Chapter

Nutritive Solutions Formulated from Organic Fertilizers

Juan Carlos Rodríguez Ortiz

Abstract

This chapter shows how organic fertilizers can provide essential nutrients soluble to plants, so as to be used in hydroponic systems in its various forms. Such materials are an important source of macro- and micronutrients. This form of plant nutrition can contribute to the sustainable production of food, both in developed and developing countries. Nutrient solutions can be formulated when soluble nutrients are extracted from the solid phase of organic manure. In some vegetables, equal yields, or sometimes higher, have been obtained in nutritive solutions formulated with synthetic chemical fertilizers. It has also been documented that the resulting edible products can be of a better nutraceutical quality. Ions can be obtained by means of preparations based on teas, extracts, leachates, digestate, urine, aquaculture, etc. Subsequently they must be diluted in water until reaching a level of electrical conductivity according to the tolerance levels of the crop to be established. The heterogeneity of the chemical composition of the solutions obtained is the main point that must be attended with the greatest possible precision to formulate the nutritive solutions and obtain satisfactory results. Therefore, it is necessary to measure the concentration of macro- and micronutrients (NO_3^-, NH_4^+, $SO_4^=$, $H_2PO_4^-$, K^+, Ca^{++}, Mg^{++}, Fe^{+++}, Cu^{++}, Mn^{++}, Zn^{++}, Cl^-) as well as the Na^+ ion (which is usually at high levels); it will also be necessary to adjust the pH. In addition, the chapter presents a broad overview and a series of research results in recent years: composition of solutions, nutrient supplements, substrates, and floating root trials in tomato, lettuce, cantaloupe melon, and green fodder. The environmental implications of inappropriate formulations are also analyzed. The nutritious solution, formulated from organic fertilizers, is not only an alternative for the nutrition of agricultural crops, but it also represents a more efficient way to use these resources.

Keywords: production systems, soilless, hydroponics, organic agriculture, plant nutrition

1. Introduction

The cyclical dynamics of the elements allow their reuse in ecosystems but also in agroecosystems. Organic matter represents a phase where they are partially and momentarily retained to follow the flow to various destinations, such as soil. Possible sources of nutrients, derived from reused or recycled materials, include wastewater; sewage sludge; biosolids; animal manure; urban waste; compost; vermicompost; digestate; biocarbon; inorganic by-products such as struvite, ammonium sulfate, and food waste; agribusinesses; and other industries [1].

This chapter focuses on manure, which is often the most available in the world's producing areas and is an important source of macro- and microelements for plant. For example, global manure nitrogen (N) production increased from 21.4 Tg N yr^{-1} in 1860 to 131.0 Tg N yr^{-1} in 2014, with a significant annual upward trend (0.7 Tg N yr^{-1}, $p < 0.01$), according to estimates of Zhang et al. (2017). These authors mention that cattle dominated the nitrogen production of manure and contributed 44% of total manure nitrogen production in 2014, followed by goats, sheep, porks, and poultries. The application of nitrogen from manure to farmland accounts for less than one-fifth of the total nitrogen production of manure during the study period.

Manure nitrogen production is expected to increase in the coming decades due to the growing demand for livestock populations as a result of increased human populations and changes in the structure of the diet with higher meat consumption (Herrero and Thornton, 2013).

While, in each country, there are significant resources of organic materials as sources of plant nutrients, their commercial use in hydroponics may be feasible if there is high availability and affordable costs, and on the other hand, they must be accompanied by guarantee of safety and food safety. This production technique is very promising for food production and efficient use of water and nutrients.

2. Formulation of the organic nutrient solution

The nutrient solution is a homogeneous mixture of water, ions (cations and anions), and oxygen that promote the growth and development of the vegetable species. Five steps are necessarily followed for the formulation of the ONS (**Figure 1**).

2.1 Step 1. Organic source selection

Oganic sources can be from different manures: bovine, poultry, sheep, goat, pork, etc. They must ensure the absence of microorganisms through effective composting and laboratory analysis to support it [2]. They must also have low heavy metal content, below the legal limits of each country. These requirements will be retaken in a space later.

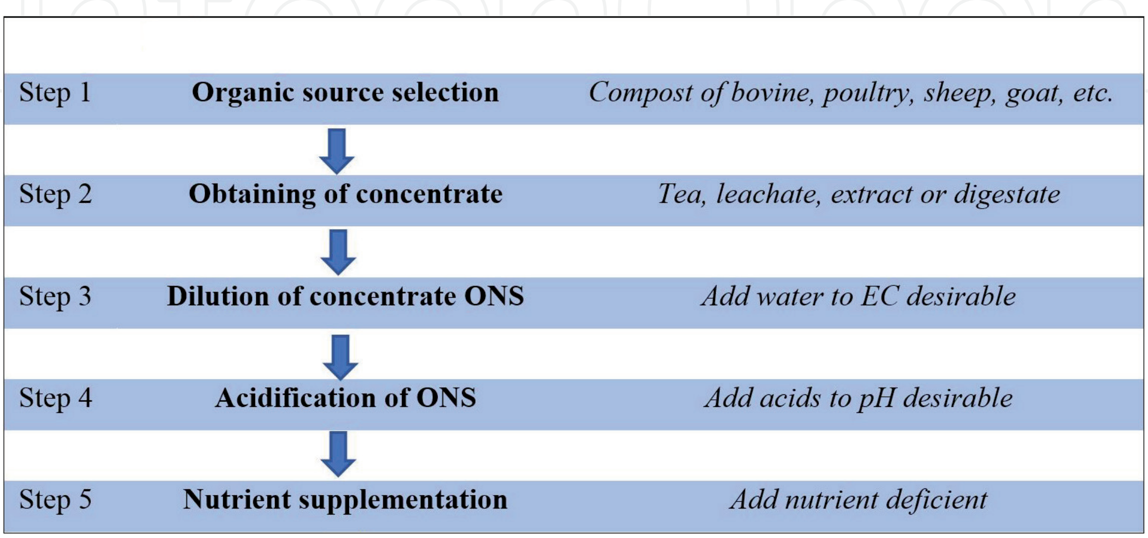

Figure 1.
Steps for the formulation of the ONS.

2.2 Step 2. Obtaining of concentrate

The concentrate is obtained from the solid organic materials, the main ones, which are the focus of this chapter, as follows: tea, leachate, extract, and digestate.

Compost tea: A "cold brewing" process, allowing growth of the organisms extracted from the compost [3].

Compost leachate: Water that drains, by oversaturation (excess moisture) of the material, during the composting process [4].

Extract: It is the product of passing water through the compost [4].

Digestate: Material remaining after various digestion processes have been applied to biomass or waste products such as animal manure, sewage sludge, and urban waste [1].

The concentrate can be obtained for unique extraction and sequential extraction.

2.3 Unique extraction

The ratios of solid and extracting organic material (usually water) are from 1:2 to 1:10; in a v:v ratio, rest times vary, typically from 8 to 48 h. The main parameter to measure is the electric conductivity (EC) of the solutions obtained and may vary due to the organic substrate, solid and extracting ratios, incubation time, and temperature of the solution, mainly (**Figure 2**). In 2013, González and colleagues studied the EC's relationship with the origin of vermicompost used in extraction (grass plus sheepman and more manure of sheep and cattle), the water/vermicompost ratio (1:2, 1:4, and 1:6), and the time (8, 16, and 24 h). They conclude that the origin of vermicompost has a high correlation with the EC, the ratio 1:2 (vermicompost/water) offers the advantage of obtaining concentrated teas with EC values, and the most suitable incubation time for tea extraction is 8 h.

Table 1 shows the total dissolved salts in a single extraction and **Table 2** for sequential extraction. It is observed that with sequential extraction it is possible to extract more dissolved solids than simple extraction, but more time is required.

2.4 Sequential extraction

Figure 3 shows the electrical conductivity of sequential extraction with poultry and bovine compost and water. The test was performed by mixing the compost with distilled water in a 1:2 (v/v) ratio with 48 h rest time between each extraction. The dynamics of the curve show that the soluble ions (measured by the EC) are released by describing a negative exponential function; the correlations had determination ratios of R^2 = 0.9388 and R^2 = 0.9042, in hen and bovine, respectively. The curves are stabilized

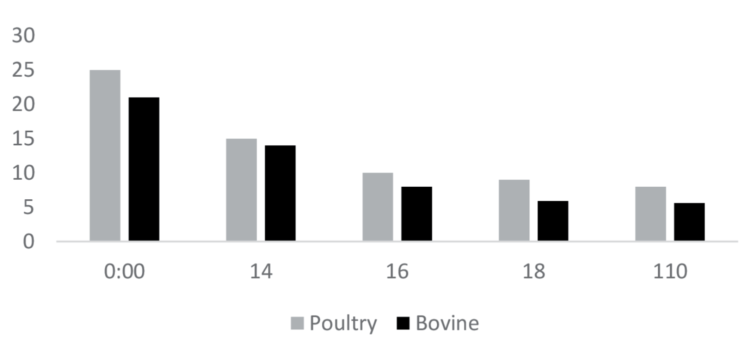

Figure 2.
EC that we obtained in five ratios dilution: 1:2, 1:4, 1:6, 1:8, and 1:10, with 24 h of rest in bovine and poultry compost extract.

Dilution ratio*	Rest time (h)	Fluid recovery (%)**	Volume recovery	Bovine	Poultry	Bovine	Poultry
						Dissolved salts	
				dS m^{-1}		§mg L^{-1}	
1:2	24	50	1	20.5	26.5	12.3	15.9
1:4	24	75	3	14	15	25.3	27
1:6	24	80	4.8	8	10	23	28.8
1:8	24	90	7.2	6	9	26	39
1:10	24	95	9.5	5.6	8	32	45.6
1:12	24	95	11.4	4	7	27.5	47.88
1.14	24	100	14	3	4.7	25.2	40
1:16	24	100	16	2.5	4	24	38.8

**Ratio solid material: volume of water applied.*
***Volume of water recovering from applied; the remaining percentage is retained by the solid phase.*
§The mg of salts dissolved per liter of liquid concentrate (factor 0.6 was used to convert from dS m^{-1} to mg L^{-1})

Table 1.
Content of dissolved salts extracted (a single extraction with 24 h rest).

Extraction	Dilution ratio*	ART§§	Fluid recovery (%)**	Volume recovery	Bovine	Poultry		Bovine	Poultry
								Dissolved salts	
					dS m^{-1}			§mg L^{-1}	
1	1:2	48	50	1	20.5	26.5		12.3	15.9
2	1:2	96	60	1.4	6.1	15.5		4.4	13
3	1:2	144	80	1.6	2.6	5.67		2.5	5.44
4w	1:2	192	85	1.7	1.6	3.3		1.6	3.4
5	1:2	240	90	1.8	1.2	1.83		1.3	2
6	1.2	288	95	1.9	1.2	1.2		1.35	1.35
7	1.2	336	100	2	1.2	1		1.44	1.2
8	1.2	384	100	2	1.2	0.9		1.44	1
							Σ	**26.33**	**43.3**

**Ratio solid material: volume of water applied*
***Volume of water recovering from applied; the remaining percentage is retained by the solid phase.*
§The mg of salts dissolved per liter of liquid concentrate (factor 0.6 was used to convert from dS m^{-1} to mg L^{-1})
§§Accumulated rest time

Table 2.
Salt content dissolved by sequential extraction (eight extractions in the same material with 48 h of rest between each extraction).

from the fifth extraction between 1.2 and 1.8 dS m^{-1} and continue with little variation until the eighth extraction. The ion balance, between the solid and aqueous phase of the mixtures, allows organic materials to be used as a source of nutrients for plants.

2.5 Dilution of concentrate to desirable EC

EC is generally used to indicate the total concentration of ionized constituents in water (Rodríguez et al., 2006). The concentrates shall be diluted with the irrigation water until the desired electrical conductivity is reached for the crop to be established (usually at 1–2 dS m^{-1}).

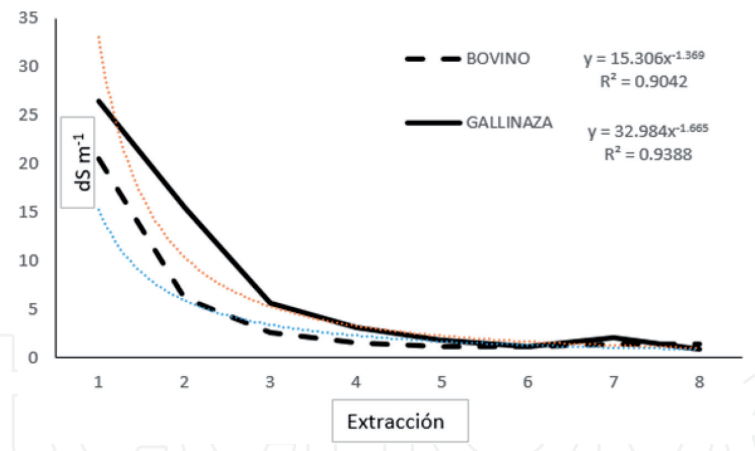

Figure 3.
Electrical conductivity of concentrates obtained sequentially from poultry and bovine compost.

2.6 Acidification of ONS

The pH indicates the degree of acidity or basicity of the solutions and is relevant by the availability of plant nutrients. **Figure 4** shows pH behavior in sequential extractions, in both composts (bovine and poultry). The pH range was 7–7.8, neutral to alkaline, indicating the possible presence of ions such as Ca^{2+}, Na^{+}, Mg^{2+}, HCO^{3-}, and CO_3^{2-}. The pH suitable for most plants in hydroponic systems is between 5 and 6 (Rodríguez et al., 2006), so organic nutrient solutions must be acidified that will partially eliminate carbonates and bicarbonates. Chemical or organic acids can be utilized; in the case of the test we conducted with bovine and poultry manure, the amount of sulfuric acid that we applied to lower pH from 7.4 to 6 per liter of ONS is 0.1 μL or 60 mL of acetic acid.

2.7 Nutrient supplementation

With the measurement of EC and pH, hydroponics solutions can be assessed. Up to this point, it is possible to use the nutritive solution obtained in small- and medium-sized plants, such as baby lettuces shown in **Figure 5**.

To produce higher biomass plants, for example, solanacea, cucurbitaceae, etc., it is recommended to have an analysis of the contents of essential elements in order to supplement in the organic nutrient solution, which can be very variable as shown in **Table 3**. The organic nutrient solutions are deficient in most essential elements when compared to known nutrient solutions. Therefore, it is necessary to supplement them with organic or inorganic sources, depending on the production system being worked.

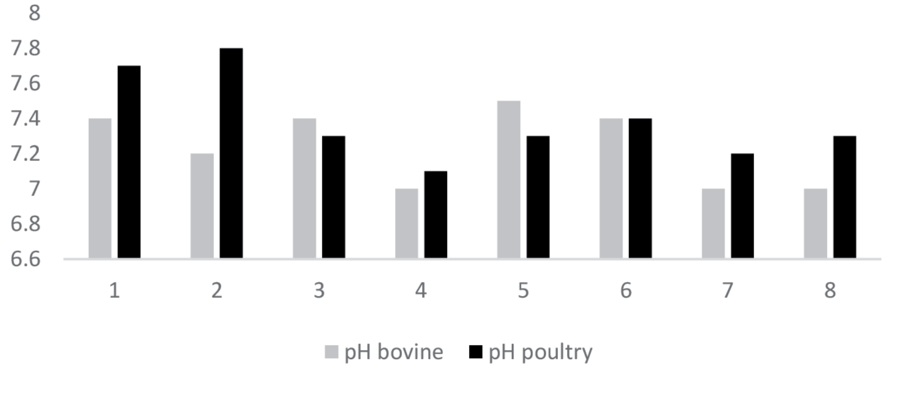

Figure 4.
pH of concentrates obtained sequentially from poultry and bovine compost.

Figure 5.
Twenty days after transplanting baby lettuce produced with chemical synthetic fertilizer (A) and manure extract (B). Both cultivated in floating root system with pH 6 and EC = 1.5 dS m^{-1}.

Author	1	2	3	4	Steiner solution	Sánchez
					References	
OM	VCG	VCP	P + B	VCB	—	—
Dilution	1:10	1:10	1:6	1:20	—	—
EC dS m^{-1}	2	2	4	1	2	2
		mg L^{-1}				
N	74.9	81.7	313.87	219	168	200
P	16.2	16.2	20.01	18.2	31	60
K	166.6	180.4	174.91	230	273	250
Ca	486	49	41.12	1.32	180	200
Mg	42.8	43.9	32.94	520	48	60
S	—		54.40	—	336	200
Fe	—	—	—	0.49	—	1
Cu	—	—	—	0.13	—	0.01
Mn	—	—	—	0.089	—	0.7
Zn	—	—	—	0.19	—	0.01

(1) Pant [5]; (2) Pant (2011); (3) González et al. [6]; (4) Ochoa et al. [7]. OM = organic material; VCG = vermicompost poultry manure; VCG = vermicompost poultry manure; CBv = compost bovine

Table 3.
Macro- and micronutrient content in some organic nutrient solutions.

3. Methods for the separation of ions in aqueous solution

In the literature, various methods for the separation of ions and cations (solute) in aqueous solution (solvent) exist. Selection of the process depends on the purity or degree of recovery that is required for both the solvent and the solute. Nowadays there are processes ranging from adsorption processes using activated carbon, which is one of the most economical materials, to reverse osmosis processes [8].

There are various chemical causes or reasons by which materials are related to ions or cations, among them attraction forces or electrostatic repulsions (mainly present in inorganic compounds), dispersive forces, or π-π interactions (organic compounds such as organic matter) stand out [9].

Among the materials used for the retention of inorganic compounds such as metals, metalloids, and heavy metals include activated carbons, zeolites, clays, lignocellulosic materials, carbon nanotubes, composites from green materials such as mixed cellulose with iron oxides and also can be used an ion exchange resins and membranes [10, 11]. In the case of organic compounds, the material traditionally used in Mexico and other countries is activated carbon.

A process that could be applied in the separation of ions and cations from organic fertilizers' derived mixture and whose main components are essentially potassium (K^+), nitrate (NO_3^-), and phosphate (PO_4^-) mixed with high organic matter content, which are an "interference" in the separation processes due to its high degree of complexity in the chemical structure, would be a sequential adsorption process [12, 13].

Therefore, as an ideal process for the elimination of this type of "interference" and the possible recovery of the ions and cations of interest, a cycle of separations must be done. First, the ion mixture must be placed in contact with carbon-based materials (this material already impregnated with that organic material can also be used for fertilizer) followed by cycles of adsorption columns with special ion exchange resins for each one of the ions. With this process, we can recover each of the components of the mixture and allocate them to the preparation of a nutrient solution according to each crop's needs.

4. Safety of organic materials

The main concern associated with the use of organic materials is mainly related to the possible presence of unwanted components, such as microbial pathogens, heavy metals, organic pollutants, waste pharmaceuticals, and personal care products, which threaten public health when undertreated. For example, organic materials could contain pesticide residues if obtained from some crop residues or antibiotics used in the diets of breeding animals, if excrement is used.

4.1 Heavy metals

The problem with regard to heavy metals is one of the most studied, and there is a vast literature dedicated to the subject. It is well known that concentrations of heavy metals above certain limits can lead to crop toxicity and may enter the food chain. The contents of MP in organic materials is very varied, since it depends on several factors, including the origin of the product, the feeding of livestock, etc. Rodriguez et al. [14] report the following total concentrations of heavy metals in cattle compost (in ppm): As 2.0 (−0.3), Cd 0.21 (−0.06), Hg <0.01, and Pb 5.9 (−1.01) and, for bovine lombricompost (in ppm), As 3.6 (−0.90), Cd 0.46 (−0.10), Hg <0.01, and Pb 16 (−2.60). For its part, Pane et al. [15] report the following heavy metal content in artichoke compost that was used to obtain nutrient solutions (78.0% artichoke, 20% woodchips, and 2% mature compost) (in ppm): Cd 0.38, Cr 20.69, Cu 21.01, Pb 13.45, Zn 13.45, and Zn 70.50, all below legal limits.

4.2 Pathogens

Depending on the source of the original material, the risks of contamination of unwanted organisms, such as pathogens, vary and are the highest in wastewater and excrement products.

Organic fertilizer production processes eliminate many pathogens as they include inactivation mechanisms such as very high temperatures, solar radiation, hydrolysis in strongly acidic or basic media, chemicals that affect pathogens, competition with other microorganisms, time, etc. (World Health Organization, 2018) [16]. If handled properly, composting can reduce pathogen levels [17]. In the inactivation of nonpathogenic *Escherichia coli*, pathogenic *E. coli* O157:H7, and *Salmonella* spp., several types of waste, such as animal manure and sewage sludge, have been reported during composting [18]. However, the persistence of *Listeria* spp., *Salmonella* spp., and nonpathogenic *E. coli* during composting [19] and the survival of *Salmonella* spp. and nonpathogenic *E. coli* in mature composts [20]. Most research on *E. coli* and *Salmonella* spp. have focused on manure or sewage sludge, but little attention has been paid to other substrates, such as green waste.

With regard to temperature, in many small composting units, degradation activity is limited by low temperature, well below 55°C. This is a very serious limitation when it comes to disinfection, since for many pathogens there is little or no reduction to temperatures below 50°C [16].

According to the US Environmental Protection Agency (US EPA) standard, Class A compost should not exceed the maximum *Salmonella* spp. limits (less than 3 most likely numbers [NMP]/4 g) or thermotolerant coliforms (less than 1000 NMP/g). The final amounts of bacteria, biological and viral, depend on the type of treatment used.

The current trend adopted in this field is to establish rigid rules that control the production process as well as to establish transport, packaging, and storage standards rather than setting pathogen limits on final products. For example, to acquire the characteristics necessary to be used in agriculture, sludge must undergo an additional disinfection process that ensures the reduction of the density of pathogens [16].

With regard to the risks of pathogens in organic fertilizers, it can be said that hazards can be excluded when production is industrialized, and this includes several disinfection procedures (pasteurization, drying, chemical media, etc.).

In addition, more or less stabilized organic substances, if poorly preserved and stored, can serve as excellent substrates for pathogens and become carriers of infections [21].

In the use of organic fertilizers, it is necessary to apply the precautionary principle, with the adoption of protective measures if there are suspicions that the products present a risk to public health or the environment. On the other hand, the danger of organic fertilizers and their amendments is certainly related to the end use of products.

Many organic compounds persist for long periods in soil, subsoil, aquifers, surface water, and aquatic sediments. These compounds, which can be of low or high molecular weight and that resist biodegradation, are known as recalcitrant. Many pesticides, mainly herbicides, have this characteristic [22].

Composting has been widely used for the remediation of organic pollutants as it, with adequate aeration, water, C-to-N ratio, and duration, accelerates their destruction [23]. The degradation of pesticides during composting depends on the pesticide and the substrate on which it is co-composted [24]. Strom [25] reported on the breakdown of organophosphorous pesticides and carbamates during composting. However, organochlorinated insecticides are resistant to degradation (Buyuksonmez et al., 1999). Differences in degradation may be related to inherent differences in the biological metabolism of the compound but may also be related to the composting process. Short-term composting (<60 days), which consists largely of the thermophilic phase, without adequate curing (mesophilic phase), may not be sufficient for the degradation of pesticides [26].

5. Humic acids, microorganisms, and hormones in organic materials

Organic materials, in addition to being a source of mineral elements (macronutrients and micronutrients), also provide the SN with other inseparable substances, among which are the microorganisms, humic acids (HA), and phytohormones.

5.1 Humic acids

Humic substances (HS) are the last substances resulting from chemical, biological, and physical transformations of plant and animal matter. The main compounds resulting from this transformation are humic acids, fulvic acids, and humines. Within these substances, humic acids, compounds soluble in alkaline solution and insoluble in acid solution and having a higher molecular weight, are the most important components [27, 28]. These substances, for their characteristics and effects on plants, have been considered as biostimulants [29].

HS are mineral compounds, among them essential elements for plants, mainly carbon, oxygen, hydrogen, nitrogen, sulfur, phosphorus (P), iron, copper, zinc and boron, in addition to functional groups among which stand out aromatic, aliphatic, carboxylic, and phenolic compounds (from [30–32]). HS are composed of hydrophobic fractions composed of aliphatic and aromatic compounds, while in another fraction, hydrophilic is composed of irregular humic fractions. These compounds, for their physicochemical characteristics, cause various effects on plants.

Among the metabolic processes that contribute to promote the growth and development of plants is the stimulation of the activity of key enzymes for the absorption and distribution of nutrients [33, 34]. The interaction of humic substances with proteins and lipids of the cell membrane improves the absorption of nutrition [35]. Mora et al. [36] mention that the presence of AH stimulated the activation of the H+-ATPase pump which led to a better distribution of NO_3^- from the root to the leaves. HSs can form latent complexes with metal ions, contributing to increased availability for root absorption as well as improving the distribution, within the plant, of metal ions [37].

There are various materials from which HS is obtained, which have been used in different crops in the hydroponic system. These substances have shown significant effects on these plants, improving growth and nutritional condition, mainly.

Haghighi and Teixeira [38] added 25 mg L^{-1} and 50 mg L^{-1} of HS extracted from forest soil moistified monthly to the nutrient solution used in the cultivation of tomato grown in perlite/vermiculite substrate. These HS were composed of 0.57% nitrogen, 0.03% phosphorus, and 4.5% potassium, with a pH of 4.5. Basically the addition of 50 mg L^{-1} of HS was the treatment that provoked the greatest effect in plants, increasing by 19% yield, 29% protein, 436% photosynthesis in growth stage, and 34% in fruiting stage. Other variables such as nitrate content, sugar content, and acidity in addition to antioxidant enzymes and chlorophyll were not affected by the presence of HS. These authors attributed the null effect on the abovementioned variables to the low concentrations of HS evaluated in the experiment.

Jannin et al. (2012) used 100 mg L^{-1} HS extracted from black peat for the formulation of Hoagland and Arnon nutrient solution (1950), for the cultivation of canola in floating root system. This material contained mainly 125, 40, 14, 9, and 2 mmol L^{-1} of potassium, sulfur, calcium (Ca), iron, and phosphorus, respectively, in addition to very low amounts of cytokinins such as zeatin, isopentenyladenine, and isopentenyladenosine. The plants were evaluated at days 1, 3, and 30 after the start of treatment, wherein the most significant effects were found at 30 days. The dry root weight was increased by 88%, while the total dry weight of the plant was increased by 29%. Nutrient absorption was increased with the presence of HS by 79% sulfur, 75% copper, 66% magnesium (Mg), 60% calcium, 57% nitrogen, and 47% potassium. Similarly, root nitrogen increased by 108% and sulfur increased by 76% in the leaf and 137% in the root. The abovementioned increases were the result of the expression of transporters present at the root responsible for the absorption of nitrogen and sulfur, in addition to the activity of the enzyme nitrate reductase.

The results showed that overall all materials were superior to the control. In particular 1 mg C L^{-1} increased the root length by 65% and the foliar area by 54%. The activity of the enzymes glutamine synthetase and glutamate synthetase, essential in nitrogen metabolism, were increased by 29% and 12%, respectively, with the addition of 10 mg C L^{-1}. Some important compounds in metabolism were increased. Protein content was increased by 43% in leaf and 8% in root at the concentration of 10 mg C L^{-1} and 1 mg C L^{-1}, respectively, while the foliar concentration of glucose and fructose were increased by 10% and 25% with the presence of 0.5 mg C L^{-1}. The activity of the enzyme phenylalanine ammonium lyase, participant in the production process of phenolic compounds, was increased by 51% by the presence of 1 mg C L^{-1}, so the content of phenolic compounds was increased by 15%.

5.2 Microorganisms and phytohormones

The use of nutritious solutions cast from organic fertilizers, such as composts, lombricomposts, vermicomposts, etc., may constitute an economic and environmental alternative to the use of chemical fertilizers for food production [39].

Organic fertilizers differ in quality, stability, and maturity because they depend on the organic waste and method by which they are prepared, so their chemical and biological composition varies and thus the nutritional composition and other elements that are present in the solutions obtained from them [40].

It is well documented that organic fertilizers contain soluble mineral nutrients such as nitrogen, phosphorus, potassium, magnesium, calcium, and other microelements, in addition to humic and fulvic acids, which the plant uses for its nutrition [39, 41]. But there is also the presence of phytohormones such as auxins, gibberellins, and cytokinins that are indispensable for the growth and development of plants [42–44].

In plants, phytohormones auxins, gibberellins, and cytokinins are the most common. Auxins, usually in the form of indolactic acid (AIA), are responsible for stimulating cell division, apical growth, and root branching [45]. Gibberellins, mainly in the form of gibberellic acid, are involved in various developmental and physiological processes, including seed germination, seedling emergence, stem and leaf growth, flowering, senescence, maturation of the plant [46]. Cytokinins play a key role in the process of cell division and bud growth and maintain photosynthetic activity and stoma opening during drought [47]. Therefore the presence of these hormones in organic fertilizers and the solutions obtained from them are of great importance and have to be considered; however, their presence has been less documented because they are difficult to detect and quantify, since they are usually found in trace concentrations and/or because they are immersed in a complex biological matrix, which makes their analysis quite difficult [44], but there are still some reports.

Zandonadi and collaborators reported the presence of indole-3-acetic acid (auxin) in humic acid extracted from a vermicompost. Zhang and collaborators (2014) reported the presence of cytokinins in tea also from a vermicompost. A study by Plant and collaborators (2012) reported the presence of isopentenyladenine-cytokinin, gibberellin 4 (GA4), and gibberellin 34 (GA34) in extracts of thermophilic compost based on chicken manure, waste vermicompost of food, and vermicompost based on chicken manure and the presence of gibberellin 24 (GA24) in vermicompost tea based on chicken manure. They also reported that a higher concentration of phytohormones can be attributed to increased activity of microorganisms present in fertilizers.

These phytohormones are produced by microorganisms present in organic fertilizers that come from soil and plant waste with which they are prepared [48, 49]. These microorganisms that produce these and other plant growth-promoting compounds are also known as plant growth-promoting microorganisms (PGPM) and are largely also responsible for biodegradation of the substrate or organic waste in the process of the production of organic fertilizers, mainly in composting [50], for example, *Azospirillum* spp. [51].

Among the microorganisms that produce auxins are those belonging to the genera *Azospirillum* spp. [52], *Azotobacter* spp. [53], *Rhizobium* spp. [54], *Bacillus subtilis* [55], *Bradyrhizobium* spp. [56], *Enterobacter* spp. [57], and *Trichoderma* spp. [58], to name a few. Within the production of gibberellins, *Azospirillum* spp. [59], *Bacillus* spp. [60], *Rhizobium* spp. [61], *Aspergillus* spp. [62], *Gibberella* spp. [63], and *Penicillium* spp. [64] are reported. The production of cytokinins is well characterized in microorganisms belonging to various genera such as *Azospirillum* [65], *Bacillus* spp. [66], and *Pseudomonas* spp. (Grokinsky et al., 2016) as well as the genera *Proteus*, *Klebsiella*, *Escherichia*, *and Xanthomonas* [43].

Although there is much research on the identification and quantification of phytohormones produced by various microorganisms (mainly bacteria and fungi that may be present in the organic waste and soil used for organic fertilizer processing and solutions obtained from them), studies related to the identification and quantification of phytohormones present in these are still scarce. This is due to the complexities necessary for the development of more sensitive and specific extractions, preparations and detection methods to analyze phytohormones. Quantification of phytohormones in organic waste solutions will be crucial for their complementation and supplementation with other compounds and improve food production more sustainably.

6. Trials of organic nutrient solutions in vegetables

6.1 Commercial and nutraceutical quality of compost extract in tomato fruits

We established a greenhouse trial with six treatments to determine the commercial and nutraceutical qualities and yield of tomato fruits (*Solanum lycopersicon*) fertilized with bovine compost and hen teas, and was treated with synthetic chemical fertilizers. Solutions were varied in electrical conductivity:

1. Compost extract of poultry manure with electric conductivity of 1.5 dS m^{-1}
2. Compost extract of poultry manure with electric conductivity of 2.0 dS m^{-1}
3. Compost extract of bovine manure with electric conductivity of 1.5 dS m^{-1}
4. Compost extract of bovine manure with electric conductivity of 2.0 dS m^{-1}
5. Steiner solution with electrical conductivity of 1.5 dS m^{-1}
6. Steiner solution with electrical conductivity 2.0 dS m^{-1}

Commercial materials were used as sources, which ensure the absence of pathogenic organisms. The cattle compost was the Organo Del brand (85% organic matter) and the hen the Meyfer brand, which has OMRI registration (37.7% organic matter). The extracts were prepared with a part compost and two water; the concentrate obtained was diluted with water until the indicated electrical conductivity and adjustment of pH to 6 with citric acid were obtained. The treatment of high-solubility synthetic chemical fertilizers used the Steiner solution.

The experiment was established in pots of 13 L capacity black plastic bags, and as a substrate was used, river sand (0.5–2 mm), previously sterilized. The genotype used was of habit determined variety "Caloro". The nutrient contents of the applied solutions, pH and EC, are presented in **Table 4**. All treatments had an average drainage of 20%. At 80 and 90–100 days after transplantation, the fruits with which the data were taken for evaluation were harvested.

The results indicate that treatments with organic solutions (hen and bovine extract) achieved production, quality in Brix grades, and phenol content statistically equal to those obtained in fertilizer, fertilizing treatments such as synthetic chemicals, regardless of the electrical conductivity of nutrient solutions (**Figure 6**). However, the antioxidant capacity was significantly higher in organic nutrient solutions with levels of 2 dS m^{-1} ($p < 0.05$).

6.2 Liquid digestate for hydroponic baby leaf lettuce (*Lactuca sativa* L.) cultivation

Ronga et al. [67] evaluated the effect of liquid digestate on the production of "baby" lettuce under hydroponic system over three cycles. This digestate was the product of anaerobic digestion of a mixture of corn, triticale, liquid dairy manure, and grape stems.

In the first and second cycle, the combination of perlite with standard nutrient solution (SNE), perlite with liquid digestate, solid digestate with SNE, solid digestate with liquid digestate, and soil control with SNE was evaluated. In the third cycle, the combinations were peat with SNE, peat with liquid digestate, pelletized digestate with SNE, and pelletized digestate with liquid digestate.

Chemical analyses showed that the liquid digestate contained 17% organic carbon, 0.34% nitrogen, and 0.95% potassium (K_2O) and has an electrical conductivity of 1.07 dS m^{-1} and a pH of 8.03, in addition to having the highest number of colony-forming units of all materials used (substrates and fertilizer materials) with 7.3 e+05 CFUs g^{-1}.

In the first cycle, treatments formed by the combination of solid digestate with SNE and perlite with liquid digestate produced higher dry weight of leaves, while the dry weight of root and total dry weight was benefited by the combination of perlite and digestate liquid. In addition, such treatment ensured the health of the crop by not finding coliforms in the plants.

Nutrient	Steiner solution	Steiner solution	Chicken manure tea	Chicken manure tea	Bovine compost tea	Bovine compost tea
	1.5	2	1.5	2	1.5	2
			dS m^{-1}			
N	115	153	39.2	49	28.45	35.56
P	23	31	9.2	11.5	8.15	10.18
K	207	277	107	133.75	103	128.75

Table 4.
N, P, and K composition of the treatments (mg L^{-1}).

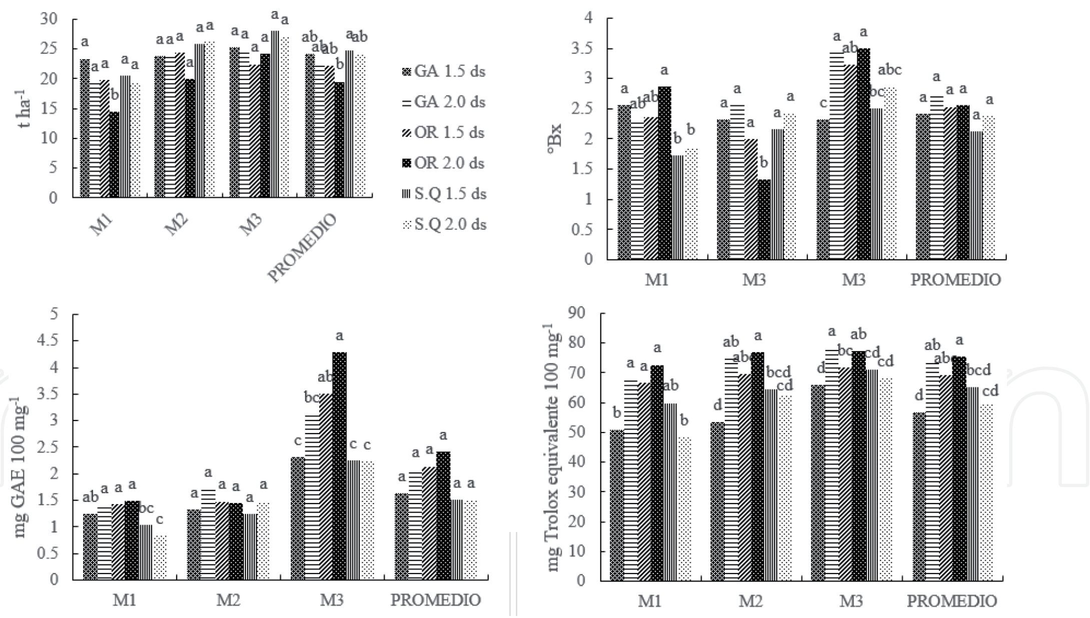

Figure 6.
Results of nutritious solution of hen, bovine, and chemical fertilizers: (a) yield by fruit cutting and average; (b) brix grades; (c) total phenols; and (d) antioxidant capacity.

In the second cycle, as in the previous cycle, the combination of solid digestate with SNE and perlite with liquid digestate produced greater dry weight of leaves. The same trend of the abovementioned variable was presented in the rest of the variables.

In the third cycle, the use of liquid digestate only equaled the SNE in the harvest index when the substrate was peat, while when the substrate was pelletized digestate, the liquid digestate produced higher plant height.

Based on the results shown, the authors consider the use of digestate for hydroponic production of lettuce to be a potential resource considering its low cost, environmental sustainability, agronomic interest, and microbial parameters.

6.3 Nutraceutical quality of cantaloupe melon fruits

The aim of the current study was to evaluate the nutraceutical quality of cantaloupe melon fruits fertilized with different organic fertilizer solutions (Preciado et al. (2015)); applied fertilization treatments consisted of an inorganic nutrient solution, compost tea, and vermicompost tea and leachate (leachate collected from vermicompost production) (**Figure 7**). The inorganic nutrient solution was prepared using highly soluble commercial fertilizers. The fertilizer solutions were adjusted to a pH of 5.5 and an EC of 2.0 dS m^{-1} via dilution with tap water to avoid phytotoxicity. The treatments were established in a completely randomized design using 10 plants per treatment, with each plant representing a treatment replicate.

The main conclusions of the present study are as follows. The applied nutrient solutions (compost tea, vermicompost tea and leachate, and inorganic Steiner solution) affected the nutraceutical quality of melon, as the fruits produced using the organic solutions exhibited higher antioxidant capacity and phenolic content than the chemically fertilized melons (**Figure 8**). It is feasible to recommend the application of vermicompost nutrient solutions (leachate and tea) as fertilizer alternatives for the production of hydroponic cantaloupe melon with an improved nutraceutical quality.

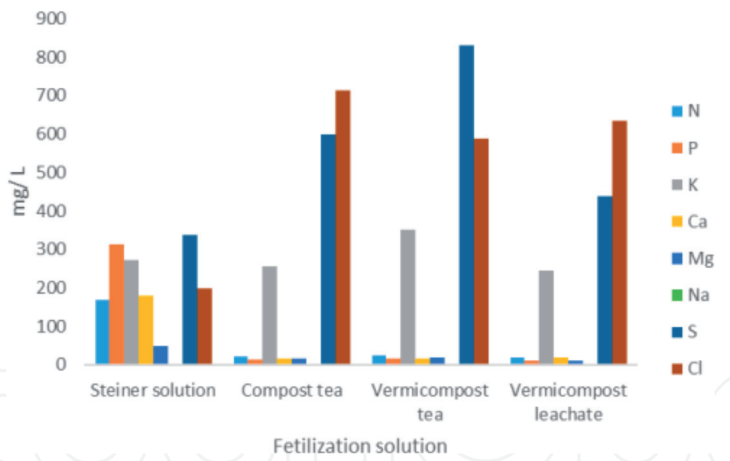

Figure 7.
Chemical composition of the nutrient solutions applied during the production of hydroponic cantaloupe melon in a greenhouse (Preciado et al., 2015).

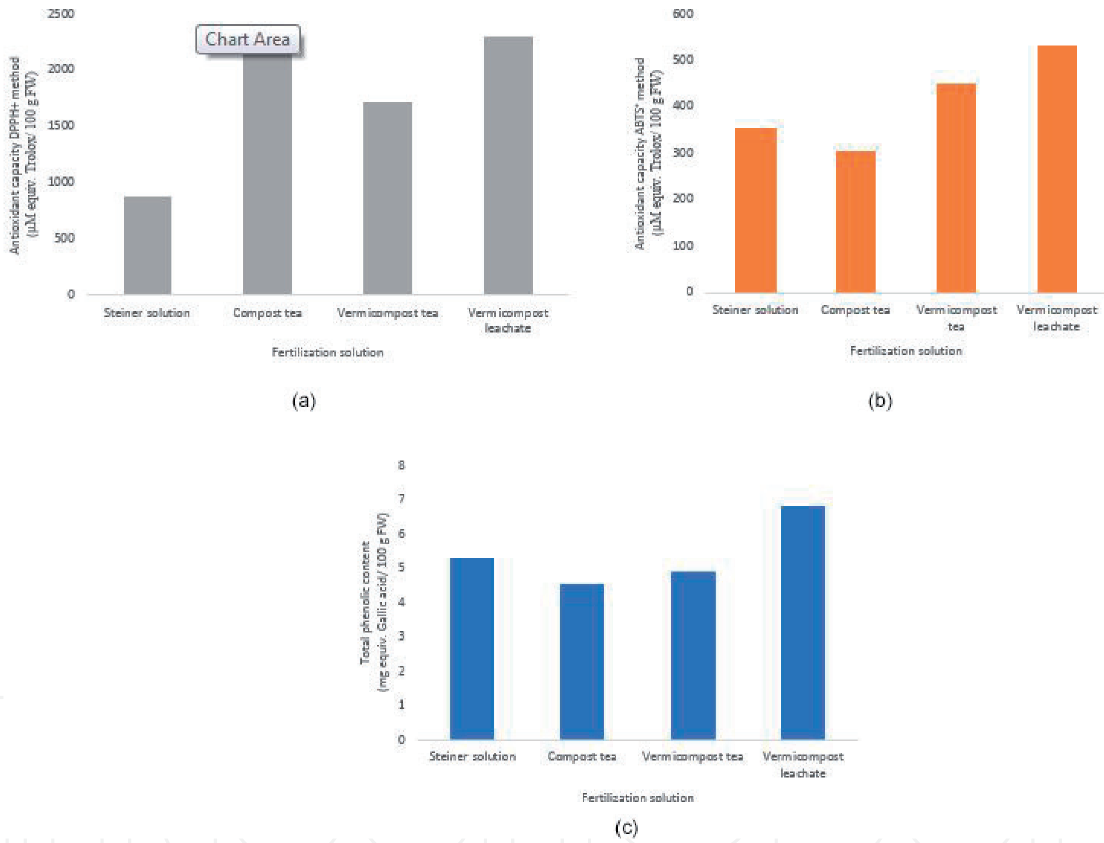

Figure 8.
Total phenolic content (a and b) and antioxidant capacity (c) of hydroponic cantaloupe melon fruits produced using different nutrient solutions.

6.4 Hydroponic green fodder

Salas et al. (2012) conducted a trial with the aim of evaluating the effect of organic nutrient solutions on yield, nutritional composition, total phenolic compounds, and in vitro antioxidant capacity of hydroponic green corn fodder produced in a greenhouse.

The treatments were vermicompost tea (TVC), compost tea (TC), and chemical solution (SQ) as a control and were applied from day 5 until harvest day. The concentration of nutrients in the treatments used is shown in **Figure 9**. Treatments were applied twice daily (8:00 and 19:00) on the aerial part of the fodder, with an average volume of 4.63 L^{-1} m^{-2} day^{-1}.

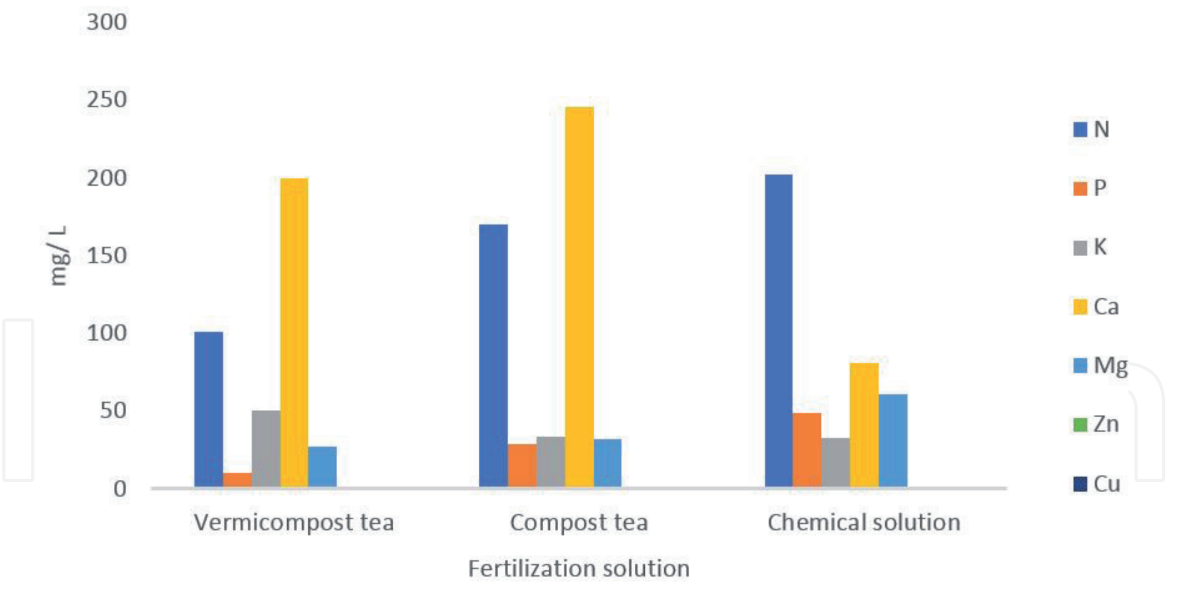

Figure 9.
Chemical composition of nutrient solutions applied in green fodder.

The yield, content of total phenolic compounds, and antioxidant capacity of the hydroponic green maize forage obtained were similar in organic and chemical fertilization treatments. Also, although differences in dry matter and protein content were found, all nutritional parameters evaluated were within the values reported as acceptable in good nutritional quality fodder (**Figures 10a–c** and **11**). On the other hand, the total phenolic content of organic and inorganically fertilized FVH was less than 1% dry base, so the consumption of such fodder does not pose health risks to livestock related to the consumption of these compounds. Therefore, it is advisable to use organic fertilization solutions in the production of fVH of maize in greenhouse, due to the advantages that such solutions would represent from the

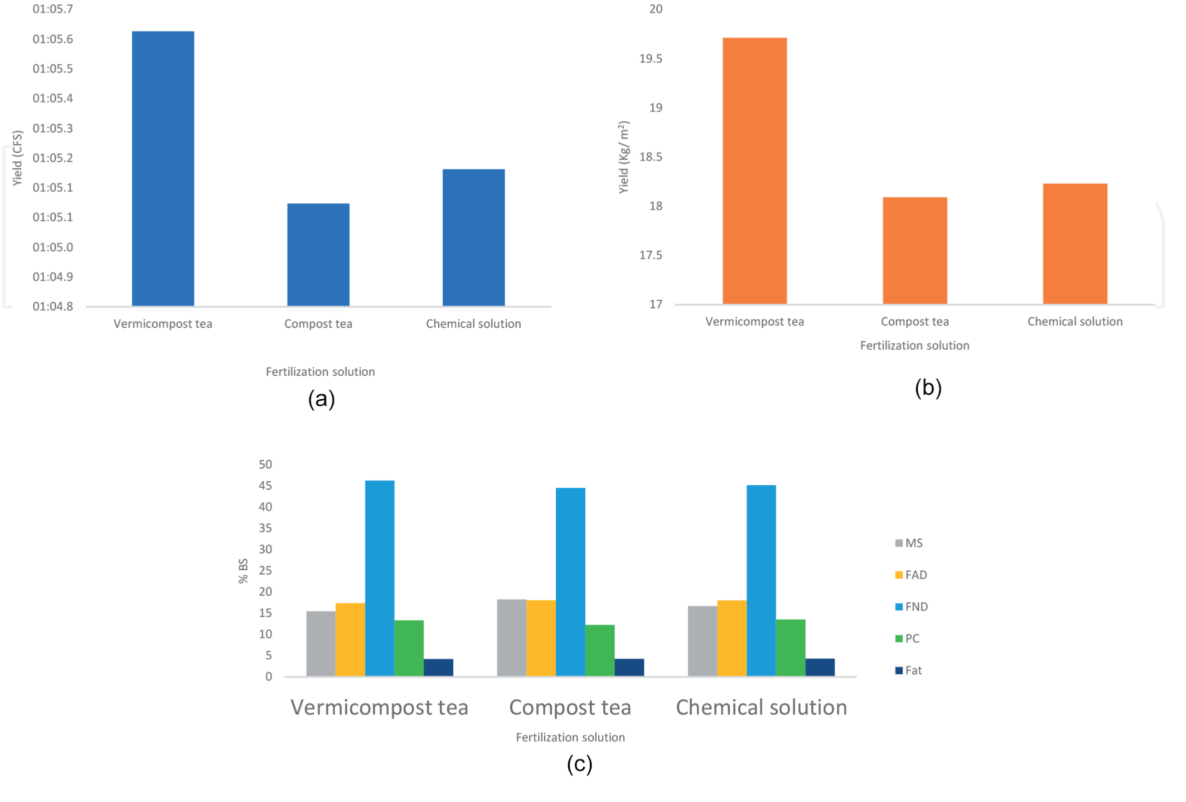

Figure 10.
Yield results and chemical composition of green fodder.

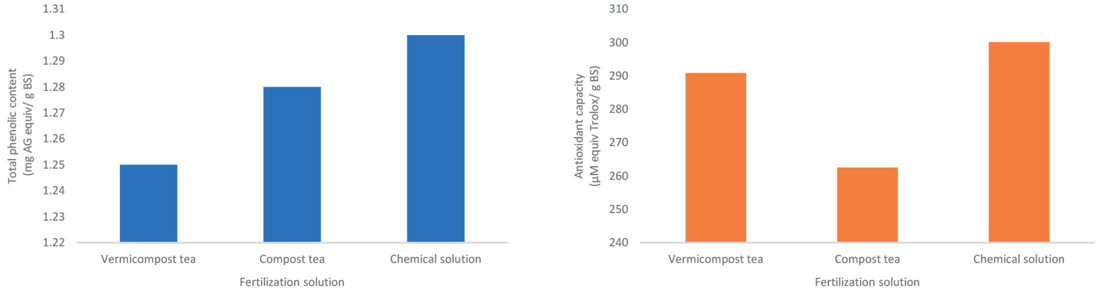

Figure 11.
Phenolic content and antioxidant content in green fodder.

point of view of sustainability by the use of available resources. It is recommended for future studies to evaluate the in vivo antioxidant properties of hydroponic green forage produced under organic fertilization as well as the identification of phenolic compounds contained in this type of fodder.

7. Conclusions

Organic fertilizers can provide essential nutrients soluble to plants, so as to be used in hydroponic systems in its various forms. Nutrient solutions can be formulated when soluble nutrients are extracted from the solid phase of organic manure, for this is essential to ensure that the organic materials used are harmless.

With these solutions it is possible to produce some vegetables without supplementing with other sources of nutrients (baby lettuce, chard, spinach, etc.). However, the solutions must be supplemented if solanaceas, cucurbits, or others plant groups are cultivated.

With organic solutions it is possible to have, in some vegetables, yields and commercial quality similar to solutions with chemical fertilizers. These vegetables also generally contain greater antioxidant capacity. The presence of other substances, in organic solutions, such as humic acids, phytohormones, and microorganisms, is responsible for the positive effects that have been obtained.

The nutritious solution, formulated from organic fertilizers, is not only an alternative for the nutrition of agricultural crops, but it also represents a more efficient way to use these resources.

Author details

Juan Carlos Rodríguez Ortiz
Facultad de Agronomía y Veterinaria UASLP, Mexico

*Address all correspondence to: juancarlos.rodriguez@uaslp.mx

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