




Article

Spatial Distribution and Mobility of Nutrients on Sand Mulching Soil for Fertigated Green Bean Crops under Greenhouse Conditions in Southern Spain: (I) Macronutrients

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Abstract: Information about the nutrients distribution in sand-mulched soils is rather scarce; therefore, the aim of this experiment was to determine the spatial distribution and mobility of macronutrients in the wet bulb zone in two sand-mulched soils (a technique where manure and sand are layered over existing soil) for fertigated green bean with a drip irrigation distribution system under greenhouse conditions. The experimental design was multifactorial (4): soil type (S₁ (1.0% organic matter (OM)) and S₂ (2.5% OM)), time of sampling (before planting and after crop harvest) and spatial distribution: distance (0.1, 0.2, and 0.3 m) from the emitter and soil depth (0.1–0.2, 0.2–0.3 and 0.3–0.4 m) with three blocks and one replication per block. The chemical parameters (pH, electrical conductivity (EC), and macronutrients concentration) were analyzed in each soil sample. The testing crop was green bean (*Phaseolous vulgaris* L. c.v. Mantra RZ), lasting 90 days. The results obtained showed the highest value of EC and NO₃⁻-N, K, and Ca concentration in the sand layer in both soils. At all soil profile depths, nutrient concentrations of NH₄⁺-N and soil EC were lower in the high OM soil. Comparing the soil profile at the beginning and at the end of the experiment, there was a significant decrease in NO₃⁻-N, P and Ca concentration and a significant increase in EC value and Mg concentration at the end of the crop. In distance, EC and K showed the highest concentration at 0.30 m. In depth, there was a decline in EC value and NH₄⁺-N, P, K, Ca and Mg concentration. The comparison between the sand layer and the soil profile in both soils reported a similar trend in pH, EC, NO₃⁻-N, P and Mg concentration. Considering the mobility of macronutrients in a sandy mulched soil, it would be recommendable to develop a sustainable and dynamic fertigation management, adjusting nutrient inputs over time.

Keywords: ammonium; electrical conductivity; nitrate; organic matter content; pH; soil depth



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1. Introduction

Southern Spain is one of the most important areas of intensive horticultural crops in Europe, with 31,614 ha of greenhouses, in which Almeria represents around 86% of total greenhouses [1]. Agricultural practices such as the use of sand mulching soil and fertigation are common in this region [2]. Sand mulching soil has been used by local growers to develop favorable conditions for the maintenance of horticultural crop growth in semiarid conditions [3]. This system is composed by sand mulching and artificial soil profile, which can be classified as a cumelic Anthrosol [4]. A manure layer is placed between the sand and the artificial soil placed on the top of the original soil [5,6]. Mulches are used to cover

the surface of soil nearby crop plants to improve plant development. The positive effects of mulches in soil, such as evapotranspiration reduction and the improvement of the root system, have been reviewed recently in detail by several authors [7,8].

There are different factors which can affect the nutrients distribution in the soil profile such as fertigation, the organic matter content and sand mulching. The displacement of the nutritive elements will depend on the type of fertilizers used and its physico-chemical reactions with the soil [9]. In the case of nutrients such as nitrogen, there is a different trend if the nutrient is supplied via fertigation as NO_3^- or NH_4^+ , since NO_3^- is highly accumulated in the root zone due to their high solubility, whereas NH_4^+ is located near to the dripper [10,11]. Regarding P, this nutrient has a low mobility in the soil profile due to its low solubility and its trend to precipitate in soils with a basic pH [12]. Additionally, K, Mg and Ca have showed low mobility in the soil due to its fixation on the soil change complex [3,13]. However, the mobility of these nutrients (K, Mg, Ca and P) is increased via fertigation since they can be mobilized to the border of the wet bulb [9].

The organic matter has some effects in the soil such as the increase in the water holding capacity, higher cation exchange capacity (CEC), soil acidification and nutrients buffering, higher variability and retention of the nutrients and the solubility of many organic compounds [14]. After reviewing the previous literature, it can be observed that some authors have reported the influence of the organic matter on the modification of pH [15], and NO_3^- , K, Ca, Mg [16] and P [17] concentration in the distribution in the soil.

The use of the sand mulching soil system has positive effects on physicochemical properties of the soil compared to a bare soil since it increases the porosity and the water holding capacity [18], organic carbon and macro or micronutrient content [19] and reduces the losses of nutrients such as total N, phosphorus and total organic carbon [20]. Moreover, mulching may modify the spatial distribution of nutrients, leading to greater concentrations in the top layer [21].

Nevertheless, the information of the influence of the sand mulching in nutrients distribution is rather limited since these studies are mainly focused on the distribution of salinity [22]; therefore, in this experiment, we aimed to determine the spatial distribution and mobility of macronutrients in the wet bulb zone in two sand-mulched soils for green beans with a drip irrigation system under greenhouse conditions.

2. Materials and Methods

2.1. Site Description and Weather Conditions

This study was developed in the Agrarian Research and Training Institute in Almería (latitude: $36^\circ 47' 14''$ N and longitude: $02^\circ 42' 15''$ W). The testing crop was green bean (*Phaseolous vulgaris* L. c.v. Mantra RZ), lasting 90 days. The climatic parameters inside the greenhouse were determined with HOBO Sensors and wet bulb air temperature (HOBO U12 Onset Computer Corp., Bourne, MA, USA). During the experimental period, the maximum and minimum temperatures were 45 and 10 °C.

2.2. Treatments and Experimental Design

Two representative horticultural soils (S_1 and S_2) were selected, and they were superficially covered with the same type of sand. The soils are classified as Cumulic anthrosols and their properties are also listed in Table 1. Soil S_2 showed higher organic matter content (OM), cation exchange capacity (CEC), NO_3^- -N, Ca, silt, stoniness, and apparent density than soil S_1 . The supplies of N and K were based on the recommendations given by other researchers under the same conditions [6] (67 and 189 kg ha⁻¹ of N and K) which were supplied by fertigation with a trickle-feed irrigation system with a capacity of 3 L h⁻¹, independent for each soil type. The nutrient solution contained (in cmol·L⁻¹): 0.20 carbonates (CO_3^{2-}), 3.30 bicarbonates (HCO_3^-), 1.17 chloride (Cl^-), 3.80 sulphates (SO_4^{2-}), 1.87 nitrates (NO_3^-), 1.75 ammonium (NH_4^+), 3.72 potassium (K^+), 2.09 calcium (Ca^{2+}), 3.40 magnesium (Mg^{2+}), 1.03 sodium (Na^+), and EC and pH values of 0.92 dS m⁻¹ and 8.02, respectively. The fertilizers used for the supplies of N and K were NH_4NO_3 (33.5% N,

50% $\text{NH}_4^+\text{-N}$ and 50% $\text{NO}_3^-\text{-N}$) and K_2SO_4 (52% K_2O and 45% SO_3). Due to the higher level of P in both soils, there were no supplies of P during the experiment. Micronutrients were not applied to the soil during the experiment. The irrigation amount was established considering the ETc values and the frequency of the irrigation was established through a tensiometer (matricial potential of -20 KPa) at 0.15 and 0.30 m of depth. The total water volume applied during the experiment was 158 L m^{-2} (24 L m^{-2} in preplanting and 134 L m^{-2} during the cycle of the crop). The yield obtained for soils S_1 and S_2 were 2.47 ± 0.16 and $2.36 \pm 0.16 \text{ kg m}^{-2}$, without significant differences between them.

Table 1. Chemical and physical properties of the soil at the beginning of the experiment.

	Soil 1	Soil 2	
Chemical Soil Properties			
pH	8.11 ± 0.28	8.02 ± 0.33	ns
EC	1.30 ± 0.14	1.35 ± 0.11	ns
Organic matter content (%)	$1.00 \pm 0.08 \text{ b}$	$2.50 \pm 0.18 \text{ a}$	*
C.E.C (meq 100 g^{-1})	$9.80 \pm 0.88 \text{ b}$	$14.50 \pm 1.17 \text{ a}$	*
Nutrients (mg kg^{-1})			
$\text{NO}_3^-\text{-N}$	$6.40 \pm 0.49 \text{ b}$	$7.71 \pm 0.68 \text{ a}$	*
$\text{NH}_4^+\text{-N}$	3.70 ± 1.17	5.80 ± 1.24	ns
P	$118.50 \pm 12.15 \text{ a}$	$69.23 \pm 6.74 \text{ b}$	*
Ca	$2213.92 \pm 212.43 \text{ b}$	$3044.01 \pm 269.75 \text{ a}$	*
Mg	284.31 ± 46.48	379.30 ± 48.88	ns
K	$396.82 \pm 34.56 \text{ a}$	$289.33 \pm 24.67 \text{ b}$	*
Physical Soil properties			
Texture	loamy-sandy	loamy-sandy	
Particle size distribution (%)			
Sand	$73 \pm 5 \text{ a}$	$58 \pm 4 \text{ b}$	*
Silt	$12 \pm 1 \text{ b}$	$30 \pm 4 \text{ a}$	*
Clay	15 ± 1	13 ± 2	ns
Stoniness ($\text{g} \cdot \text{g}^{-1}$)	$0.30 \pm 0.04 \text{ b}$	$0.51 \pm 0.06 \text{ a}$	*
Apparent density ($\text{g} \cdot \text{cm}^{-3}$)	$1.52 \pm 0.08 \text{ b}$	$1.71 \pm 0.07 \text{ a}$	*

Different letters and * indicate significant differences at $p \leq 0.05$. ns: indicates non-significant differences.

2.3. Soil Sampling

To determine the spatial and temporal distribution of macronutrients in the sand mulching soil, four factors were considered: soil type (S_1 and S_2), time of sample (before planting without any previous fertigation and after crop harvest, 90 DAT) and spatial distribution: distance of the sample from the emitter (0.1, 0.2, 0.3 m) and depth (0–0.1 m, sand layer), 0.1–0.2, 0.2–0.3 and 0.3–0.4 m (soil profile) and their interactions (Figure 1). To reduce the physiochemical variability of the soils, each greenhouse was divided into three blocks. Each sample was constituted for 20 subsamples corresponding with 20 random points of soil which were mixed to achieve a representative soil sample per block.

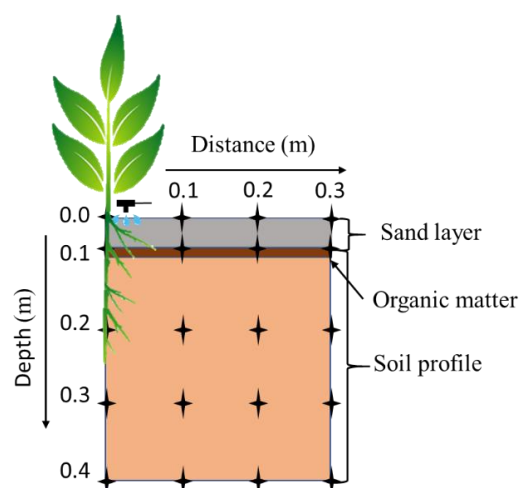


Figure 1. Sampling points.

2.4. Physical and Chemical Analysis

The soil samples were dried in a forced air oven (MEMMERT Model 800, Memmert GmbH, Schwabach, Germany) at 50 °C for 48 h. Then, soil samples were ground and sieved through a 2 mm screen. Soil particle size distribution (sand, silt, and clay content) was determined using the hydrometer method [23]. Soil pH and electrical conductivity (EC) were measured in a saturated extract with a pH-meter (MicroPH 2002 Crison; Crison Instruments, Barcelona, Spain) and conductivity meter (GLP31 Crison; Crison Instruments, Barcelona, Spain). Ammonium, K^+ , Ca^{2+} and Mg^{2+} were extracted with 1.0 N sodium acetate (pH 8.2). Ammonium was quantified by spectrophotometry at 630 nm according to the Baethgen and Alley [24] method. Potassium, Ca and Mg were analyzed by atomic absorption at 769, 422 and 285 nm, respectively [23]. Nitrate was extracted from soil with 1N $CuSO_4$ and was determined spectrophotometrically at 410 nm using reagent brucine [25]. Phosphorus was extracted from soil with 0.5 M $NaHCO_3$ and analyzed by colorimetric molybdenum blue method [26].

2.5. Statistical Analysis

Multifactor ANOVA tests were performed to identify the significant factors and their interactions. One test was for the sand layer (for $2 \times 2 \times 3$ factorial) and other for the soil profile (for a $2 \times 2 \times 3 \times 3$ factorial) and the last test to compare sand layer and soil profile parameters (for a 2×2 factorial) considering 4 complete blocks. If ANOVA was significant, least significant difference (LSD) tests ($p \leq 0.05$) were performed with Statgraphics Plus v. 5.1 (Statgraphics, Warrenton, VA, USA).

3. Results

Table 2 shows the values of the chemical parameters of the sand layer and the interactions between the factors studied (soil type, time of sampling and distance of the sample from the emitter).

The pH value and NH_4^+ -N concentration were similar in both soils, without changes for the time of sampling and the distance of the sample from the emitter.

Electrical conductivity (EC) was significantly higher in S_1 than S_2 . The EC showed an increase at the end of the crop and was affected by the distance, showing an increase at 0.3 m from the emitter in both soils.

Nitrate concentration was similar in both soil types. Nevertheless, there was an increase in NO_3^- -N concentration at the end of the crop and in the distance from the emitter in both soils.

The phosphorus concentration was only affected by the time of sampling, so at the end of crop cycle, the concentration decreased by 45% compared to the beginning of the crop cycle.

The potassium concentration was affected by the soil type, time of sampling and the distance of the sample from the emitter. The potassium concentration was higher in S_1 than S_2 and increased at the end of the experiment and also with the distance of the sample from the emitter.

The calcium concentration was neither affected by the soil type nor the distance of the sample from the emitter. Nevertheless, the calcium concentration showed an increase of 9% at the end of the crop in both soils.

The magnesium concentration only showed differences in the distance of the sample from the emitter, being higher at 0.2–0.3 m in both soils. There were no significant interactions between the factors studied for these chemical parameters.

Table 3 shows the values of the chemical parameters of the soil profile and the interaction between the factors studied (soil type, time of sampling, distance of the emitter and depth sample).

Table 2. Chemical parameters of sand layer (0–0.1 m) depending on the studied factors: (A) soil type, (B) T. sampling (time of sampling) and (C) distance from the emitter and their interactions. EC and nutrients concentration are expressed in dS m^{-1} and mg kg^{-1} , respectively.

Factor		pH	EC	$\text{NH}_4^+\text{-N}$	$\text{NO}_3^-\text{-N}$	P	K	Ca	Mg
Soil Type		ns	*	ns	ns	ns	*	ns	ns
	S ₁	7.51 ± 0.18	4.30 ± 0.37 a	6.79 ± 0.55	18.12 ± 1.48	26.38 ± 2.51	181.90 ± 42.25 a	1455.63 ± 100.54	56.22 ± 9.26
T. sampling	S ₂	7.56 ± 0.19	3.41 ± 0.44 b	6.68 ± 0.40	15.94 ± 1.05	27.12 ± 2.12	108.54 ± 38.78 b	1512.78 ± 173.36	56.91 ± 7.72
		ns	*	ns	*	*	*	*	ns
Distance	Initial	7.63 ± 0.17	2.24 ± 0.15 b	6.82 ± 0.47	15.25 ± 1.17 b	34.74 ± 4.56 a	95.63 ± 15.69 b	1419.24 ± 57.62 b	55.74 ± 7.36
	Final	7.44 ± 0.14	5.47 ± 0.35 a	6.61 ± 0.37	18.84 ± 1.22 a	18.78 ± 5.65 b	194.71 ± 19.12 a	1549.20 ± 61.24 a	57.33 ± 6.54
Interaction	0.1	ns	*	ns	*	ns	*	ns	*
	0.2	7.64 ± 0.25	3.33 ± 0.25 b	7.03 ± 0.38	13.73 ± 2.17 b	23.23 ± 3.64	117.46 ± 15.74 b	1487.25 ± 184.65	41.90 ± 7.36 b
	0.3	7.49 ± 0.17	3.74 ± 0.28 b	6.77 ± 0.24	18.21 ± 1.85 a	25.28 ± 2.64	154.87 ± 21.36 a	1523.64 ± 151.46	66.54 ± 5.67 a
	Soil Type × T. sampling	7.47 ± 0.11	4.52 ± 0.39 a	6.50 ± 0.44	19.19 ± 1.59 a	26.60 ± 3.51	163.12 ± 18.54 a	1441.63 ± 118.69	61.19 ± 7.48 a
	Soil Type × Distance	ns	ns	ns	ns	ns	ns	ns	ns
	T. sampling × Distance	ns	ns	ns	ns	ns	ns	ns	ns

Different letters and * indicate significant differences at $p \leq 0.05$. ns: indicates non-significant differences.

Table 3. Chemical parameters of soil profile depending on the studied factors: (A) soil type, (B) T. sampling (time of sampling), (C) distance from the emitter, (D) depth and their interactions. EC and nutrients concentration are expressed in dS m^{-1} and mg kg^{-1} , respectively.

Factor		pH	EC	$\text{NH}_4^+\text{-N}$	$\text{NO}_3^-\text{-N}$	P	K	Ca	Mg
Soil Type		ns	*	*	*	*	*	*	*
	S ₁	8.11 ± 0.30	1.04 ± 0.03 b	8.81 ± 0.72 a	14.05 ± 2.02 b	68.43 ± 9.73 b	220.16 ± 9.21 b	1453.61 ± 101.13 b	249.83 ± 11.98 b
	S ₂	8.12 ± 0.22	1.24 ± 0.03 a	7.31 ± 0.62 b	27.62 ± 3.08 a	106.22 ± 11.54 a	254.64 ± 10.23 a	1911.84 ± 117.54 a	318.42 ± 17.35 a
T. sampling		ns	*	*	*	*	ns	*	ns
	Initial	8.12 ± 0.17	1.02 ± 0.03 b	8.52 ± 0.36 a	23.03 ± 1.15 a	100.14 ± 9.31 a	235.53 ± 17.59	1725.36 ± 16.42 a	268.66 ± 25.64
Distance	Final	8.03 ± 0.31	1.23 ± 0.03 a	7.53 ± 0.29 b	18.61 ± 1.36 b	74.31 ± 7.36 b	240.27 ± 22.35	1640.24 ± 20.45 b	299.62 ± 32.67
		ns	*	ns	*	*	*	ns	ns
Depth	0.1	8.13 ± 0.24	1.04 ± 0.14 b	7.82 ± 1.02	18.87 ± 3.15 b	74.23 ± 2.84 c	207.22 ± 28.94 b	1700.33 ± 50.35	290.71 ± 21.36
	0.2	8.02 ± 0.28	1.12 ± 0.09 b	7.92 ± 0.98	18.81 ± 2.94 b	85.94 ± 3.64 b	208.03 ± 28.65 b	1648.19 ± 65.65	267.14 ± 33.98
	0.3	8.10 ± 0.24	1.31 ± 0.08 a	8.21 ± 1.10	24.92 ± 2.55 a	102.26 ± 4.17 a	301.02 ± 30.65 a	1710.33 ± 49.36	288.16 ± 41.36
Interaction	(0.1–0.2)	ns	ns	*	ns	*	*	*	*
	(0.2–0.3)	8.10 ± 0.30	1.15 ± 0.07 a	8.77 ± 0.35 a	22.34 ± 3.25	100.82 ± 5.65 a	265.64 ± 22.65 a	1755.92 ± 54.35 a	319.87 ± 17.36 a
	(0.3–0.4)	8.11 ± 0.24	1.17 ± 0.06 a	8.12 ± 0.28 b	21.22 ± 3.21	89.01 ± 6.47 b	233.92 ± 19.24 ab	1694.85 ± 47.36 a	276.42 ± 13.74 b
	Soil type × T. sampling	8.13 ± 0.22	1.01 ± 0.06 b	7.45 ± 0.34 c	18.91 ± 2.99	71.86 ± 7.64 c	212.65 ± 21.21 b	1597.56 ± 39.41 b	255.13 ± 11.68 b
	Soil type × Distance	ns	ns	*	ns	ns	ns	ns	*
	Soil type × Depth	ns	ns	ns	ns	ns	*	ns	ns
	T. sampling × Distance	ns	ns	ns	*	ns	ns	ns	ns
	T. sampling × Depth	ns	ns	ns	ns	ns	ns	ns	ns
	Distance × Depth	ns	ns	ns	ns	ns	ns	ns	ns

Different letters and * indicate significant differences at $p \leq 0.05$. ns: indicates non-significant differences.

The pH value was not affected by soil type, time of sampling, distance of the sample from the emitter and depth sample.

Electrical conductivity was significantly higher in soil S₂ than S₁, showing an opposite trend than the sand layer. The EC values increased significantly at the end of the crop in both soils, as happens in the sand layer. The EC values were also affected by the distance and depth sample, showing an increase at 0.3 m from the emitter of the plant as it happens in the sand layer, and a decrease at a depth of 0.3–0.4 m.

The ammonium concentration was affected by the soil type, time of sampling and depth, showing an interaction between soil type and time of sampling. The NH₄⁺-N concentration was lower in soil S₂. Nevertheless, at the end of the crop cycle, it showed similar concentrations (Figure 2). In addition, there was a decrease in NH₄⁺-N concentration with the depth sample in both soils.

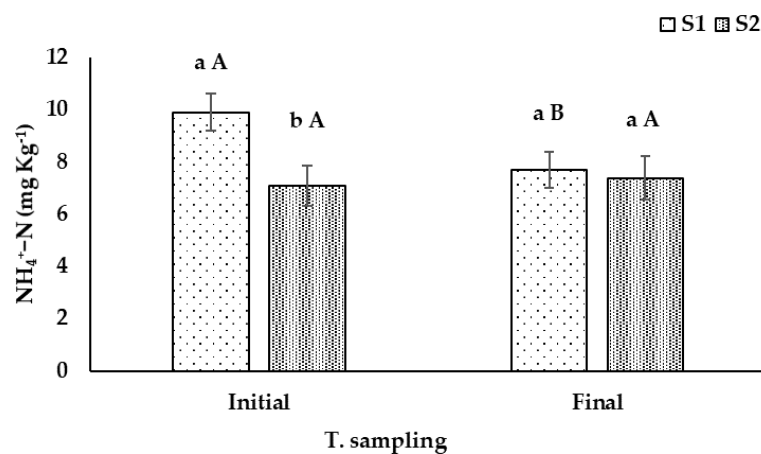


Figure 2. Interaction between time of sampling (initial and final) and soil type (soils S₁ and S₂) for soil NH₄⁺-N concentration (mg kg⁻¹). Lowercase letters are used for the comparison between soil type in each time of sampling and uppercase letters are used for the comparison between time of sampling for each soil type.

The nitrate concentration was affected by the soil type, time of sampling and the distance of the sample from the emitter. The NO₃⁻-N concentration showed the highest value in soil S₂. In the interaction between the time of sampling and distance of the sample from the emitter (Figure 3), there was a remarkable increase in NO₃⁻-N concentration at the beginning of the crop at 0.3 m from the emitter, whereas at the end of the experiment, there were no significant differences. These effects were similar compared to the effects reported in the sand layer.

The phosphorus concentration was affected by the soil type, time of sampling, distance of the sample from the emitter of the plant and depth sample. The soil S₁ showed the lowest P concentration with a mean value of 68.4 mg kg⁻¹. At the end of the crop cycle, the P concentration decreased compared to the initial values in both soils. In addition, there was an increase in P concentration with the distance of the sample from the emitter and a decrease with the depth sample in both soils.

The potassium concentration was also affected by the soil type, distance of the sample from the emitter and depth sample. The opposite trend was observed in the sand layer, where the K concentration was higher in soil S₂ than S₁. There were two interactions between factors: soil type and distance of the sample from the emitter and soil type and depth sample (Figure 4a,b). The potassium concentration was similar in distance of the sample from the emitter and depth sample in soil S₁. Nevertheless, the K concentration increased with the distance of the sample from the emitter and decreased in depth in soil S₂.

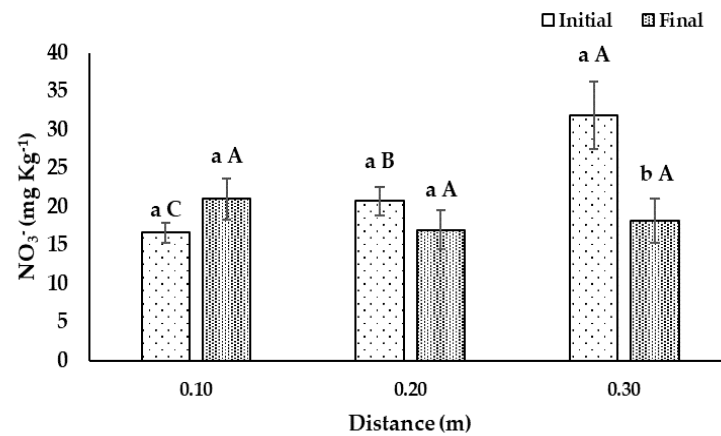


Figure 3. Interaction between distance from the emitter (0.10, 0.20 and 0.30 m) and time of sampling (T. sampling) (initial and final) for soil NO₃⁻-N concentration (mg kg⁻¹). Lowercase letters are used for the comparison between the time of sampling in each distance from the emitter and uppercase letters are used for the comparison between each time of sampling and distance from the emitter.

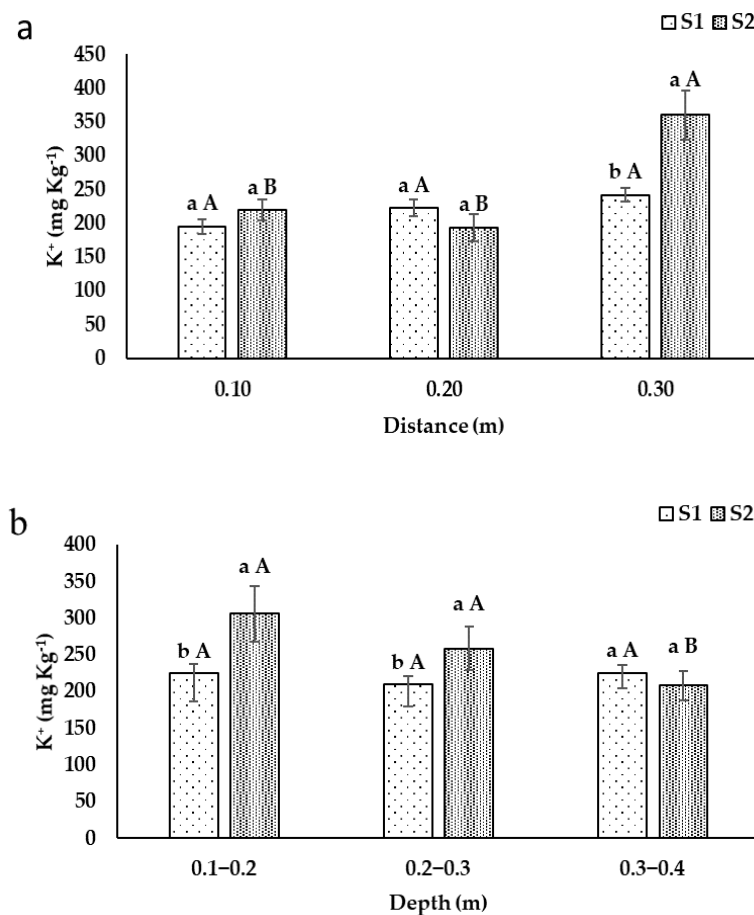


Figure 4. Interaction between distance (0.10, 0.20 and 0.30 m) and soil type (soils S₁ and S₂) (a) and depth (0.1–0.2, 0.2–0.3 and 0.3–0.4 m) and soil type (soils S₁ and S₂) (b) for soil K concentration (mg kg⁻¹). (a) Lowercase letters are used for the comparison between the soil type in each distance from the emitter and uppercase letters are used for the comparison between each type of soil and distance from the emitter, (b) lowercase letters are used for the comparison between the soil type in each depth and uppercase letters are used for the comparison between each type of soil and depth.

The calcium concentration was affected by the soil type, time of sampling and depth sample. The Ca concentration was higher in soil S₂ than S₁. The calcium concentration also decreased at the end of the crop cycle compared to the initial values in both soils. There was an interaction between soil type and depth sample, showing the soil S₂ with the highest concentration but decreasing with the depth, whereas, S₁ was similar at different depths (Figure 5).

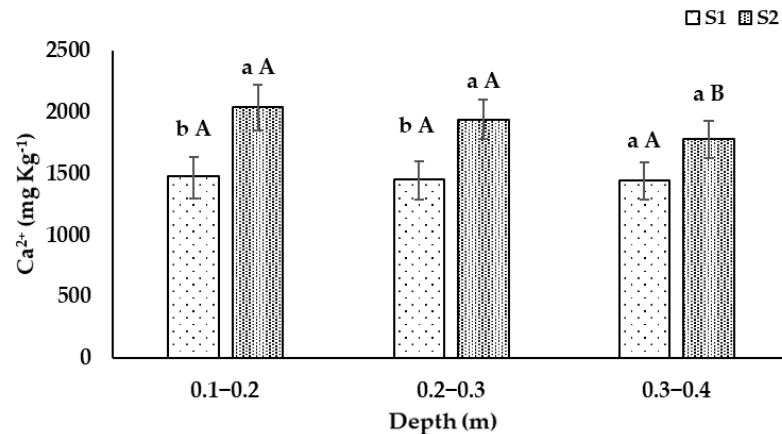


Figure 5. Interaction between depth (0.1–0.2, 0.2–0.3 and 0.3–0.4 m) and soil type (soils S₁ and S₂) for soil Ca concentration (mg kg⁻¹). Lowercase letters are used for the comparison between the soil type in each depth and uppercase letters are used for the comparison between each type of soil and depth.

The magnesium concentration was affected by the soil type, time of sampling and depth sample. There was an interaction between soil type and time of sampling, with the soil S₂ showing the highest concentration and increasing at the end of the cycle crop (Figure 6). In depth, the magnesium concentration decreased in both soils.

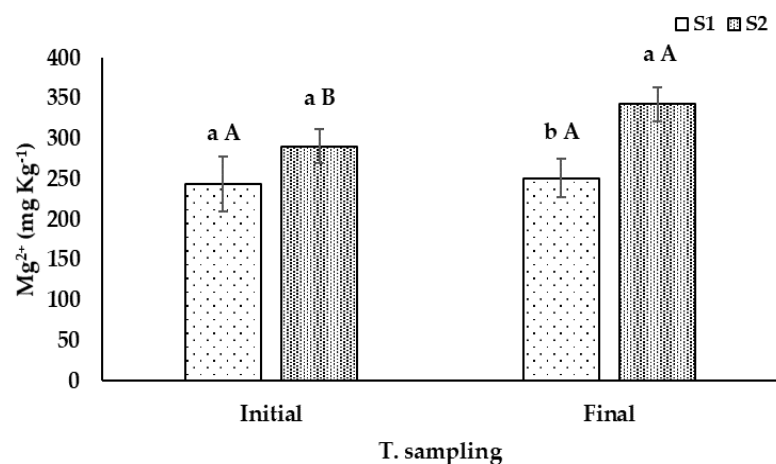


Figure 6. Interaction between time of sampling (T. sampling) (initial and final) and soil type (soils S₁ and S₂) for soil Mg concentration (mg kg⁻¹). Lowercase letters are used for the comparison between soil type in each time of sampling and uppercase letters are used for the comparison between time of sampling for each soil type.

The comparison between the sand layer and soil profile at the beginning and the end of the crop in both soils was shown in Table 4. In the soil S₁, the pH values, P and Mg concentrations were lower in the sand layer at the beginning and at the end of the crop. Contrary to the other parameters, EC values and NO₃⁻-N concentration showed the highest value in the sand layer in both periods of time compared to the soil profile.

Additionally, NH_4^+ -N and Ca showed the greatest concentration in the soil profile at the beginning of the crop, but at the end of the crop, the greatest concentration was found in the sand layer. The K concentration was higher in the soil profile at the beginning of the crop, but at the end of the crop, the sand layer and the soil profile had similar concentration.

Table 4. Comparison between the sand layer and the soil profile at the beginning and at the end of the crop in both soils. EC and nutrients concentration are expressed in dS m^{-1} and mg kg^{-1} , respectively. Soil profile determinations are the average of the determinations at the different depths recorded.

Parameter	T. of Sampling	S_1			S_2		
		Sand	Soil Profile		Sand	Soil Profile	
pH	Initial	7.54 ± 0.12 b	8.13 ± 0.14 a	*	7.67 ± 0.12 b	8.13 ± 0.15 a	*
	Final	7.34 ± 0.11 b	7.87 ± 0.12 a	*	7.48 ± 0.13 b	8.08 ± 0.13 a	*
EC	Initial	2.47 ± 0.23 a	0.94 ± 0.13 b	*	1.76 ± 0.24 a	1.10 ± 0.12 b	*
	Final	5.90 ± 0.54 a	1.13 ± 0.14 b	*	5.12 ± 0.55 a	1.22 ± 0.14 b	*
NH_4^+ -N	Initial	6.24 ± 0.45 b	7.67 ± 0.5 a	*	6.91 ± 0.56 a	5.43 ± 0.47 b	*
	Final	6.33 ± 0.36 a	5.40 ± 0.34 b	*	6.60 ± 0.50 a	5.55 ± 0.43 b	*
NO_3^- -N	Initial	16.38 ± 1.12 a	3.81 ± 0.49 b	*	14.24 ± 1.19 a	6.34 ± 0.72 b	*
	Final	20.14 ± 1.16 a	2.28 ± 0.23 b	*	17.39 ± 1.44 a	6.05 ± 0.63 b	*
P	Initial	32.22 ± 2.48 b	120.04 ± 9.16 a	*	37.18 ± 2.58 b	80.04 ± 6.46 a	*
	Final	21.76 ± 2.11 b	92.75 ± 8.37 a	*	15.63 ± 1.33 b	56.84 ± 5.39 a	*
K	Initial	118.85 ± 11.78 b	212.94 ± 20.15 a	*	75.74 ± 6.75 b	260.28 ± 21.58 a	*
	Final	248.13 ± 21.49	226.83 ± 23.76	ns	141.08 ± 12.46 b	254.21 ± 21.46 a	*
Ca	Initial	1378.65 ± 48.16 b	1508.3 ± 42.37 a	*	1459.72 ± 43.50 b	1957.43 ± 42.15 a	*
	Final	1532.46 ± 44.37 a	1403.56 ± 41.84 b	*	1568.94 ± 55.17 b	1875.62 ± 58.64 a	*
Mg	Initial	43.29 ± 4.15 b	244.02 ± 19.53 a	*	68.13 ± 8.49 b	290.64 ± 18.33 a	*
	Final	63.71 ± 6.16 b	250.94 ± 23.18 a	*	44.34 ± 4.18 b	343.04 ± 28.72 a	*

Different letters and * indicate significant differences at $p \leq 0.05$. ns: indicates non-significant differences. Different times were analyzed independently.

In the comparison between the sand layer and soil profile in the soil S_2 , the pH values, P, K, Ca and Mg concentrations were lower in the sand layer at the beginning and at the end of the crop. Contrary to the other parameters, EC values and NH_4^+ -N and NO_3^- -N concentration showed the highest value in the sand layer in both periods of time compared to the soil profile.

4. Discussion

In our experiment, the pH was stable during the crop cycle both in sand layer and soil profile. These results could be due to the buffer soil properties [27], especially in limestone soils [28]. A similar trend was found by Lao et al. [29] in a tomato crop grown in gravel–sand mulching soil. The lowest values found in sand layer could be ascribed to the low buffering capacity of the sand and the chemical characteristics of the sand [30].

The higher values of EC in sand layer compared to the soil profile in our experiment can be ascribed to the retention of salts by sand in the evaporation process [31], which depends on the abrupt changes in pore size (sand and sandy loam layers) that affect water movement by capillary action. The increase in EC in depth in the soil profile at the end of the crop can be related to the accumulation of the salts coming from the mineralization process of organic matter content [32] and the nutrient leachates from fertilizer supplies by fertigation during the crop [33]. The increase in the EC values with the distance in the sand layer and soil profile could be related with the pushing of the salts by the water to the fringes of the humid bulb, forming a desalinization zone in the center near to the drip [34]. A similar trend was reported by Wang et al. [35] in a strawberry crop, where the highest EC value was found at the greatest distance from the plant (0.3 m).

The results obtained in our experiment with a similar concentration of NH_4^+ -N in time sampling in the sand layer may suggest that nitrification rates were equal to ammonification rates and that most NH_4^+ was converted to NO_3^- . Contrary to this trend, the soil profile S_1

showed a decrease in $\text{NH}_4^+\text{-N}$ concentration at the end of the crop which can be related to the better condition of the nitrification process or to the consumption of the element by the plant [10]. The constant concentration of $\text{NH}_4^+\text{-N}$ without changes in distance can be ascribed to the lateral movement of the water and the uniform distribution of the nutrient solution [36], since a sandy mulching soil develops a wet strip due to the physical characteristics of the sand layer [22] and the use of a drip system irrigation (drip 3 L h^{-1} and distance of 0.5 m). Additionally, the wet strip can develop saturation conditions and therefore anaerobic conditions, thus reducing the ammonium nitrification process [10]. On the other hand, Badr et al. [37] found the highest concentration of $\text{NH}_4^+\text{-N}$ near the drip (4 L h^{-1} and distance of 0.4 m) and a decrease with the distance in a bare soil. The decrease in the $\text{NH}_4^+\text{-N}$ concentration in depth in our experiment can be due to the enrichment of the superficial layer by organic matter mineralization [32] and its retention by exchange cationic capacity [14].

In our experiment, we found that the NO_3^-N concentration in soil S_2 was higher than soil S_1 . A similar trend has been found in the other elements studied and this fact can be associated to the higher release of nutrients in the soil with a high organic matter content as reported by Thomas et al. [15]. The highest concentration of NO_3^-N in the sand compared to the soil layers in the time of sampling can be due to the retention of this nutrient by the sand in the evaporation process, as occurred in EC. The distribution in distance in the sand and soil showed the highest concentration at 0.30 m. The same lateral mobility was found by Chaverria et al. [38] in a soil profile. This distribution was most frequently found at the beginning of the experiment due to the pre-plant irrigation that was held to washes of salts, which is a common practice between the farmers [39]. However, it is important to mention that under fertigation, at the end of the experimental period, the distribution of the NO_3^-N concentration in soil depth was homogeneous, which can be due to NO_3^-N mobility and the appropriate supplies of water [40] and nutrients [41] considering the nutritional requirements of the crop for these conditions in order to avoid their lixiviation.

It is necessary to point out that there were no supplies of P during the experimental period due to the higher level of P in the soil. The lowest concentration of P was found in the sand in both soils and this can be ascribed to the lower capacity of nutrient retention of the sand [14] and the precipitation of this nutrient in the soil layers due to the highest pH values found [42]. The decrease in P during the crop cycle can be due to the uptake of this element by plants, from soil reserves, which ranges from 6.7 to 9.3 kg ha^{-1} considering the recommendations given by other researchers [43]. The higher concentration of P at 0.3 m from the emitter and in superficial layers, can be due to the higher uptake of this element near to the plant in distance and also in depth, where the highest density of roots is found, being in line with the results reported by Martínez [44] who noted a higher root development in green beans in the first 0.2 m of the soil profile in a sandy mulching soil. Moreover, it can be pointed out that the mobility of P in distance using fertigation is higher especially for sandy soils and fine-textured clay loams [45]. This enhancement in mobility could be attributed to the movement of P with irrigation water after the saturation of the reaction sites near the zone of P supply. In contrast, some authors found that most of the P applied may be turned to non-soluble form in a short time after its application and the concentrations building up near the water source could affect root growth and create unfavorable conditions for P uptake [37].

The lowest concentration of K was found in the sand layer in both soils. The K concentration showed a similar trend as P when the sand layer was compared with the soil profile and this trend can be due to the fixation of this element in the soil and the lower capacity of nutrient retention of the sand [14]. The decrease in K during the crop cycle can be also due to the uptake of this element by plants, from soil reserves, which ranges from 62.7 to 84.4 kg ha^{-1} considering the recommendations given by other researchers [43]. In our experiment, a lateral movement was observed in K, showing the highest concentration at the highest distance of the dripper. The same distribution for K in this experiment was reported by Chaverria et al. [38] and Neilsen et al. [46] who proposed that when the

concentration of K in the soil is very high (close to saturation), low and continuous deposits of this element bring about a displacement of this cation to the fringes of the humid bulb. This tendency was more pronounced in soil S₂ than S₁ and this can be due to its higher CEC. The lower concentration of K in the sand layer compared to the soil profile can be ascribed to the low capacity of retention of the sand and the fixation of the elements in the soil [14].

In the sand layer, Ca and Mg presented a homogenous distribution as NH₄⁺-N and also these elements were homogenous in the soil profile considering the distance. Additionally, the constant concentration of Ca and Mg could be due to the lateral movement of the water and the uniform distribution of the nutrient solution [36] in the sand layer as it was explained in NH₄⁺-N. Different results were reported by Chaverriá et al. [38] who noted the highest concentration of Ca and Mg at 0.3 m from the emitter due to the high mobility of these elements. The highest concentration in the superficial layer of the soil profile for K, Ca and Mg can be due to the illuviation layer of materials coming from mineralization of organic layer, where these elements were fixed [14] and also due to the greater decomposition of soil organic matter and crop residues releasing inorganic nutrients and contributing to the accumulation at 0.1–0.2 m [32]. Nevertheless, it is important to highlight that, in the case of K and Ca, this only happened in the soil S₂, suggesting that the highest organic matter concentration can be associated to this fact.

Besides to the explanations already given, it is necessary to point out that the differences in nutrient concentrations may have also been affected by differences in root growth and plant uptake between the two soils.

5. Conclusions

According with these results, it is concluded that green bean cultivated in sand mulching soil under fertigation showed an accumulation of NO₃⁻-N, K, and Ca concentration at the end of the crop in the sand layer in both soils, and also increased EC, showing the highest value on the periphery of the bulb at 0.30 m. Related to the soil profile, the soil S₂ with higher organic matter content increased all nutrients except NH₄⁺-N. Nevertheless, along the crop, there was a significant decrease in NO₃⁻-N, P and Ca concentration and a significant increase in EC value and Mg concentration. It is necessary to highlight, according to the spatial distribution, that EC and K showed the highest concentration on the periphery of the bulb at 0.30 m and there was a decrease in EC value and NH₄⁺-N, P, K, Ca and Mg concentration in depth. Comparing the sand layer and the soil profile in both soils, the results obtained reported a similar trend in pH, EC, NO₃⁻-N, P and Mg concentration. These results show the heterogeneity and mobility of nutrients in a soil, highlighting the importance of an adequate sampling to make a sustainable and dynamic fertigation management.

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