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Agro-Ecological Impact of Irrigation and Nutrient Management on Spinach (*Spinacia oleracea* L.) Grown in Semi-Arid Conditions

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Abstract: The environment is affected by most anthropogenic activities; among them, agriculture is one activity with more negative effects, especially when management is inadequate, causing soil degradation or contamination. This paper presents the results of an agronomic field trial on a spinach (*Spinacia oleracea* L.) crop. The objective of which was to monitor soil and crop properties under two doses of irrigation and organic fertilization. The results showed that the use of excessive doses of irrigation and fertilization increased the electrical conductivity (ECext) from 5.5 to 8.5 dS m^{-1} and the concentration of ions in the soil solution which, for the most soluble ions (NO_3^-, Cl^-, Na^+), leached towards the deep horizons, reaching 2194.8 mg L^{-1} in the case of NO_3^-. However, their use did not increase spinach production and is thus a waste of resources that increases the risk of soil salinization. Nutrient inputs to the soil were much higher than extractions (between 12% for N and 99% for Fe), partly because of agronomic management and especially because of the return of crop residues, which increased the organic carbon stock by about 2500 kg ha^{-1} (4–6%), enhancing its function as a CO_2 sink. These surpluses form part of complex organic structures or are immobilized as carbonates or alkaline phosphates. Preservation of the agrosystem studied requires limiting the use of low-quality irrigation water and adjusting fertilization.

Keywords: sustainable management; organic fertilization; CO_2 sink; nutrient balance

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1. Introduction

Agriculture may be the activity that causes the most negative effects on the environment, especially when it is carried out through aggressive practices aimed solely at increasing production and the economic profitability. Thus, episodes of nitrate pollution, soil erosion and desertification, eutrophication, etc., are widespread and commonly described [1–3]. Such degradation processes can be minimized through sustainable management [4], a concept that implies the economic viability of agricultural enterprises and the conservation of natural resources, including soil and water [5]. The European Union and other international institutions are promoting this management model through the implementation of what they have come to call "good agricultural practices", historically included in the regulations governing the Common Agricultural Policy, which are preserved and promoted by the European authorities [6]. Good agricultural practices must be adapted to each specific situation according to the soil and climate characteristics in order to avoid or at least minimize the undesirable effects of agriculture on the environment in general and on the quality of the soil–plant system and water resources in particular [7]. Therefore, it is becoming increasingly common for crop production to design fertilization and water management that take environmental factors into account, with the aim of increasing the efficiency of water use and lowering energy consumption [8–10], as well as encouraging the use of organic amendments [11–13] inclusive of the recycling of crop residues in the field [14,15]. In this regard, proper water and crop nutrient management have been

shown to increase soil organic carbon (OC) accumulation and agricultural productivity by preserving a sound ecological environment [16].

For decades, the use of fertilizers and irrigation has been a key factor in obtaining a substantial increase in agricultural productions in a broad sense; however, their administration must be controlled in terms of proper measurements to avoid the possible contamination of aquifers by excess fertilizer and the waste of water, especially in arid and semi-arid climates [17,18]. For this reason, in recent years, the use of slow-release inorganic fertilizers and organic amendments has been prioritized, which—although limited by certain factors such as high prices, inconvenient transport, and insufficient supply [16]—are still valued for their ability to moderate dependence on chemical fertilizers and mitigate soil degradation [13,19,20]. Several researchers have shown that the application of organic manure significantly improves soil OC levels [13,21–23], an effect that is reinforced when the appropriate management practices are applied [24–27].

The use of organic fertilizer in place of mineral fertilizer could significantly increase annual soluble OC sequestration [24,28,29] and thus contribute to increasing the largest OC pool in the biosphere, representing approximately two thirds of the terrestrial carbon stock [30]. Studies have shown that the use of manure can improve soil hydraulic characteristics [31,32], maintain soil bacterial community diversity [33,34], and increase crop yields sustainably over a period of time [13,22,35].

On the other hand, the quality and quantity of water used in irrigation can induce changes in some soil properties; for example, when the salinity in soil is high, salinization processes are triggered that limit and even prevent the agricultural use of this resource, as has been widely described by several authors [36–38]. Moreover, these water inputs are the main abiotic drivers of variation in the carbon pool [39,40].

The crop selected for this experiment was spinach (*Spinacia oleracea* L). This leafy vegetable has many nutritional properties and is a very important source of vitamins and minerals, with a high content of vitamin A, vitamin C, and essential minerals such as Fe [41]; in recent years, its worldwide consumption has increased by 5.6%, and it occupies an important niche in the market [42].

The hypotheses that justified this study were the following:

The agronomic management of crops, especially fertilization and irrigation, causes significant changes in the edaphic environment and in production. These changes should be reflected in some properties, especially those of the rapid response [24], such as the electrical conductivity (ECext) and ions present in a soil solution, if nutrient and other salt inputs, are not provided in an adequate quantity and nature, they can lead to changes in the input–output balance of the soil, resulting in economic losses and environmental problems.

The objectives of this study were as follows:

To determine the concentration and the temporal and spatial evolution of anions and cations in a soil dedicated to spinach cultivation and to study the extractions of macronutrients and micronutrients as well as to determine the balance between inputs and extractions and analyzing the role of the soil as a source or sink of CO_2 under the cultivation conditions studied.

Regarding the innovative aspects of this work may be the experimental model, where irrigation doses and organic fertilizer doses are combined, to test its environmental impact in the production of spinach crop. In addition, this field study aims to check the balance of nutrients in the soil and in the plant, in order to optimize agronomic management and minimize the environmental impact of the crop, including the contribution of crop residues in this balance.

2. Materials and Methods

The study was carried out in an experimental plot located in Campo de Cartagena, SE Spain, in the municipality of Fuente Álamo (Murcia), coordinates 37°43′45.32″ N and 1°8′24.60″ E (Figure 1), in an area of 5019 m^2 and an altitude of 127 m above sea level. The soil in the study area is formed from polygenic quaternary sediments of limestone and

dolomitic marbles, phyllites, and quartzites [43]. The soil climate is known as an aridic humidity regime, with a mean annual rainfall of 320 mm, and a thermal soil temperature regime, with an average annual temperature of 18.2 °C. The climatic data were supplied by the Fuente Álamo (Murcia) weather station. The potential vegetation in the area corresponds to the *Chamaeropo humilis–Rhamnetum lycioidis* association; however, at present, advanced stages of degradation predominate, with crops of horticultural, citrus, and fruit species, all under irrigation.



Figure 1. Geographical location of the study area.

The experiment was carried out on a soil with an Ap1-Ap2-Ab-Bk profile (Table 1), which meets the requirements for classification as a Haplic Calcisol [44] and Typic Calciorthid [45].

Table 1. Characteristics of the soil at the beginning the experiment.

Horizon	Depths (cm)	OC (g kg^{-1})	TN (g kg^{-1})	NO_3^- (mg kg^{-1})	C/N	$CaCO_3$ (g kg^{-1})	CEC ($cmolc_{(+)}$ kg^{-1})	pH_w	pH_k	ECext (dS m^{-1})	SAR
Ap1	0–25	10.4	1.6	462	6.5	416	11.9	7.76	7.61	6.58	3.1
Ap2	25–65	4.0	0.9	256	4.4	395	11.7	8.37	7.53	1.23	2.8
Ab	65–98	11.3	1.9	101	5.9	262	13.1	8.21	7.38	2.08	2.1
Bk	+98	2.9	1.0	57	2.9	470	10.1	8.35	7.90	1.76	2.9

OC—organic carbon; TN—total nitrogen; C/N—carbon-nitrogen ratio; $CaCO_3$—total calcium carbonate; CEC—cation exchange capacity; pH_w—pH in water solution; pH_k—pH in 1 M KCl solution; ECext—electrical conductivity in saturated paste; SAR—sodium adsorption ratio.

2.1. Experimental Design and Sampling

For this study, a block sampling design was established [46] with two fertilization treatments and two irrigation treatments, each having four replications (Figure 2). Regarding the fertilization treatments, we compared a treatment where the optimum dose was applied, calculated from the N consumption recommended by different authors [47–49], with another surplus treatment that contained an additional 20% of N. The first treatment was carried out using sheep manure (SM), with a dose of 16,000 kg ha^{-1}, while the second (surplus) had the same dose of SM plus 3000 kg ha^{-1} of a commercial organic fertilizer in the form of pellets (P). The use of pellets as the organic amendment in the experiment (P) was due to the ease of their distribution and handling in the different plots, as well as their incorporation into the soil. The physicochemical characteristics and amounts of macronutrients supplied are shown in Tables 2 and 3, respectively.

For each of the treatments, irrigation systems with different water flow rates were installed: optimum irrigation (O) with a flow rate of 1200 L h^{-1} and excess irrigation (E) with a flow rate of 1700 L h^{-1}. The discharge rates for each of the sprinklers were 15.3 L m^{-2} and 21.7 L m^{-2}. A sprinkler irrigation system was used. For this purpose, sprinklers for optimum (O) and excess irrigation (E) were installed 10 m apart connected by 50 mm diameter polyethylene hoses.

The irrigation water had an ECext of 6.4 dS m^{-1} and a pH_w of 8.1, with the following salt content: the HCO_3^-, Cl^-, and SO_4^{2-} content was 287, 1170, and 1186 mg L^{-1}, respectively, while Na^+ was the predominant cation (808 mg L^{-1}), followed by Ca^{2+}, Mg^{2+}, and K^+, at 237, 153, and 20 mg L^{-1}, respectively.

Combining the fertilization and irrigation trials, the following four treatments were obtained:

PO: sheep manure + pellets (P) + optimum irrigation (O) (sampling sites 1, 2, 9, and 10).
PE: sheep manure + pellets (P) + excess irrigation (E) (sampling sites 3, 4, 11, and 12).
SMO: sheep manure (SM) + optimum irrigation (O) (sampling sites 5, 6, 13, and 14).
SME: sheep manure (SM) + excess irrigation (E) (sampling sites 7, 8, 15, and 16).

Water consumption during the vegetative cycle was 4060, 4420, 5090, and 5590 m^3 ha^{-1} in PO, SMO, PE, and SME, respectively. Irrigation control was achieved with a set of Watermark electrical resistance blocks (Irrometer Inc., Riverside, CA, USA), which were installed about 15 cm from the plant row at a depth of 30 cm. The hardness of the irrigation water is expressed in French degrees (°F).

To monitor soil salinity (ECext), soil samples taken at each sampling point from two depths, shallow (0–30 cm) and at depth (30–60 cm), were used. Four samplings were carried out throughout the crop cycle on 27 December 2017, 12 January 2018, 9 February 2018, and 14 April 2018.

Prior to sowing the spinach, background fertilization was carried out with organic fertilizers, providing 100% of the nutritional needs of the crop. The spinach was sown on 10 January 2018 and harvested on 22 April 2018; the crop cycle was 72 days.

Lysimeters and tensiometers were installed at different depths at each of the 16 sampling sites (Figure 2). Every 15 days during the cultivation period, the agronomic monitoring of the crop and characterization of the soil solution were carried out using lysimeters installed at different depths, including 25–30 cm (Irrometer-SSAT-LT-300, Riverside, CA, USA) to determine the bioavailability of nutrients during the cultivation cycle and 55–60 cm (Irrometer-SSAT-LT-600, Riverside, CA, USA) to quantify the leaching of nutrients to the deep soil horizons.

For the analysis of plant material, samples of the spinach crop, both leaves and roots, were obtained from each of the four treatments. For this purpose, all plants were harvested in an area of 20 × 20 cm, washed with distilled water, and dried at 105 °C in a forced-air oven. Leaves were separated from roots and these fractions were crushed and homogenized integrally in a Dito Sama K55 Cutter-Emulsifier 5.5 L mill (Aubusson, France). An aliquot of 3 g was taken from each sample and processed with an A10 Analytical Mill 50/60 Hz (IKA Works Inc., Wilimington, NC, USA) to obtain a fine grind suitable for acid digestion.

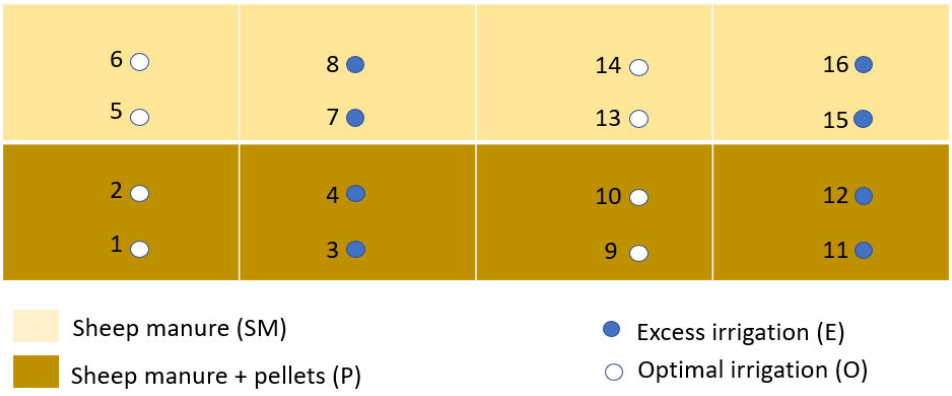


Figure 2. Experimental design with fertilization and irrigation treatments. The different soil sampling sites where rain gauges, lysimeters, and tensiometers were installed at different depths are numbered from 1 to 16.

Table 2. Chemical analysis of sheep manure (SM) and commercial organic amendment (P) nutrients, performed on dry matter basis.

Amendment	M	pH_w	ECext	C/N	TOM	TN	P	K	Ca	Mg	Fe	Cu	Mn
SM	38.6	8.4	8.7 *	13.1	486	21.5	22.6	26.2	71.6	19.1	7.8	0.05	0.4
P	30.0	6.0	2.4 **	16.9	350	12.0	12.0	12.0	4.1	1.4	10.0	0.04	0.7

M—% moisture); pH_w—pH_{water} (1:2.5); ECext—electrical conductivity (* dilution 1:5, ** dilution 1:10, dS m^{-1}); TOM—total organic matter (g kg^{-1}); TN—total nitrogen (g kg^{-1}); P—total phosphorus (g kg^{-1} of P_2O_5); K—total potassium (g kg^{-1} of K_2O); Ca—total calcium (g kg^{-1} of CaO); Mg—total magnesium (g kg^{-1} of K_2O); Fe—total iron (g kg^{-1}); Cu—total copper (g kg^{-1}); Mn—total manganese (g kg^{-1}).

Table 3. Macronutrient supply (Kg ha^{-1}) and irrigation water (m^3) in each treatment.

Macronutrient		SMO	SME	PO	PE
TN	Irrigation water	-	-	-	-
	Sheep manure	132.78	132.78	132.78	132.78
	Pellet	-	-	25.20	25.20
	Total inputs	132.78	132.78	157.98	157.98
P_2O_5	Irrigation water	-	-	-	-
	Sheep manure	139.58	139.58	139.58	139.58
	Pellet	-	-	25.20	25.20
	Total inputs	139.58	139.58	154.78	154.78
K_2O	Irrigation water	112.10	141.77	98.79	129.09
	Sheep manure	161.81	161.81	161.81	161.81
	Pellet	-	-	25.20	25.20
	Total inputs	273.91	303.58	258.80	316.10
CaO	Irrigation water	1423.24	1799.98	1347.84	1638.98
	Sheep manure	442.20	442.20	442.20	442.20
	Pellet	-	-	8.6	8.6
	Total inputs	1865.44	2242.18	1798.65	2089.79
MgO	Irrigation water	1068.17	1350.92	1036.96	1230.08
	Sheep manure	117.96	117.96	117.96	117.96
	Pellet	-	-	2.94	2.94
	Total inputs	1186.13	1468.88	1157.86	1350.98
Irrigation water		4420	5590	4060	5090

2.2. Physical and Chemical Analysis of the Soil Samples, Soil Solutions, and Plants

The air-dried soil samples were screened at 2 mm and the following analyses were carried out:

Organic carbon (OC) and total nitrogen (TN) contents were determined in an elemental analyzer (Leco, model CHNS-932, St. Joseph, MI, USA), while pH was measured in a 1:1 suspension of soil in water (pHw) and a 1:1 suspension of soil in 1 M KCl (pHk) [50]. Total carbonates ($CaCO_3$) were determined by volumetric analysis using a Bernard calcimeter [51]. A soil-saturated paste was prepared for ECext determination [51]; in the extracts obtained, K^+, Na^+, Mg^{2+}, and Ca^{2+} were determined by ICP-OES (Varian Vista MPX, Palo Alto, CA, USA) and anions (NO_3^-, NO_2^- PO_4^{3-}, and SO_4^{2-}) by ion chromatography (METROHM 861 Advanced Compact IC; METROHM 838 Advanced Sampler, Herisau, Switzerland). CO_3^{2-} and HCO_3^- were measured by valuation [52]. The sodium adsorption ratio (SAR) was calculated from the concentrations of Na^+, Ca^{2+}, and Mg^{2+} (meq L^{-1}) in the soil saturation extract prepared for ECext determination [51], applying the formula:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad (1)$$

The soil solution samples obtained from the lysimeters were assessed for pH, EC, and the ions K^+, Na^+, Mg^{2+}, Ca^{2+}, NH_4^+, NO_3^-, NO_2^- PO_4^{3-}, SO_4^{2-}, CO_3^{2-}, and HCO_3^-, following the same methodology as that for the samples obtained from the soil saturation extract mentioned in the previous paragraph.

The chemical characterization of the plant material was carried out by fine grinding and acid digestion (HNO_3 + $HClO_4$). Na, K, Ca, Mg, P, Fe, Cu, Mn, Zn, and Mo contents were determined by ICP-OES (Varian Vista MPX), while TN, OC, and S contents were determined using an elemental analyzer (Leco, model CHNS-932). Nutrient extractions by the crop are expressed in kg ha^{-1} and were calculated based on the total biomass production (aerial + roots) and the chemical composition obtained in the elemental analysis of the plant material.

The nutrient balance in the soil was calculated as the difference between the input and removal of elements, including amendments (SMS or P), irrigation water, and the return of biomass (roots + aerial biomass) not harvested as inputs; in terms of removal, only the extractions by the crop that were finally marketed as harvest were considered, i.e., the commercial production, as well as the percentage of OC mineralization, calculated from the values found by Almagro et al. [53] in soils similar to those of this study, who set mineralization at 0.19 mg C (CO_2) g^{-1} OC day^{-1}.

2.3. Crop Yield

Samples of the spinach crop were obtained for analysis. For each of the four treatments and in quadruplicate, all plants were harvested in an area of 20 × 20 cm for the evaluation of the yield parameters (total yield (Yt) and commercial yield (Yc)) and harvest index (HI), calculated as the percentage of Yc/Yt. Commercial yield (Yc) corresponds to the commercial specifications required by customers to generate the pre-prepared convenience food formats, which are standardized as the total length of the stem plus 20 cm leaves. Harvesting was mechanized, cutting the top 20 cm of the plant and leaving the rest in the field. The selection and packaging were carried out in the field.

2.4. Statistical Analysis

The data were analyzed using the general linear model of the SPSS Version 25 statistical package (SPSS, Chicago, IL, USA). The experimental data were subjected to an analysis of variance (ANOVA) [46] using Tukey's multiple range test to estimate statistical differences among the mean values for the treatments (SMO, SME, PO, and PE). Differences were considered significant at the 5% level (p = 0.05).

3. Results

3.1. Spatial and Temporal Content and Evolution of Salts in the Soil during the Crop Cycle

3.1.1. Electrical Conductivity (ECext)

In our examination of ECext behavior, we observed a significant increase in surface area with respect to depth at the beginning of the crop cycle (SM and P treatments, Figure 3); however, this trend tended to become more homogenized—or even reverse—by the end of the growing season (SMO, SME, PO, and PE treatments, Figure 3). As for the temporal evolution in each treatment, ECext increased as the crop cycle progressed, with values slightly higher than 5 dS m^{-1} at the beginning and 8.5 dS m^{-1} at the end, implying a change in the degree of soil salinity [54] from moderately saline to saline. At the spatial level, there were also statistically significant differences in the depth horizons between treatments with optimal and surplus irrigation, being superior in the latter.

At the same time, from the data collected by the lysimeters installed in the field, it was found that when irrigation was optimal, leaching did not occur in the deep horizons and no extract was found in the soil dissolution lysimeters; when leaching did occur, the concentration of salts on the surface was significantly higher than at depth, reaching EC values close to 25 and 13 dS m^{-1}, respectively. However, when the irrigation dose was in excess, all the lysimeters installed at 60 cm collected leachates from the upper horizons,

with significant differences in ECext between the surface and depth, with values ranging between 15 and 20 dS m^{-1}, respectively. Finally, during the crop cycle, there was an average increase in pH_w from 6.8 to 7.3 between January and March, as well as in ECext, especially in the treatments with optimum irrigation, where ECext reached values of 22.4 dS m^{-1} in January and 30 dS m^{-1} in March (PO).

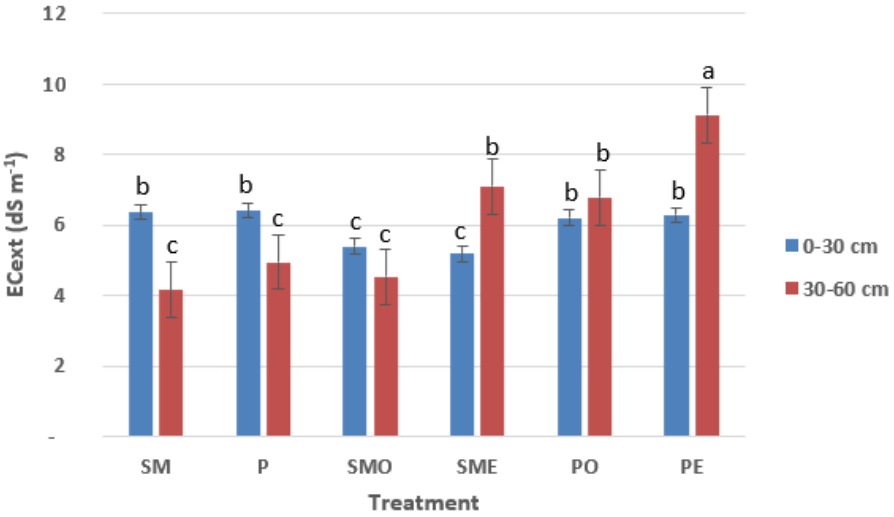


Figure 3. ECext values for the different treatments. SM and P treatments represent the ECext values at the beginning of the crop cycle. SMO, SME, PO, and PE treatments represent the mean values during the crop cycle. "a", "b", and "c" indicate significant differences between treatments at the 95% confidence level.

3.1.2. Ions in Soil Solution

The analysis of anions and cations obtained from the soil saturation extract to determine the CE showed that NO_3^- (Figure 4) reached its maximum concentration at the soil surface at the beginning of the experiment (SM and P treatments) and decreased drastically during the crop cycle while increasing in depth for all treatments except PO.

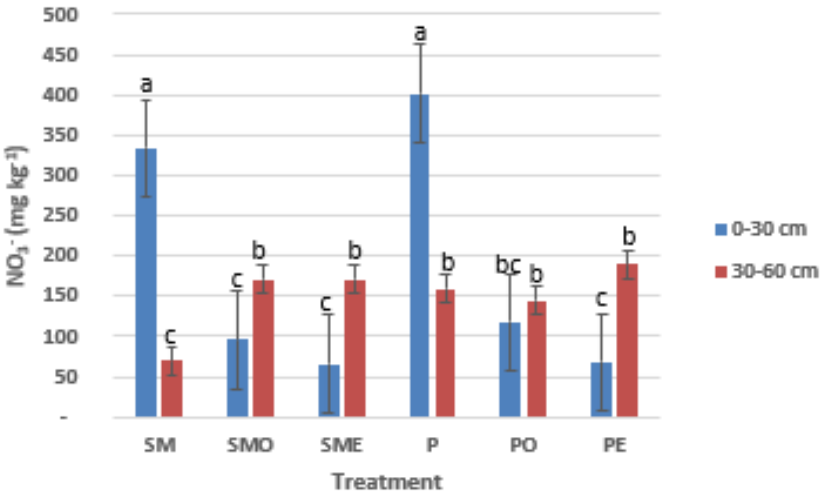


Figure 4. NO_3^- concentration (mg kg^{-1}) in the saturation extract of the different treatments. "a", "b", and "c" indicate significant differences between treatments at the 95% confidence level.

Regarding the Cl^- concentration in the soil saturation extract (Figure 5A), apart from the higher concentration observed at the surface in baseline conditions, no defined spatial trend was observed for the rest of the treatments, except for PE, where the concentration at depth was statistically higher.

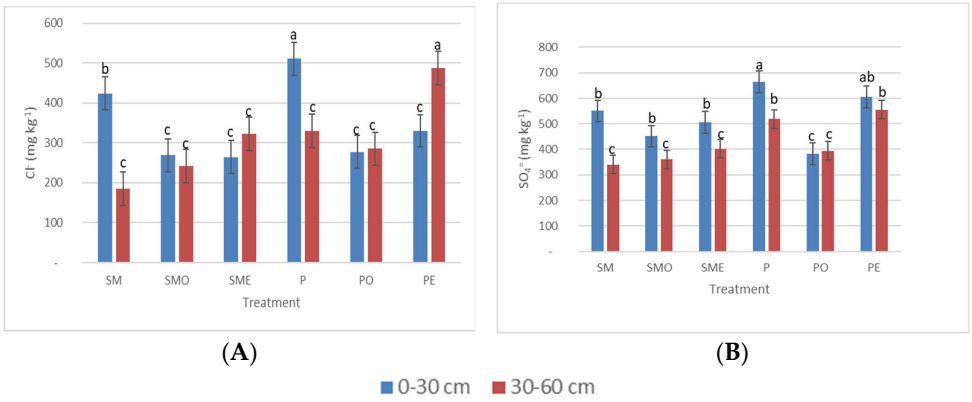


Figure 5. (**A**) Cl^- concentration (mg kg^{-1}) and (**B**) SO_4^{2-} concentration (mg kg^{-1}) for the different treatments. "a", "b", and "c" indicate significant differences between treatments at the 95% confidence level.

As for SO_4^{2-} (Figure 5B), the concentration was significantly higher at the surface than at depth for the treatments with sheep manure, regardless of the irrigation dose, while it remained constant in the treatments where pellets were added, except in the initial stage, where the same behavior as that in SM was observed. On the other hand, when we compared between irrigation doses, it was observed that there were no significant differences in the manure-based treatments, while the sulphate concentration was higher in PE than in PO in the pellet-based treatments. With regard to the rest of the anions analyzed, nitrites, carbonates, and phosphates were not detected; bicarbonates did appear but did not show significant differences between treatments, with average levels close to 40 mg kg^{-1} of soil.

As for the cations, Na^+ did not show significant differences between the shallow and deep horizons during the crop cycle; when compared between fertilizer treatments, higher concentrations were reached in PO than in SMO and, considering irrigation doses, the levels in SME were higher than in SMO, while the rest remained homogeneous (Figure 6A). On the other hand, K^+ levels in the soil saturation extract did not show a defined behavioral pattern and were not statistically significant with the treatments studied.

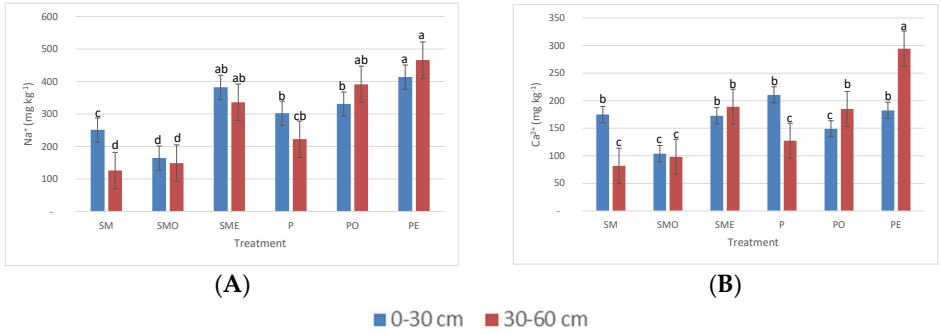


Figure 6. (**A**) Na^+ concentration (mg kg^{-1}) and (**B**) Ca^{2+} concentration (mg kg^{-1}) in the different treatments. "a", "b", "c", and "d" indicate significant differences between treatments at the 95% confidence level.

In the case of divalent cations (Figure 6B), Ca^{2+} showed a behavior very similar to that of Na^+; except in PE, they did not show significant differences between the depth and surface horizons during the crop cycle. With respect to fertilizer treatments, PO and PE had higher concentrations at depth than SMO and SME, respectively. Finally, considering irrigation doses, the levels reached with excess doses were statistically higher than those obtained with deficit doses, in most cases. Mg^{2+} behaved similarly to Ca^{2+}, although absolute concentrations remained below 100 mg kg^{-1}.

On the other hand, the extracts obtained during the crop cycle in the lysimeters installed in the field showed that, at the beginning of the crop cycle, there was a higher concentration of NO_3^- at the soil surface than at depth, ranging between 4323 and 1268 mg L^{-1}, respectively, in the PO treatment, which is where the maximum and minimum concentrations of all the treatments studied were found. However, its concentration decreased as crop development progressed; this trend was also observed by Citak et al. [55]. These differences between surface and depth were maintained throughout the cycle in treatments with optimal irrigation and were reversed in those with surplus irrigation, with a higher concentration between 30 and 60 cm than at the surface (2194.8 and 93.7 mg L^{-1}, respectively). The Cl^- concentrations adopted a very similar pattern, but reached higher concentration levels, oscillating between 6422 and 2555 mg L^{-1} at depth and at the surface, respectively, in the PO treatment. SO_4^{2-}, as it is much more soluble, tended to accumulate on the surface, regardless of the irrigation or fertilization treatment. Finally, the absence of CO_3^{2-}, PO_4^{3-}, NO^{2-}, and NH_4^+ should be noted, while Na^+, K^+, Ca^{2+}, and Mg^{2+} cations showed the same behavior as Cl^-.

3.2. Total Yield (Yt), Commercial Yield (Yc), and Harvest Index (HI)

As can be seen in Figure 7, the influence of fertilizer treatment under the same irrigation conditions translated into a statistically significant increase in Yc when the optimum fertilizer dose was used, i.e., Yc was higher in SMO than in PO and higher in SME than in PE. Likewise, when the influence of irrigation was analyzed, Yc was statistically homogeneous between treatments receiving different irrigation doses—that is, between SMO and SME and between PD and PO—while in the case of Yt, the treatments with excess irrigation, SME and PE, had higher yields than their homologues where the optimum irrigation dose was used (SMO and PO, respectively).

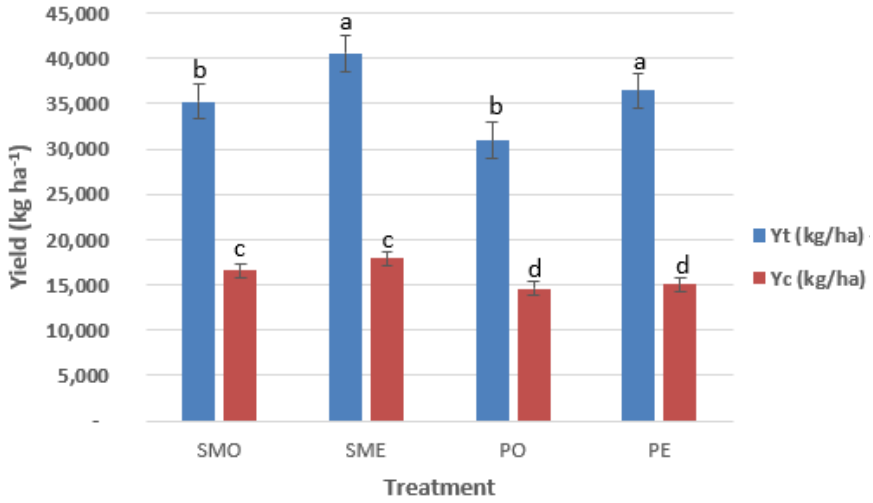


Figure 7. Total yield (Yt) and commercial yield (Yc) for each treatment. "a", "b", "c", and "d" indicate significant differences between treatments at the 95% confidence level.

With respect to HI, statistically significant differences were found between SMO (54%) and the other treatments, with mean percentages close to 45%. Finally, in dry matter production, no significant differences were observed between treatments, regardless of aerial or root biomass, with mean productivity of 1883 and 847 kg ha^{-1}, respectively.

3.3. Bioelement Extractions

Nutrient extraction by plants in general and, in our case, by the spinach crop is an indicator of nutrient loss in the soil and is responsible, in some cases, for the appearance of imbalances between nutrient inputs and extractions in the edaphic environment; therefore, it should form the basis of fertilization programs. On the other hand, taking into account

that the accumulation of bioelements is not homogeneous in different plant tissues and that some of these elements return to the soil after harvesting, the extraction of macro and micronutrients in the aerial biomass and the root were determined separately; the results are shown below.

3.3.1. Macronutrients

The amounts of macronutrients extracted by the spinach crop are different depending on the part of the plant where they accumulate (aerial biomass or root) and on each element in question. Here, in aerial biomass, significant differences were detected between treatments for N, which was higher in PO than in the rest, and P_2O_5, K_2O, CaO, and MgO, which were higher in PO and PE than in SMO and SME, respectively. In the root, significant differences were only found for P_2O_5, which was higher in the PO and PE treatments. As can be seen in Table 4, the highest extraction corresponded to K and was almost double that of N, the next highest extraction. Mg, Ca, and P were extracted in intermediate amounts. Finally, S was the macronutrient least demanded by the spinach crop. For most of the nutrients, these extractions accumulated in the aerial biomass, where they accounted for around 80% of the total, while the roots were responsible for the remaining 20%. However, P showed a different behavior, since 36% of the total P extracted from the soil was accumulated in the roots.

Table 4. Macronutrient extraction (N, P_2O_5, K_2O, S, CaO, and MgO) (kg ha^{-1}) by aerial biomass and roots in a spinach crop subjected to different fertilization and irrigation treatments. "a" and "b" indicate significant differences between treatments at the 95% confidence level.

Treatment	N	P_2O_5	K_2O	S	CaO	MgO
Aerial biomass	93.8	22.9	160.4	5.0	23.5	34.2
SMO	94.0 b	20.3 b	138.6 b	5.5 a	23.6 b	32.2 b
SME	88.1 b	20.2 b	141.6 b	4.3 b	19.4 b	28.4 b
PO	113.2 a	26.1 a	184.3 a	5.9 a	25.7 a	39.9 a
PE	80.0 b	25.0 a	177.2 a	4.3 b	25.4 a	36.2 a
Root	21.3	13.0	41.2	1.2	6.3	8.0
SMO	22.5 a	13.0 b	46.4 a	1.2 a	4.8 a	8.9 a
SME	18.5 a	11.2 b	37.2 a	0.9 a	7.0 a	6.9 a
PO	22.4 a	14.5 a	43.2 a	1.4 a	5.7 a	8.7 a
PE	21.6 a	13.3 a	38.2 a	1.1 a	7.5 a	7.4 a
Total plant	115.1	35.9	201.6	6.2	29.8	42.1
% (aerial biomass)	82	64	80	81	79	81
% (root)	19	36	20	19	21	19

3.3.2. Micronutrients

According to Table 5, the amounts of micronutrients extracted from the soil by the crop varied widely depending on the element and the tissues where they accumulated; in addition, as in the case of macronutrients, there were also significant differences between the different treatments. The order of absolute extractions in both roots and aerial biomass was as follows: Fe > Zn, Mn > Cu > Mo. As for their accumulation in the different plant organs, Mn and Zn behaved identically, with 74% of the extractions representing the aerial biomass and 26% representing the roots; Fe, with 62% and 38%, respectively, and—to a lesser extent—Cu (70% and 30%, respectively) tended to accumulate to a greater extent in the roots, while Mo behaved in an opposite fashion, concentrating in the leaves.

Regarding the influence of the treatments, the values for Cu and Mo were higher in the aerial biomass of PO and PE, while for Zn, SMO, PO, and PE had homogeneous values, higher than those for SME. In Fe, a complementary behavior was observed between the aerial part and the root, especially under the SMO treatment, obtaining the maximum and minimum values, respectively, while in SME and PE the opposite occurred, where the maximum was obtained in the root and minimum in the aerial biomass. The rest of the micronutrients were not sensitive to root treatments.

Table 5. Micronutrient extraction (Fe, Cu, Mn, Zn, and Mo) (g ha^{-1}) by aerial biomass and roots in a spinach crop subjected to different treatments. "a", "b", and "c" indicate significant differences between treatments at the 95% confidence level.

Treatment	Fe	Cu	Mn	Zn	Mo
Aerial biomass	1257.2	38.4	175.3	226.5	1.6
SMO	2310.4 a	32.9 b	190.6 a	263.2 a	15 ab
SME	642.0 c	31.1 b	152.1 b	171.8 b	12 b
PO	1231.2 b	42.9 a	196.2 a	237.0 a	1.8 a
PE	845.3 c	46.7 a	162.1 b	234.1 a	1.9 a
Root	763.5	16.1	62.3	78.8	0.4
SMO	479.9 c	15.7 a	65.3 a	74.4 a	0.3 a
SME	931.4 a	12.6 a	56.7 a	66.8 a	0.2 a
PO	673.0 b	18.1 a	65.5 a	92.8 a	0.4 a
PE	969.6 a	17.9 a	61.5 a	81.3 a	0.6 a
Total plant	2020.7	54.4	237.5	305.3	2.0
% (aerial biomass)	62	70	74	74	80
% (root)	38	30	26	26	20

3.4. Soil Nutrient Balance

The nutritional needs of spinach crops are realized through the absorption of bioelements, either from the soil solution or from the atmosphere, a process that causes a decrease in the chemical fertility of the soil, making it necessary to replenish bioelements by adding fertilizers to preserve the balance between extractions and inputs. This balance can be achieved by establishing management systems that, among other aspects, ensure a neutral balance between inputs and outputs, which is why the FAO and other international organizations are promoting alternative or conservation agriculture models that, in addition to considering the historical functions of the soil as a source of food production, consider other ecological functions to provide ecosystem goods and services, including acting as a carbon sink.

3.4.1. Macronutrients

According to the results shown in Table 6, an excess of nutrient inputs was observed in all treatments, and especially in PO and PE. Thus, in the case of N, where the balance was more optimal, there was an excess of fertilization ranging between 12 and 36% in SMO and PE, respectively. Of the nutrients N, P, and K, phosphorus was the most unbalanced, with an excess of around 76% in all treatments, although this excess did not manifest itself in the levels of phosphates in the soil solution. For potassium, being the nutrient that is most intensely absorbed by the spinach crop, there was also an excess of fertilization between 20 and 41% in PO and SMO, respectively, essentially as a consequence of its incorporation in the irrigation water. Finally, Ca and Mg were present in all sources (water, pellets, and sheep manure); thus, they were incorporated in excess and increased the already high levels in the soil, although they were mostly present in a non-assimilable form.

These fertilization excesses are increased as a consequence of crop management and, in particular, the harvesting system used, where only a percentage of the aerial biomass of the crop is harvested (45% on average), the rest being incorporated together with the subway biomass (roots). In the case of N, which is the base nutrient used when making fertilization calculations, taking into account this biomass return, the excess fertilization would increase to 62% in SME and 73% in PE; most of this would be incorporated into the soil in the form of organic N as harvest residues.

Table 6. Macronutrient balance (TN, P_2O_5, K_2O, CaO, and MgO) (kg ha^{-1}) in a spinach crop subjected to different fertilization and irrigation treatments.

		SMO	**SME**	**PO**	**PE**
		TN			
Inputs	Water irrigation	-	-	-	-
	Sheep manure	132.78	132.78	132.78	132.78
	Pellet	-	-	25.20	25.20
	Total inputs	132.78	132.78	157.98	157.98
Removals	Aerial biomass	94.00	88.09	113.16	80.04
	Root	22.47	18.52	22.47	21.59
	Removals	116.47	106.61	135.63	101.63
Balance		16.31	26.17	22.35	56.35
		P_2O_5			
Inputs	Water irrigation	-	-	-	-
	Sheep manure	139.58	139.58	139.58	139.58
	Pellet	-	-	25.20	25.20
	Total inputs	139.58	139.58	154.78	154.78
Removals	Aerial biomass	20.28	20.21	26.14	24.97
	Root	13.00	11.23	14.52	13.27
	Removals	33.29	31.44	40.66	38.25
Balance		106.29	108.14	124.12	126.53
		K_2O			
Inputs	Water irrigation	112.10	141.77	98.79	129.09
	Sheep manure	161.81	161.81	161.81	161.81
	Pellet	-	-	25.20	25.20
	Total inputs	273.91	303.58	258.80	316.10
Removals	Aerial biomass	138.64	141.56	184.28	177.16
	Root	46.39	37.16	43.20	38.19
	Removals	185.08	178.72	227.48	215.35
Balance		88.88	124.86	58.32	100.75
		CaO			
Inputs	Water irrigation	1423.24	1799.98	1347.84	1638.98
	Sheep manure	442.20	442.20	442.20	442.20
	Pellet	-	-	8.6	8.6
	Total inputs	1865.44	2242.18	1798.65	2089.79
Removals	Aerial biomass	23.56	19.40	25.70	25.42
	Root	4.8	6.99	5.75	7.50
	Removals	28.36	26.39	31.45	32.92
Balance		1837.09	2215.80	1767.21	2056.87
		MgO			
Inputs	Water irrigation	1068.17	1350.92	1036.96	1230.08
	Sheep manure	117.96	117.96	117.96	117.96
	Pellet	-	-	2.94	2.94
	Total inputs	1186.13	1468.88	1157.86	1350.98
Removals	Aerial biomass	32.18	28.40	39.93	36.17
	Root	8.91	6.85	8.74	7.38
	Removals	41.09	35.25	48.67	43.56
Balance		1145.04	1433.63	1109.19	1307.43

3.4.2. Micronutrients

The balance between the input and removal of micronutrients was in excess in all treatments. In this sense, the most notable excess occurred with Fe, where significantly higher amounts were contributed than extracted by the crop, this excess being between 94% in SMO and 97% in PE; however, as was the case for phosphorus, Fe was not found in the soil solution. Therefore, it must be present as organic Fe or precipitated as $Fe_2(CO_3)_3$.

The rest of the micronutrients were supplied in average excesses of 85, 89, and 83% for Cu, Mn, and Zn, respectively (Table 7). As with the macronutrients, these excesses increased with the return of biomass, which raised the levels of micronutrients contributed to the soil in relation to the net extractions to 99, 93, 96, and 94% for Fe, Cu, Mn, and Zn, respectively.

Table 7. Micronutrient balance (Fe, Cu, Mn, and Zn) (kg ha^{-1}) in a spinach crop subjected to different fertilization and irrigation treatments.

		Fe			
		SMO	**SME**	**PO**	**PE**
Inputs	Water irrigation	-	-	-	-
	Sheep manure	48.17	48.17	48.17	48.17
	Pellet	-	-	21.00	21.00
	Total inputs	48.17	48.17	69.17	69.17
Removals	Aerial biomass	2.31	0.64	1.23	0.85
	Root	0.48	0.93	0.67	0.97
	Removals	2.79	1.57	1.90	1.81
Balances		45.38	46.60	67.27	67.36
		Cu			
Inputs	Water irrigation	-	-	-	-
	Sheep manure	0.31	0.31	0.31	0.31
	Pellet			0.08	0.08
	Total inputs	0.31	0.31	0.39	0.39
Removals	Aerial biomass	0.03	0.03	0.04	0.05
	Root	0.02	0.01	0.02	0.02
	Removals	0.05	0.04	0.06	0.06
Balance		0.26	0.27	0.33	0.33
		Mn			
Inputs	Water irrigation	-	-	-	-
	Sheep manure	2.47	2.47	2.47	2.47
	Pellet			1.47	1.47
	Total inputs	2.47	2.47	3.94	3.94
Removals	Aerial biomass	0.19	0.15	0.20	0.16
	Root	0.07	0.06	0.07	0.06
	Removals	0.26	0.21	0.26	0.22
Balance		2.21	2.26	3.68	3.72
		Zn			
Inputs	Water irrigation	-	-	-	-
	Sheep manure	2.07	2.07	2.07	2.07
	Pellet			0.19	0.19
	Total inputs	2.07	2.07	2.26	2.26
Removals	Aerial biomass	0.26	0.17	0.24	0.23
	Root	0.07	0.07	0.09	0.08
	Removals	0.34	0.24	0.33	0.32
Balance		1.73	1.83	1.93	1.94

3.4.3. Elements with Environmental Impacts

Apart from the nutritional balances of macro and micronutrients, which are essential for the calculation of fertilization doses and to guarantee the balance between inputs and outputs in the soil, it is very important to take into account other elements, such as carbon, to evaluate the influence of cultivation techniques on the ecological functions of the soil, or Cl^- and Na^+, to quantify the salinization or alkalinization processes that may result from the use of water of low agronomic quality.

As can be seen in Table 8, the organic amendments incorporated into the soil, as well as soil management, especially selection and packaging in the field, resulted in a net incorporation of OC into the soil, representing between 4 and 6% of its total stock, in addition to the inorganic

fraction provided by irrigation water in the form of $Ca(HCO_3)_2$. Thus, a crop cycle of spinach managed according to the design of this experiment can fix almost 2500 kg ha^{-1} of C, mainly in the form of OC and to a lesser extent inorganic C. This was observed as an increase from average OC levels of 1.45, 1.49, 1.30, and 1.24% in SMO, SME, PO, and PE, respectively, before the experiment to 1.53, 1.57, 1.39, and 1.30% after cultivation.

Table 8. C, Cl^-, and Na^+ balance (kg ha^{-1}) in a spinach crop subjected to different fertilization and irrigation treatments.

C (Inorganic Carbon in Water Irrigation + Organic Carbon)					
		SMO	**SME**	**PO**	**PE**
Inputs	Water irrigation	151.00	190.90	138.70	173.90
	Sheep manure	1745.08	1745.08	1745.08	1745.08
	Pellet			427.33	427.33
	Biomass return	338.30	275.42	358.87	330.75
	Total inputs	2234.38	2211.40	2669.97	2677.06
Removals	OC mineralization	221.62	174.52	259.01	195.30
	Removals	221.62	174.52	259.01	195.30
Balance		2012.76	2036.88	2410.96	2481.76
Cl^-					
Inputs	Water irrigation	5189.79	6563.56	4767.10	5976.48
	Sheep manure	107.20	107.20	107.20	107.20
	Pellet			20.10	20.10
	Total inputs	5296.99	6670.76	4894.40	6103.78
Balance		5296.99	6670.76	4894.40	610378
Na_2O					
Inputs	Water irrigation	4795.70	6065.15	4426.02	5522.65
	Sheep manure	81.52	81.52	81.52	81.52
	Pellet			13.02	13.02
	Biomass return	51.80	31.55	38.07	40.35
	Total inputs	4929.02	6178.22	4558.63	5657.55
Removals	Aerial biomass	33.61	49.98	45.44	41.14
	Removals	33.61	49.98	45.44	41.14
Balance		4895.41	6128.24	4513.19	5616.41

With respect to the elements that can cause soil salinization or alkalinization processes, both Cl^- and Na^+ were also incorporated in large quantities, reaching more than 6500 and 6128 kg ha^{-1}, respectively, and becoming the major anion and cation in the soil solution.

4. Discussion

4.1. Electrical Conductivity and pH

The use of low-quality irrigation water and, to a lesser extent, the incorporation of organic amendments in the soil caused an increase in ECext at the surface with respect to deeper horizons, results that coincide with those reported by Rotondo et al. [56]. Throughout the course of the crop cycle, and as a consequence of the washing of soluble salts from amendments or other sources, surface salinity was generally attenuated, increasing in parallel in the depth horizons as vegetative development progressed, a behavior that was also reported by Hernández et al. [57,58]. In fact, by the end of the crop cycle, the EC was greater in the depth horizons than at the surface, especially under the excess fertilization and irrigation treatments (PE and SME). This trend was confirmed by the lysimeters installed in the field; in the treatments with optimal irrigation doses, there was rarely any leaching of salts to the deep horizons, while in those with excess, the lysimeters installed at 60 cm received leachates from the overlying horizons. The most soluble ions (NO_3^-, Cl^-, Na^+, etc.) were concentrated in these leachates, similar to the results reported by Li-Xan et al. [59] Finally, the increase in pH observed in some treatments has been attributed by some authors [60] to

the alkalinizing effect of the organic amendments added and to the high concentration of Na^+ in the irrigation water, which may induce the alkalinization of the exchange complex and, therefore, an increase in soil pH.

4.2. Ions in Soil Solution

The calcareous nature of the parent material and the slightly basic pH of the soil, among other properties, were the main factors controlling the content and dynamics of ions in the soil solution. Thus, the absence of soluble phosphates and carbonates must be attributed to their precipitation in the form of Ca_3PO_4 and $CaCO_3$, respectively, favored by the basic pH and the Ca^{2+} saturation of the soil solution. However, the absence of NO_2^- must be related to the soil aeration conditions, which make the soil an oxidizing medium where N predominantly undergoes a nitrification process, resulting in the mineralization of soil N to its most oxidized forms (NO_3^-) [61]. In turn, the dynamics of NO_3^- in the soil are related to the vegetative development of the spinach crop, which justifies its decrease at the surface as the cycle progresses [55,62]; it is estimated that weekly N uptake can reach 60 kg ha^{-1} [63]. The leaching of excess fertilizer, responsible for the increase in depth, was found in the PE treatment, where excess fertilizer in the form of pellets was partially mobilized to the deeper horizons, while in PO no such behavior was observed.

The vertical dynamics of chlorides in the soil horizons is due to the washing process, typical in these soils under both natural and cultivated conditions, which justifies the generalized decrease in the concentration of Cl^- at the surface that stabilizes as the cycle progresses, as has also been shown by Sánchez-Navarro et al. and Fontela et al. [60,64], among others, who point to a process of soil salinization. However, the dynamics of SO_4^{-2} in the soil are affected, as is NO_3^-, by the processes of absorption by the crop and washing, which should cause a decrease in concentration at the soil surface as vegetative development progresses; however, the significant contribution by irrigation water compensates for these processes and, together with its low solubility, justifies the increase in concentration in the surface horizons.

The dynamics and content of cations, particularly Ca^{2+} and Mg^{2+}, are controlled fundamentally by the geological material (i.e., limestone, dolomites, and quaternary sediments rich in these elements), by the organic amendments added, and by the irrigation water (hardness is higher than 120 °F). All this would explain the spatial homogeneity between surface and depth horizons; however, at the beginning of the trial, the concentration was higher on the surface for the SM and P treatments, due to the fact that it was in this horizon that the amendments were added. This behavior was reversed during the crop cycle in the trials with pellets (PO and PE), due to the washout of Ca^{2+} and Mg^{2+}, which are part of the chemical composition of the pellets and which, according to their behavior, should be more soluble than those of the geological material or sheep manure.

4.3. Total Yield (Yt) and Commercial Yield (Yc)

The highest biomass yields (Yt) were obtained in the treatments with surplus irrigation due to the fact that spinach grown under these conditions develops a longer stem; however, this is not commercially exploited, since the commercial specifications of the clients for whom this product is intended limit the length of the stem to 20 cm. Therefore, Yc did not present significant differences attributable to the irrigation dose, as occurred with the production of dry matter. According to the results, it can be inferred that the differences found in Yt were exclusively due to the higher percentage of crop moisture from treatments with excess irrigation, such that at the production level, the use of excess fertilization and irrigation doses represents a waste of water and nutritional resources that does not translate into an increase in commercial production. These results coincide with those obtained by various authors [65,66], who agree that the establishment of adequate fertilization and irrigation doses eliminates the situations mentioned above and allows the plant to find not only the water but also the oxygen and nutrients it needs with minimal energy costs,

which can result in an improvement in crop yield when the rest of the production factors are controlled.

4.4. Macro and Micronutrient Extraction

As has been shown by different authors [67,68], the extraction of nutrients by the spinach crop is influenced by the nature of the bioelement in question and, sometimes, by the treatment to which they have been subjected. In the case of macronutrients, extractions were greater when fertilized in excess, a behavior justified by the greater availability in the soil solution, as was seen in previous sections. Likewise, the proportion at which they accumulated in plant tissues was similar for all elements except phosphorus, which, due to its lower mobility in the plant, tended to concentrate in the roots [68,69], representing an energy reserve for plant growth [70]. Of the micronutrients, Fe reached much higher levels than the rest and, due to its low mobility, accumulated in the roots in greater proportions, similar to P. The differences in concentrations between treatments must be related to photosynthetic activity [71].

4.5. Balances

The balance between nutrient inputs and extractions by the crop showed that the doses used in fertilization treatments were excessive, even for N, which is the nutrient for which the dose is most adjusted, since it is the element from which the fertilization dose is determined [62]. These nutrient excesses were especially high for P as a consequence of its high concentration in the organic amendments and the low crop demand for this nutrient, as well as Ca and Mg, due to the additional incorporation of these nutrients into irrigation water [49]. In terms of micronutrients, they were also supplied in significantly higher amounts than required [49] due to their high concentration in the amendments. In view of all this, one may think that the calculations for the nutritional balances were not adequate; however, a priori, when the planning of fertilization is carried out exclusively using organic amendments, as in our case, it is difficult to adjust the fertilization programs since the organic amendments used have a characteristic chemical composition and, therefore, the contribution of nutrient elements is a function of this [72]. On the other hand, it should be noted that these surplus nutrients were mostly not found in soluble forms, which is why they were not detected in the soil saturation extract and were instead part of the complex organic structures (amino acids, proteins, polysaccharides, etc.) present in plant remains or amendments as well as inorganic compounds such as phosphates and alkaline carbonates, contributing in both cases to increasing the potential fertility of the soil [73] without causing environmental problems associated with mobility in their soluble forms. For example, with NO_3^-, Na^+, and K^+, the excess can leach [62] resulting in subsequent environmental problems.

Together with the agronomic function of the soil, it is important to highlight the results related to the ecological functions and especially to that of carbon sink. In this sense, it can be observed that the contribution of organic amendments as the basis of fertilization, together with the return of biomass from crop residues and $CaCO_3$ provided in the irrigation water, entail the sequestration of C in the soil; although partially compensated by oxidation processes as shown in Martínez-Mena et al. [74], the net balance confirms that the soil under these management conditions is a C sink, thus contributing to the achievement of one of the objectives established at the Paris Climate Conference (COP21), which is to increase the OC content of agricultural soils by 4 per 1000, thereby promoting the transition to resilient agriculture. In this mode of agriculture, sustainable soil management is practiced, which generates jobs and ensures the sustainable development of rural agroecosystems. On the other hand, the use of poor-quality irrigation water causes a considerable increase in salts in the soil, some of which cause salinization and alkalinization processes, as has been shown by different authors [60], which can lead to the loss of its productive potential and even make it unviable for agricultural use. This conclusion was reached by the authors

of [75], who indicated that by 2050, these types of degradation could reduce arable land by between 8 and 20%, especially in arid and semi-arid areas such as the Mediterranean basin.

5. Conclusions

The results obtained showed that the use of low-quality irrigation water, and to a lesser extent the incorporation of organic amendments to the soil, were the main causes of the increase in ECext in the depth horizons, especially under treatments with the highest irrigation doses. Therefore, we considered that the main cause of the increase in soil salinity was the use of water of low agronomic quality. On the other hand, the mobility of ions in the soil and the oxidation state in which they were found was strongly influenced by the pH and the redox potential of the soil, causing the precipitation of carbonates and phosphates and the oxidation of nitrogenous forms to NO_3^-, among other constituents. This in turn explains the movement of the more soluble ions (NO_3^-, Cl^-, and Na^+), from the surface horizons to the depth horizons, especially in treatments with surplus irrigation, while with optimal irrigation, the less soluble ions (HCO_3^-, SO_4^{2-}, Ca^{2+}, and Mg^{2+}) tended to accumulate on the surface and rarely leached to the depth horizons.

The extraction of macro and micronutrients by the spinach crop was very different and depended on the fertilization dose: in the case of macronutrients, extractions increased significantly when fertilizer was in excess (PO and PE), while for micronutrients, extractions occurred preferentially under treatments with optimal irrigation levels. However, maximum crop profitability was found when fertilization and irrigation doses were optimal (SMO), such that the SME, PO, and PE treatments represent an economic waste and an environmental risk, either due to the potential contamination, especially with NO_3^-, of nearby ecosystems or groundwater or the induction of salinization or alkalinization processes in the soil as a consequence of the incorporation of Cl^- and Na^+ in excess.

The balances between the contributions and extractions of nutritive elements in the soil showed an excess of fertilization which was minimal in the case of TN (12%). However, as a consequence of the partial return of plant remains to the soil, TN increased considerably, therefore, a reduction in the contribution of organic amendments must be implemented in the fertilization programs of these farms. On the other hand, when the selection and packaging is performed in the field, with the consequent return of part of the biomass, the ecological functions of the soil are enhanced, especially that of the CO_2 sink, since it contributes to the increase in OC.

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