concentrations to T0. The evolution of the data shows a decrease in the concentration of N-NH_4^+ over time, which is possibly an indicator of bacterial activity in the transformation of N-NH_4^+ to N-NO_3^- [24]. As indicated previously, the higher concentration of O_2 in T1 favors increases in the microbial populations present in the vermicompost tea, allowing greater availability of oxygen for microbial reactions for the conversion of ammonium to nitrate [24], decreasing the concentration of ammonium.

Table 2. Mean values and SDs (standard deviations) for the chemical composition (mmol L^{-1}), pH, EC (dS m^{-1}), and O_2 concentration (mg L^{-1}) of the nutrient solution analyzed by fortnight from transplant as functions of the treatments evaluated in a lettuce hydroponic crop. T0, conventional nutrient solution; T1, aqueous extract with supplementary aeration in a recirculation tank; T2, aqueous extract without supplementary aeration in a recirculation tank.

Fortnight		T0	T1	T2
1	NO_3^-	11.25 ± 1.06 a	7.10 ± 0.21 b	6.05 ± 0.49 c
	$H_2PO_4^-$	2.60 ± 0.02 a	0.41 ± 0.91 b	0.21 ± 0.93 c
	Cl^-	10.85 ± 1.63 a	8.35 ± 2.19 a	7.15 ± 2.19 a
	NH_4^+	0.25 ± 0.21 a	0.20 ± 0.14 a	0.20 ± 0.14 a
	K^+	3.95 ± 1.48 a	3.15 ± 0.07 a	2.70 ± 0.28 a
	Ca^{2+}	4.25 ± 0.07 a	3.20 ± 0.14 a	3.35 ± 0.78 a
	Mg^{2+}	2.00 ± 0.57 a	1.20 ± 0.14 b	1.20 ± 0.14 b
	Na^+	9.55 ± 0.64 a	8.95 ± 0.64 a	7.10 ± 0.14 b
	pH	7.00 ± 0.47 b	8.54 ± 0.05 a	8.23 ± 0.16 a
	EC	2.63 ± 0.28 a	2.11 ± 0.14 b	1.91 ± 0.65 b
	O_2	6.89 ± 0.14 b	7.62 ± 0.22 a	6.91 ± 0.13 b
2	NO_3^-	11.03 ± 2.10 a	7.25 ± 0.37 b	5.38 ± 0.41 c
	$H_2PO_4^-$	2.20 ± 0.04 a	0.38 ± 0.05 b	0.36 ± 0.06 b
	Cl^-	9.83 ± 1.90 a	9.85 ± 1.98 a	10.28 ± 1.66 a
	NH_4^+	0.43 ± 0.10 a	0.28 ± 0.15 a	0.30 ± 0.13 a
	K^+	4.50 ± 0.90 a	4.13 ± 0.99 a	4.00 ± 0.72 a
	Ca^{2+}	4.45 ± 2.40 a	3.82 ± 0.70 a	4.05 ± 0.68 a
	Mg^{2+}	1.60 ± 0.30 a	1.10 ± 0.30 a	1.20 ± 0.70 a
	Na^+	11.30 ± 2.34 a	9.35 ± 1.47 a	8.75 ± 4.37 a
	pH	6.87 ± 0.10 b	8.41 ± 0.30 a	8.26 ± 0.20 a
	EC	2.83 ± 0.15 a	2.36 ± 0.05 b	2.35 ± 0.16 b
	O_2	6.72 ± 0.14 b	7.36 ± 0.22 a	6.73 ± 0.13 b
3	NO_3^-	9.80 ± 1.27 a	6.92 ± 0.27 b	5.54 ± 0.56 c
	$H_2PO_4^-$	2.10 ± 0.06 a	0.38 ± 0.12 b	0.32 ± 0.03 b
	Cl^-	11.50 ± 3.54 a	11.88 ± 4.22 a	10.92 ± 4.05 a
	NH_4^+	0.50 ± 0.14 a	0.20 ± 0.09 b	0.20 ± 0.07 b
	K^+	5.05 ± 0.92 a	3.80 ± 0.93 ab	3.08 ± 1.02 b
	Ca^{2+}	3.85 ± 0.49 a	4.42 ± 1.15 a	5.04 ± 1.20 a
	Mg^{2+}	1.80 ± 0.14 a	1.98 ± 0.72 a	1.72 ± 0.73 a
	Na^+	9.00 ± 0.14 a	12.40 ± 3.81 a	10.90 ± 3.47 a
	pH	7.12 ± 0.06 b	8.30 ± 0.20 a	8.18 ± 0.20 a
	EC	2.59 ± 0.27 b	2.93 ± 0.05 a	2.85 ± 0.05 b
	O_2	6.60 ± 0.14 b	7.18 ± 0.22 a	6.67 ± 0.13 b

Different letters express significant differences (LSD ≤ 95%) between treatments.

Phosphorus is the second key element after nitrogen as a nutrient in qualitative terms for plants. Regarding the concentration of P-$H_2PO_4^-$ in the nutrient solution, there were highly significant differences between the mineral treatment group (T0) and the organic treatment groups (T1 and T2). As expected, T0 maintained an adequate concentration for lettuce cultivation. In the organic treatment groups (T1 and T2), the concentration of P-$H_2PO_4^-$ was deficient with respect to optimal nutritional requirements [19]. According to

Ruiz and Salas [9], the P present in the extract is in organic form, while some of the mineral forms may be precipitated with other cations, making them inaccessible and leaving a very deficient level for a nutrient solution. The high pH (>8) of the organic solution does not facilitate the solubilization of P-$H_2PO_4^-$. It is advisable, during specific moments, to lower the pH of the aqueous extract with acids authorized for use in organic agriculture, such as acetic acid. According to the results, it is necessary to increase the concentration of this element in the nutrient solution by adding P from other sources, such as mineral rock and/or the inoculation of phosphorus-solubilizing microorganisms [16,28].

In the initial stage of cultivation, there were no significant differences in the concentration of K^+ in the nutrient solutions between treatment groups. In all treatment groups, the nutrient solution had a concentration of 65% of that recommended by Valverde [29] for lettuce in a hydroponic system. During fortnights 1 and 2, the concentration of K^+ in the nutrient solution increased in all treatment groups. However, in the third fortnight, it decreased, possibly due to an increase in the crop's K^+ needs in this last stage. K^+ is a fundamental element in osmotic adjustment for cellular turgor [30]. During the final stage of cultivation, according to the results presented in this work, in the organic nutrient solution, it is recommended to control and, if necessary, increase the concentration of K^+ to avoid possible deficiencies.

In the third fortnight, in the aerated organic solution, the concentrations of nitrate and potassium increased significantly compared to the organic solution without aeration. The results of this experiment agree with those of Pant et al. [14], who found higher concentrations of nitrate and potassium when aeration was maintained during the extraction process compared to non-aerated compost extracts.

In terms of the concentration of Ca^{2+}, there were no significant differences between treatment groups in the three samplings carried out during the crop cycle. An increase in the Ca^{2+} concentration was observed over time in all treatment groups. This increase was generated because Ca is an element that is slowly assimilated by the plant [31], and consequently, its accumulation occurs in the tank of the recirculated nutrient solution.

Throughout the entire crop cycle, the concentration of Mg^{2+} in T0 is within acceptable values, while in the organic treatment groups (T1 and T2), it does not reach the recommended concentration for lettuce until the third fortnight. The increase is achieved by accumulation in the nutrient solution tank due to the slow absorption of Mg^{2+} due to competition with other cations [32], as occurs with Ca.

The concentrations of Na^+ and Cl^- did not register statistically significant differences between treatment groups during the crop cycle, except for the concentration of Na^+ in the first fortnight, which showed significantly lower values in T2 compared to T0 and T1 (Table 2). The greatest increase in the concentration of Na^+ in T1 was due to the effect of aeration, which increases the solubilization of elements such as Na^+ [24]. Control of the sodium concentration is important, since sodium is a non-essential element for plants that frequently causes stress or toxicity situations in crops when it is present in high concentrations and limits the absorption of K^+ [33].

The lower pH in the mineral treatment group (T0) was due to its control using HNO_3, as indicated in the Materials and Methods Section, a process that was not carried out in the organic treatment groups (T1 and T2). Organic treatments produce alkaline pH values. High pH values are largely associated with the mineralization processes of organic matter, which are favored in turn by the availability of O_2 [26].

The effect of using a high EC in the fertigation solution was an osmotic imbalance (dehydration), which hindered the flow of water and nutrients in the plant [34]. Consequently, for the preparation of aqueous extracts, conditioning the amount of vermicompost per volume of water to the EC limit values ensures that elements such as Na+ do not reach excessive concentrations. It is also assumed that it limits the concentrations of other elements that are as important as P. The concentrations of ions during the preparation of liquid solutions depend directly on the EC, which is determined by the types and amounts of solid materials dissolved in the water.

The content of dissolved oxygen in the nutrient solution was higher in T1 with more statistically significant differences (LSD 95%) than the rest of the treatments as a consequence of the aeration system included in this treatment. Our results agree with the data obtained by St Martín and Brathwaite [24], who mentioned that the solubility of nutrients in the composts, as well as the different rates of consumption and release of nutrients by microorganisms present in the compost teas, appear to be the main factors that affect the concentrations of nutrients across the brewing time.

3.2. Nutritional Status of the Crop: Petiole Cellular Extract Analysis (ECP)

During cultivation, the nutritional status of the crop was assessed through the rapid analysis of petiole cellular extract or plant sap analysis, as recommended by Cadahía [22], with the aim of assessing the effect of an unbalanced nutrient solution. To do this, we compared the concentrations of the main ions in the sap of lettuce grown with organic solutions (T1 and T2) and in the T0 treatment, which was considered to be a control.

The maximum concentrations of N-NO_3^- in the petiole cell extract (Table 3) were obtained in the T0 (mineral) and T1 (organic + aeration) plants without statistical differences between them, which shows the adequate availability and good assimilation of this element by cultivation. This result agrees with the analysis of the nutrient solution where the highest concentrations of N-NO_3^- were found in T0 and T1.

Table 3. Plant sap analysis: Ion concentration (mmol L^{-1}) according to the treatments evaluated in a lettuce hydroponic crop. T0, conventional nutrient solution; T1, aqueous extract with supplementary aeration in a recirculation tank; T2, aqueous extract without supplementary aeration in a recirculation tank.

	NO_3^-	$H_2PO_4^-$	Cl^-	K^+	Ca^{2+}	Mg^{2+}	Na^+
T0	59.0 ± 3.5 a	12.1 ± 3.0 a	49.3 ± 3.5 b	76.0 ± 5.0 a	1.4 ± 0.1 a	1.8 ± 0.4 a	29.0 ± 5.0 a
T1	53.6 ± 0.5 b	7.9 ± 1.5 b	69.0 ± 3.0 a	71.3 ± 2.0 a	0.5 ± 0.0 c	0.5 ± 0.0 b	26.6 ± 3.7 a
T2	50.0 ± 2.6 b	8.5 ± 1.1 b	64.0 ± 5.0 a	71.0 ± 3.6 a	0.7 ± 0.0 b	0.4 ± 0.0 b	18.6 ± 1.5 b

Values with the same letters within each column are statistically similar (LSD ≤ 95%).

The highest concentrations of P-$H_2PO_4^-$ were obtained in the mineral treatment group (T0) due to the higher concentration of this nutrient in the nutrient solution (T0). In the organic treatment groups (T1 and T2), the concentrations were significantly lower than in T0, without significant differences (LSD 95%) between them, coinciding with the already-mentioned low concentrations of P-$H_2PO_4^-$ in the organic nutrient solutions.

In terms of the concentration of K^+ in ECP, no statistically significant differences were observed between the treatment groups, which indicates that the different nutrient solutions and/or aeration treatments had no influence on this element. The behavior of K^+ concentrations in sap coincides with that of the concentration of this element in the nutrient solution.

The concentration of Ca^{2+} in sap presented significant statistical differences (LSD 95%) between the organic treatment groups (T1 and T2) and the mineral group (T0). It is important to mention that the Ca^{2+} content in the nutrient solutions did not show significant differences between the organic and mineral treatment groups, which is why the result obtained in the ECP differs from what was expected. The treatment with mineral fertilization (T0) led to the highest concentration of Ca^{2+} in sap, while the organic treatment groups presented considerably lower concentrations of Ca^{2+}. The low absorption of Ca^{2+} in the organic treatment groups may be a consequence of the low concentration of P-$H_2PO_4^-$ in the nutrient solution. According to Jakobsen [35], the Ca^{2+} assimilation capacity of plants is limited by the phosphate content, and the Ca^{2+} absorption capacity increases depending on the phosphate concentration. The concentration of P in the T1 and T2 solutions was limited, with concentrations lower than the needs of the crop, a limiting factor in the absorption of Ca^{2+}. This would also lead to limited Ca^{2+} availability due to the alkaline pH in the nutrient solution.

The highest concentration of Mg^{2+} in the petiole was obtained in the mineral treatment group (T0), which showed statistically significant differences compared with the organic treatment groups (T1 and T2). The lower concentration of Mg^{2+} in the organic treatment groups could be caused by the low concentration of Mg^{2+} in the first fortnight and/or the high concentration of Na^{+} in the last fortnight in the nutrient solution, which may have had a direct effect on the absorption of Mg^{2+} [32].

The Cl^{-} content in sap was higher in the two organic treatment groups, with an average concentration of 66.5 mmol L^{-1}, while the culture with inorganic nutrition accumulated the lowest amount of Cl^{-} in the ECP, with an average value of 49.3 mmol L^{-1}. The competition, described by Cadahía [36], between the absorption of Cl^{-} and $NO_3{}^{-}$ would also justify the lower petiole concentration of $NO_3{}^{-}$ in the organic treatment groups.

The highest concentrations of Na^{+} in the plant sap analysis were found in the crops irrigated with mineral solution (T0) and aerated organic solution (T1), significantly higher than those in the plants in treatment group T2.

3.3. Generation of the Aerial Part and Root Part Biomasses

The greatest fresh weight of the aerial part of the plant, without statistical differences, was obtained in the organic treatment group with aeration (T1) with an average of 170 g plant^{-1} (Table 4). The increase in the total biomass production (aerial and root parts) in T1 is justified by the higher concentration of O_2 in the nutrient solution (Table 2) with respect to T2 and the more balanced nutrient solution. The high concentrations of O_2 in the nutrient solution prepared from aqueous extract (T1) allow for the maintenance of higher NO_3 concentrations than in T2. Regarding the root biomass (fresh weight), significantly greater fresh root weights found in the organic treatment groups (T1 and T2) also show that with lower nutrient concentrations in the irrigation solution, equal levels of weight could be obtained in the aerial part.

Table 4. Fresh weights and dry weights of the aerial and root parts of lettuce plants according to the treatments evaluated in a lettuce hydroponic crop. T0, conventional nutrient solution; T1, aqueous extract with supplementary aeration in a recirculation tank; T2, aqueous extract without supplementary aeration in a recirculation tank.

	Fresh Weight (g Plant^{-1})		Dry Matter (%)	
	Aerial Part	**Root**	**Aerial Part**	**Root**
T0	159.10 ± 28.44 a	26.67 ± 2.25 b	11.83 ± 1.54 a	25.97 ± 2.00 a
T1	170.61 ± 16.72 a	53.81 ± 9.20 a	6.84 ± 0.63 b	14.10 ± 1.17 b
T2	154.98 ± 12.85 a	42.97 ± 6.88 a	7.11 ± 0.74 b	15.95 ± 1.86 b

Values with the same letters within each column are statistically similar (LSD ≤ 95%).

The values obtained show that treatment with inorganic nutrition led to the highest percentages of dry matter in the aerial and root parts (Table 4), with statistically significant differences. The results do not coincide with those obtained by Masarirambi et al. [37], who mentioned that treatment with mineral nutrition leads to a lower percentage of dry matter compared to organic fertilization in a lettuce crop. The difference between both manuscripts may be caused by the type of organic matter used as amendment and its richness in nutrients. In our experiment, the aqueous extracts (T1 and T2) present low concentrations of P (Table 2), which justifies that the dry matter of the organic treatments is lower, even with aeration, as it does not reach the recommended values for lettuce (T0). The dry weight of the root and aerial part of the T0 treatment are significantly greater than those quantified in the organic treatments (T1 and T2). This increase, more than 4% and 10% in the dry matter of the aerial part and root, respectively, may be caused by the increase in the assimilation, translocation, and utilization of phosphorus as a consequence of the higher concentration of H_2PO_4 (Table 2) in the T0 (P concentration in T0, is six times higher than in T1 and T2), which is corroborated by the highest concentration of P in sap (Table 3). Phosphorus is essential for the processes of photosynthesis and respiration; in this regard, [38] Russo and Pappelis (1995) report that phosphorus promotes greater elongation and production of root hairs that lead to an increase in the dry weight of the plant.

3.4. Yield and Leaf Nitrate Content

No statistically significant differences were observed during production (kg m^{-2}) between the mineral treatment group (T0) and the organic treatment groups (T1 and T2), coinciding with the average weights of the plants (Figure 3). The weight of the harvested pieces (aerial part) was not affected by lower concentrations of some nutrients in the nutrient solution or in the plant sap analysis. The organic treatment group T1 was the most productive, reaching an average yield of 5 kg m^{-2} according to the plantation density. The results agree with the data reported by Masarirambi et al. [37], who mentioned that a higher yield is obtained with the application of organic fertilizers compared to conventional management in lettuce cultivation. They also coincide with the results of González et al. [39] and Xu et al. [40], who showed that differences between vegetables depend on whether they were grown with fertilizers from organic sources or through inorganic fertilization and the greatest quantity and quality are obtained in organic crops. Martínez et al. [41] showed that percentages of dissolved oxygen greater than 90% in nutrient solution generate the greatest increases in the production of lettuce crops. This coincides with the result showing that T1 had an average value of 7.39 mg L^{-1}, which is equivalent to 92.47% dissolved oxygen. T1, throughout the culture, has a significantly higher concentration than T0 and T2.

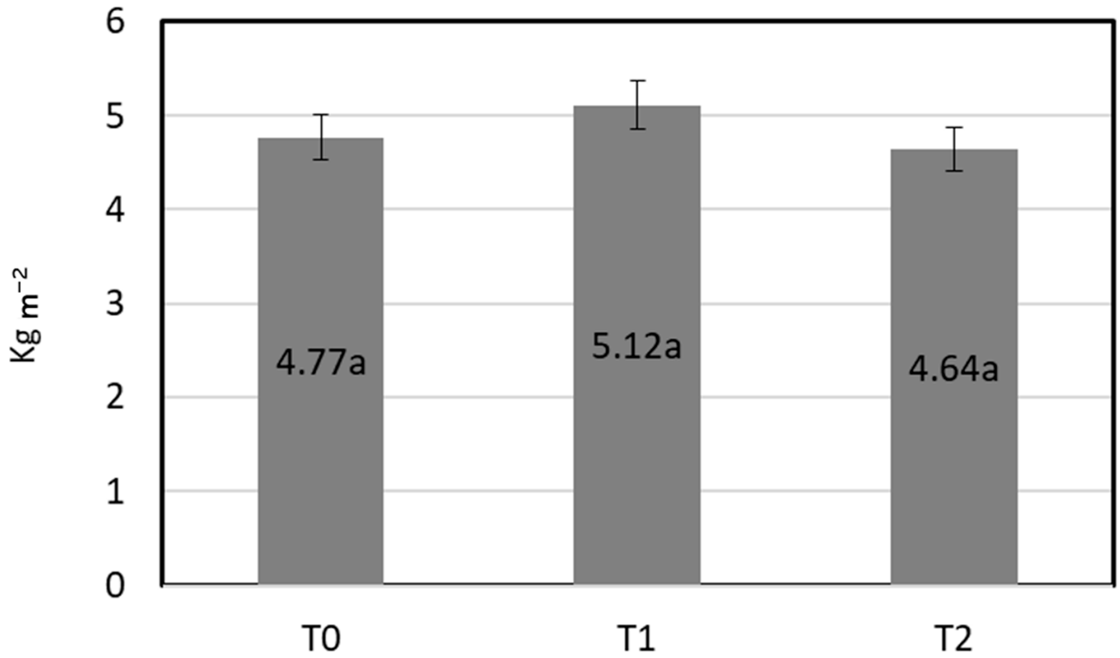

Figure 3. Yields of lettuce crops according to the treatment groups: T0, conventional nutrient solution; T1, aqueous extract with supplementary aeration in a recirculation tank; T2, aqueous extract without supplementary aeration in a recirculation tank. Numerical values followed by different letters indicate statistically significant differences (LSD $\leq$ 95%).

The main difference between the mineral and organic treatments lies in the time necessary to reach the harvest size. The crop cycle increased by 15 days in the T1 and T2 treatment groups compared to T0. The growing cycle increased the number of days to harvest by 40%.

3.5. Nitrate Content in Leaves

The nitrate content in the leaves of edible vegetables is one of the main factors that drive the production of organic vegetables. Minimizing the $N\text{-}NO_3^-$ content in edible leaves contributes to an improvement in the quality of food in relation to consumer health. In turn, the correct management of organic fertilizers contributes to a reduction in the environmental impact of inorganic fertilizers. In 2011, the European Commission [42] established the maximum permitted content of nitrates in vegetables for their marketing and consumption with the aim of protecting consumers from potential toxicological risks due to the consumption of foods with high nitrate contents.

The greatest accumulation of nitrates in leaves was found in lettuce plants grown with inorganic fertilization (T0), with values close to 3000 mg NO_3^- kg^{-1} m.f. (Table 5). This is below the limit established by the European Commission [42] (relative to the maximum nitrate content in lettuce produced in a greenhouse between April 1 and September 30).

Table 5. Nitrate content in lettuce leaves.

Treatment	mg NO_3 kg^{-1} f.m. [1]
T0	2946 ± 47 a
T1	557 ± 43 b
T2	509 ± 33 b

Values ± standard deviations. T0, conventional nutrient solution; T1, aqueous extract with supplementary aeration in a recirculation tank; T2, aqueous extract without supplementary aeration in a recirculation tank. Different letters express significant differences (LSD ≤ 95%). [1] f.m. Fresh matter.

The accumulation of nitrates in leaves treated with organic nutrient solution (T1 and T2) was notably lower than in the control group (T0), with values of around 500 mg $NO_3^-\cdot Kg^{-1}$ m.f. observed, six times lower than those produced with the mineral treatment. There were no significant statistical differences in the leaf nitrate content between plants treated with organic fertilizer; however, as with the compositions of nutrient solutions, the treatment group with greater aeration (T1) had the highest concentration of $N\text{-}NO_3^-$ in the leaves. This was directly related to the ionic composition of the vermicompost tea used as a nutrient solution.

The concentration coincides with the values obtained by Pavlou et al. [7] in lettuce cultivated with organic fertilization. Magkos et al. [43] mentioned a significant difference between the nitrate contents in the organic and traditional agriculture systems, mainly regarding the cultivation of leafy vegetables, finding the accumulation of nitrates to be three times lower in organic systems compared to that in traditional production systems.

A lower nitrate concentration adds value to the quality of the product. Mineral fertilizer sources with high solubility allow easy availability of nutrients in assimilable form, sometimes leading to plants for luxury consumption.

The slow mineralization of organic N in organic treatments induces the progressive absorption of N by plants. This slow absorption provides the time necessary for the metabolic assimilation processes to be carried out in the plant tissues to form structures, so the accumulation of nitrates is lower [44]. However, the time necessary for the plants to reach the size considered to be appropriate for commercial harvest also increases, going from 35 days from transplant in the mineral treatment group to 50 days in the organic treatment group.

The lower leaf nitrate contents in the organic treatment groups are also justified by the relationship of nitrate with the dry weights of the harvested plants since the plants from treatment groups T1 and T2 had aerial part dry weights that were almost two times lower (Table 4) than those of the mineral treatment plants (T0).

According to the results of this work, it is possible to work towards the replacement of mineral nutrient solutions through hydroponics or soil-less cultivation techniques, either totally or partially, with solutions generated from aqueous extracts of local plant remains, a process known as biofertigation [9]. The reintegration of agro-waste into the same agriculture site fulfils the objective of the European Bio-Economy Strategy 2018–2030 [5] and reduces transport costs, waste volume, and the need for mineral fertilizers [45,46]. Many alternatives to the disposal of agro-waste have been evaluated, with the use of organic matter as a source of crop nutrients being the most competitive solution in an area in which intensive agriculture activity is prevalent [6,45,47].

4. Conclusions

The aqueous extract vermicompost tea from horticultural plants is used as a nutrient solution in a hydroponic system, providing concentrations of NO_3^-, K^+, and Ca^{2+} that are sufficient for the development of the lettuce crop. However, the $H_2PO_4^-$ and Mg^{2+} concentrations in the aqueous extract are lower than the needs of the culture, as corroborated by the analyses in sap.

For the preparation of the aqueous extract, conditioning the amount of vermicompost per volume of water to the EC limit values ensures that elements such as Na^+ do not reach excessive concentrations. It is assumed that this preparation methodology limits the concentrations of other elements that are as important as P.

The high concentration of dissolved O_2 (>7 mg L^{-1}) in the organic nutrient solution achieved through aeration throughout the crop cycle allows a commercial production level similar to that obtained with treatment with mineral fertilizers with greater generation of root biomass. It allows adequate nutritional levels in sap for the crop to be obtained.

There was an improvement in the quality of the harvest of plants fertigated with organic nutrient solution, with a leaf N-NO_3^- content that was six times lower than that in the leaves produced with the traditional system involving irrigation with synthetic fertilizer. However, the duration of the growing cycle until harvest increased when an organic nutrient solution was used.

The vermicompost tea prepared from horticultural vegetable waste could be an alternative to mineral nutrient solutions for the production of short-cycle hydroponic crops such as lettuce.

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References

1. Preciado, P.; Fortis, H.M.; García-Hernández, J.L.; Rueda, E.O.; Esparza, J.R.; Lara, A.; Segura, M.A.; Orozco, J.A. Evaluación de soluciones nutritivas orgánicas en la producción de tomate en invernadero. *Interciencia* **2011**, *36*, 689–693.
2. Shinohara, M.; Aoyama, C.; Fujiwara, K.; Watanabe, A.; Ohmori, H.; Uehara, Y.; Takano, M. Microbial mineralization of organic nitrogen into nitrate to allow the use of organic fertilizer in hydroponics. *Soil Sci. Plant Nutr.* **2011**, *57*, 190–203. [CrossRef]
3. Pardossi, A.; Incrocci, L.; Salas, M.C.; Gianquinto, G. Managing Mineral Nutrition in Soilless Culture. In *Rooftop Urban Agriculture*; Orsini, F., Dubbeling, M., de Zeeuw, H., Gianquinto, G., Eds.; Springer: Cham, Switzerland, 2017.
4. Jensen, M.H. Principales sistemas hidropónicos: Principios, ventajas y desventajas. En: Hidroponía comercial. In Proceedings of the Conferencia Internacional, 6–8 August 1997; Universidad Agraria La Molina y Hidroponic Society of America: Lima, Perú, 1997; pp. 35–48.
5. Reglamento (UE) 2019/1009 del Parlamento Europeo y del Consejo de 5 de junio de 2019, por el que se establecen disposiciones relativas a la puesta a disposición en el mercado de los productos fertilizantes UE. Available online: https://www.boe.es/doue/2019/170/L00001-00114.pdf (accessed on 22 November 2023).

6. Carricondo-Martínez, I.; Berti, F.; Salas-Sanjuán, M.d.C. Different Organic Fertilisation Systems Modify Tomato Quality: An Opportunity for Circular Fertilisation in Intensive Horticulture. *Agronomy* **2022**, *12*, 174. [CrossRef]
7. Pavlou, C.G.; Constantinos, D.; Ehaliotis, V.; Kavvadias, A. Effect of organic and inorganic fertilizers applied during successive crop seasons on growth and nitrate accumulation in lettuce. *Sci. Hortic.* **2007**, *111*, 319–325. [CrossRef]
8. Mejia, P.A.; Salas, M.C.; López, M.J. Evaluation of physicochemical properties and enzymatic activity of organic substrates during four crop cycles in soilless containers. *Food Sci. Nutr.* **2018**, *6*, 2066–2078. [CrossRef]
9. Ruiz, J.; Salas, M.C. The use of plant growth promoting bacteria for biofertigation; effects on concentrations of nutrients in the inoculated aqueous vermicompost extract and on the yield and quality of tomatoes. *Biol. Agric. Hortic.* **2022**, *38*, 145–161. [CrossRef]
10. Ingham, E.R. The Compost Tea Brewing Manual: Latest Methods and Research. *Soil Food Web* **2005**, 13–86.
11. Atiyeh, R.M.; Subler, S.; Edwards, C.A.; Bachman, G.; Metzger, J.D.; Shuster, W. Effects of vermicompost and composts on plant growth in horticultural container media and soil. *Pedo Biol.* **2000**, *44*, 579–590. [CrossRef]
12. Mejía, P.A.; Ruíz-Zubiate, J.L.; Correa-Bustos, A.; López-López, M.J.; Salas-Sanjuán, M.d.C. Effects of Vermicompost Substrates and Coconut Fibers Used against the Background of Various Biofertilizers on the Yields of *Cucumis melo* L. and *Solanum lycopersicum* L. *Horticulturae* **2022**, *8*, 445. [CrossRef]
13. Hargreaves, J.C.; Adl, M.S.; Warman, P.R. Are compost teas an effective nutrient amendment in the cultivation of strawberries? Soil and plant tissue effects. *J. Sci. Food Agric.* **2009**, *89*, 390–397. [CrossRef]
14. Pant, A.P.; Radovich, T.J.K.; Hue, N.V.; Paull, R.E. Biochemical properties of compost tea associated with compost quality and effects on pak choi growth. *Sci. Hortic.* **2012**, *148*, 138–146. [CrossRef]
15. González, S.K.; Rodríguez, M.M.; Trejo, T.L.; Sánchez, E.J.; García, C.J. Propiedades químicas del té de vermicompost. *Cienc. Agrícolas* **2013**, *5*, 901–911.
16. Ruiz, J.; Salas, M.C. Evaluation of organic substrates and microorganisms as bio-fertilisation tool in container crop production. *Agronomy* **2019**, *9*, 705. [CrossRef]
17. Cooper, A. *The ABC of NFT*; Casper Publications Pty Ltd.: Narrabeen, Australia, 1996; pp. 145–196.
18. Williams, K.A.; Nelson, J.S. Challenges of using organic fertilizers in hydroponic production systems. *Acta Hortic.* **2016**, *1112*, 365–370. [CrossRef]
19. Steiner, A.A. A universal method for preparing nutrient solutions of certain desired composition. *Plant Soil* **1961**, *15*, 134–154. [CrossRef]
20. Murphy, J.; Riley, J.P. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* **1962**, *27*, 31–36. [CrossRef]
21. Guzmán, M. Equilibrios Nutricionales en Condiciones de Invernadero: Corrección, y Mejora de la Cosecha. Ph.D. Thesis, Universidad de Granada, Granada, Spain, 1987.
22. Cadahía, C. *La Savia Como Índice de Fertilización. Cultivos Agroenergéticos, Hortícolas, Frutales y Ornamentales*; Mundi-Prensa: Madrid, Spain, 2008; pp. 35–68.
23. Cataldo, M.; Schrader, L.E.; Youngs, V.L. Rapid Colorimetric Determination of Nitrate in Plant Tissue by Nitration of Salicylic Acid. *Soil Sci. Plant Anal.* **1975**, *6*, 71–80. [CrossRef]
24. St. Martín, C.C.G.; Brathwaite, R.A.I. Compost and compost tea: Principles and prospects as substrates and soil-borne disease management strategies in soil-less vegetable production. *Biol. Agric. Hortic.* **2012**, *28*, 1–33. [CrossRef]
25. Kannangara, T.; Forget, B.; Dang, B. Effects of aeration, molasses, kelp, compost type, and carrot juice on the growth of Escherichia coli in compost teas. *Compost Sci. Util.* **2006**, *14*, 40–47. [CrossRef]
26. Sánchez, M.M.; Roig, C.; Bernal, M.P. Nitrogen transformation during organic waste composting by the Rutgers system and and it effects on pH, EC, and maturity of the composting mixtures. *Bioresour. Technol.* **2001**, *78*, 301–308. [CrossRef]
27. Goto, E.; Both, A.J.; Albright, L.D.; Langhans, R.W.; Leed, A.R. Effect of dissolved oxygen concentration on lettuce growth in floating hydroponics. *Acta Hortic.* **1996**, *440*, 205–210. [CrossRef]
28. Kumar, V.; Singh, K.P. Enriching vermicompost by nitrogen fixing and phosphate solubilizing bacteria. *Bioresour. Technol.* **2001**, *76*, 173–175. [CrossRef] [PubMed]
29. Valverde, K.; Chang, M.; Rodríguez, D.A. Effect of the Light Quality on the Nitrate Reductase Activity in Lettuce Plants Grown in NFT. *Acta Hortic.* **2009**, *843*, 89–96. [CrossRef]
30. Afzal, I.; Hussain, B.; Ahzmed, S.M.; Ullah, S.H.; Shakeel, Q.; Kamran, M. Foliar application of potassium improves fruit quality and yield of tomato plants. *Acta Sci. Pol. Hortorum Cultus* **2015**, *14*, 3–13.
31. Monge, E.; Val, J.; Sanz, M.; Blanco, A.; Montañés, L. El calcio nutriente para las plantas. Bitter pit en manzano. *An. Estac. Exp. Aula Dei* **1994**, *21*, 189–201.
32. Mengel, K. Potassium. In *Handbook of Plant Nutrition*; Barker, A.V., Pilbeam, D.J., Eds.; CRC Press: Boca Raton, FL, USA, 2007; pp. 91–120.
33. Wu, S.C.; Cao, Z.H.; Li, Z.G.; Cheung, K.C.; Wong, M.H. Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth: A greenhouse trial. *Geoderma* **2005**, *125*, 155–166. [CrossRef]
34. Numan, M.; Bashir, S.; Khan, Y.; Mumtaz, R.; Shinwari, Z.K.; Khan, A.L. Plant growth promoting bacteria as an alternative strategy for salt tolerance in plants: A review. *Microbiol. Res.* **2018**, *209*, 21–32. [CrossRef] [PubMed]

35. Jakobsen, T.S. Interaction between Plant Nutrients: IV. Interaction between Calcium and Phosphate. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **1993**, *43*, 6–10. [CrossRef]
36. Cadahía, C. (Ed.) *Fertirrigación. Cultivos Hortícolas, Frutales y Ornamentales*, 3rd ed.; Ediciones Mundi-Prensa: Madrid, Spain, 2008; pp. 75–76.
37. Masarirambi, T.M.; Hlawe, M.M.; Oseni, T.O.; Thokozile, E. Effects of organic fertilizers on growth, yield, quality and sensory evaluation of red lettuce (*Lactuca sativa* L.) 'Venezaoxa'. *Agric. Biol. J. N. Am.* **2010**, *6*, 1319–1324. [CrossRef]
38. Russo, V.; Pappelis, A. Senescence in sweet corn as influenced by phosphorous nutrition. *Plant Nutr.* **1995**, *18*, 707–717. [CrossRef]
39. González, S.K.; Rodríguez, M.M.; Trejo, T.L.; Sánchez, E.J.; García, C.J. Efluente y té de vermicompost en la producción de hortalizas de hoja en sistema NFT. *Interciencia* **2013**, *28*, 863–869.
40. Xu, H.L.; Wang, R.; Xu, R.Y.; Mridha, M.A.U.; Goyal, S. Yield and quality of leafy vegetables grown with organic fertilizations. *Acta Hortic.* **2005**, *627*, 25–33. [CrossRef]
41. Martínez, G.G.; Ortiz, H.Y.; López, P.R. Oxigenación de la solución nutritiva recirculante y su efecto en tomate y lechuga. *Rev. Fitotec. Mex.* **2012**, *35*, 49–52. [CrossRef]
42. Reglamento (UE) No 1258/2011 de la Comisión. de 2 de diciembre de 2011. Modifica el Reglamento (CE) no 1881/2006 por lo que respecta al contenido máximo de nitratos en los productos alimenticios. *D. Of. De La Unión Eur.* **2011**, *L 320*, 15–17.
43. Magkos, F.; Arvaniti, F.; Zampelas, A. Putting the safety of organic food into perspective. *Nutr. Res. Rev.* **2003**, *16*, 211–221. [CrossRef] [PubMed]
44. Hernández, T.; Chocano, C.; Moreno, J.L.; García, C. Use of compost as an alternative to conventional inorganic fertilizers in intensive lettuce (*Lactuca sativa* L.) crops—Effects on soil and plant. *Tillage Res.* **2016**, *160*, 14–22. [CrossRef]
45. López, M.J.; Masaguer, A.; Paredes, C.; Perez, L.; Muñoz, M.; Salas, M.C.; Hernandez, R. De resíduos a recursos. El camino hacia la Sostenibilidad. *Red Española Compost.* **2015**, 91–121.
46. Janssen, B.H.; Oenema, O. Global economics of nutrient cycling. *Turk. J. Agric. For.* **2008**, *32*, 165–176.
47. Aznar-Sánchez, J.A.; Velasco-Muñoz, J.F.; García-Arca, D.; López-Felices, B. Identification of opportunities for applying the circular economy to intensive agriculture in Almería (South-East Spain). *Agronomy* **2020**, *10*, 1499. [CrossRef]