Agro-ecological validation of an organic fertigation protocol in vulnerable areas to nitrate contamination

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INTRODUCTION

The inefficient use of fertilizers has caused diffuse-source pollution of surface and groundwater bodies, which is considered as one of the main challenges by the EU in its environmental and agricultural policies. In the Region of Murcia (Spain), the agricultural activity is the main economic sector, and the irrigated agriculture is a key agent in food production (fruit and vegetables) at European level. Therefore, should be priority to achieve an agriculture compatible with the environment and that it remains economically viable, issue that could be resolved through investment in technological modernization, in a practical and efficient way, and different crop managements.

AIMS

Evaluate the impact of the application of a fertigation protocol with **natural origin fertilizers** on a lettuce cultivation cycle by measuring of physiological parameters, soil physical-chemical and microbiological characteristics, crop yield and quality and of the N use efficiency, without there being applications of synthetic inorganic fertilizers.

DEVELOPMENT OF RESEARCH (M&M)

The experimental plot was located in zone 1 of the Mar Menor environment (Murcia, Spain)

Lettuce ***(Lactuca sativa var. capitate)***

Experimental plot and vegetal material

Irrigation strategy

Fully irrigation (FI, 100% ET_c)

Fertilization protocol: 29.8-8.1-29.3 UF/ha of N-P-K, plus 15.5 UF/Ha of Aa.

Experimental design:

Staggered planting frame 0.24 x 0.24 m

3 standard replicates at random.

Measurements (throughout the vegetative cycle)

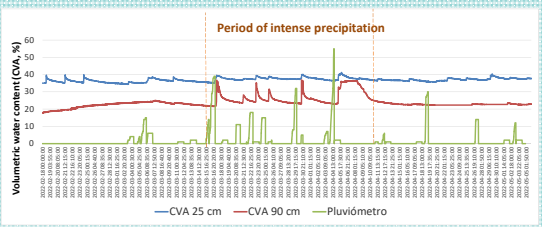
- ✓ Soil volumetric water content sensors at two depths (25 and 90 cm) (A, B)
- ✓ Gas exchange (g_s, $(mol \cdot m^{-2} \cdot s^{-1})$ (C)
- ✓ Leaf nutritional status (D)
- ✓ Soil quality (E)
- ✓ Yield and Harvest quality (F)
- ✓ N15 stable isotope (G)

by Romero-Trigueros et al. (2017, 2021a,,b)

RESULTS

1. SOIL VOLUMETRIC WATER CONTENT SENSORS

The sensor installed at a depth of 25 cm in the soil detected all precipitation and fertigation episodes during the crop cycle and its volumetric water content (CVA, %) was between 34.4 and 41.2%. On the contrary, the sensor installed at a depth of 90 cm did not detect such events (rain or irrigation), except during heavy precipitation perceived between approximately March 15 and April 8, 2022, showing values that fluctuated between 17.8 and 49.3% (Figure 1).



Therefore, it can be concluded that the fertigation schedule carried out during the trial did not lead to significant drainage events and leaching of salts and nutrients. However, the heavy episodes of rainfall that occurred did give rise to the washing and leaching of salts and nutrients to deeper layers (of 90 cm), thus demonstrating the sensitivity, robustness and usefulness of installing humidity sensors at the two depths tested.

Figure 1*. Volumetric water content in soil at two depths during the crop cycle.*

2. EDAPHOLOGICAL ASSESSMENT

2.1 PHYSICAL-CHEMICAL QUALITY OF THE SOIL (Figure 2):

At the end of the trial, the fertigation protocol resulted in a reduction in EC at all depths, although it was only significant at 60 cm (42.9%), compared to the EC at these depths at the start of the trial. This reduction was mainly due to the rainfall that occurred during the test (Figure 2).

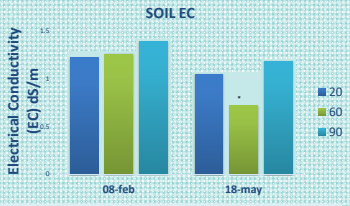


Figure 2*. Electrical conductivity (EC) of the soil at different depths (20, 60 and 90 cm) at the beginning (08.02.2022) and at the end (18.05.2022) of the test.*

2.2 MACRO AND MICRO-ELEMENTS. N, C, C/N, C_{org}, MOT AND LIMESTONE:

After the crop cycle (Table 1), the fertigation protocol significantly reduced the levels of C_{org} and MOT by approximately 24-25%, but only in the most superficial layer. However, it is noteworthy that all values, both at the beginning and at the end of the test, are considered normal.

Regarding the C/N ratio, the fertigation protocol significantly decreased its value after the crop cycle because the C_{total} content was reduced to a greater degree than that of N_{total} (the decrease in the latter was not statistically significant).

Total limestone values were not significantly affected by the fertigation protocol.

Table 1*. Values of total N (N_{total}), total C (C_{total}), C/N ratio, organic carbon (C_{org}), organic matter (MOT) and calcium carbonate ($CaCO_3$) of the soil at depths for the treatment at the beginning (Beg) and end (End) of the trial. *indicate significant differences among time for the same depth and parameter p<0.05.*

		Soil Depth		
		20 cm	60 cm	90 cm
N_{total} (%)	Beg	0.11±0.01	0.06±0.00	0.05±0.00
	End	0.10±0.00	0.07±0.00	0.06±0.01
C_{total} (%)	Beg	7.2±0.1*	7.0±0.1	6.9±0.1
	End	6.7±0.2	6.6±0.2	6.7±0.1
C/N	Beg	11.3±0.5*	13.2±0.9	12.4±0.3
	End	9.4±0.5	9.2±0.3	10.4±1.7
C_{org} (%)	Beg	1.2±0.0*	0.8±0.0	0.6±0.0
	End	0.9±0.0	0.7±0.0	0.6±0.0
MOT (%)	Beg	2.1±0.1*	1.4±0.0	1.1±0.0
	End	1.6±0.0	1.1±0.1	1.1±0.1
$CaCO_3$ (%)	Beg	50.0±0.5	51.1±0.8	52.2±1.1
	End	48.4±1.4	49.3±1.6	50.5±0.5

After the growing cycle, **reductions in the content of NO_3^- (52, 55 and 68% at 20, 60 and 90 cm, respectively) (Figure 3) and PO_4^{-3} (100% at 20 cm)** were observed:

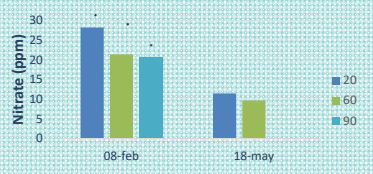
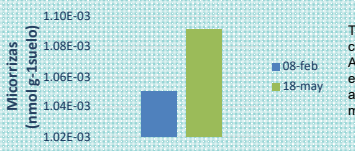


Figure 3*. Nitrate content (NO_3^-) at different soil depths for the treatment. *indicate significant differences between times at different depths (p<0.001).*

2.3 SOIL BIOLOGICAL QUALITY



The fertigation protocol decreased, although within the range considered normal, the levels of bacteria (Gram+, Gram-, Actinobacteria), fungi, saturated acids and the activity of the enzymes beta-glucosidase, phosphatase and dehydrogenase, and increased the G+/Gram- and Fungus/Bacteria ratios and mycorrhizae (Figure 4).

Figure 4*. Content in Mycorrhizae at the beginning (08.02.2022) and at the end (18.05.2022) of the test.*

3. WATER AND NUTRITIONAL STATUS

Both gas exchange (net photosynthesis and stomatal conductance) and leaf nutritional status (macro and microelements and phytotoxics), measured weekly throughout the vegetative cycle, were considered normal, with adequate physiological activity and water status. Likewise, plants reached the vegetative stage of maturation satisfactorily (sampling on 03/05/2022).

4. YIELD QUALITY AND TOTAL PRODUCTION

Table 2*. Quality parameters of lettuce plants.*

Fresh weight head (g)	544.84±135.10
Dry weight (g)	13.36±3.24
Relative water content head (%)	97.53±0.27
Perimeter head (cm)	44.50±2.84
Fresh weight root (g)	22.73±4.72
Dry weight root (g)	5.26±0.81
Relative water content root (%)	76.30±3.98
Total plant weight (g)	956.94±117.01
Yield (Kg/ha)	**29,277.3**

Table 3*. Maturity Indicators of lettuce plants.*

Groyne length (GL, cm)	4.4±0.5
Lettuce length (LL, cm)	13.8±0.7
Ratio GL/LL	0.3±0.0
Groyne width (mm)	35.6±2.1
Lettuce width (mm)	13.1±1.0
Compactness	3

All the plants had the values of the aforementioned parameters and indicators (Table 2 and 3) within the optimal ranges. Besides, the total production (kg/ha) and the caliber of the lettuce were considered acceptable.

Moreover, **the Regulation (EU) 1258/2011**, that modifies the Regulation (CE) 1881/2006 *regarding the maximum content of nitrates in food products*, indicates that the maximum permitted content of nitrates (determined in fresh weight) in iceberg-type lettuce grown in at free air is 2000 ppm. In this case, **the NO_3^- average value of plants was 125,8 ppm, fully complying with this regulation**.

5. NITROGEN USE EFFICIENCY (NUE) AND NITROGEN BALANCE

Fractionation of N15 in plant was lower than that of soil and water, indicating a good degree of NUE in this agricultural system, since the lower the level of δ15N in the plant with respect to the soil, the more efficient is the system (Romero-Trigueros et al., 2014) (Table 4).

Table 4*. Enrichment in δ N15 (‰) in the irrigation water, in the soil at depths of 20, 60 and 90 cm at the beginning (Beg) and end (End) of the trial, and in the head of lettuce harvested (07/05/2022).*

		Beg	End
$\delta N15_{irrigation\ water}$		11.1±0.3	10.1±0.2
$\delta N15_{soil}$	20 cm	7.17±0.02	7.19±0.01
	60 cm	7.30±0.03	7.16±0.02
	90 cm	7.57±0.04	6.98±0.01
$\delta N15_{plant}$		-	5.06±1.34

- ✓ The application of this fertigation protocol gave rise to an **extraction of N from the soil by the crop of 21.9 kgN/ha** in a crop cycle of 3 months, (taking into account the total production and the amount of assimilation of total N of the harvest).
- ✓ The application of this fertigation protocol (without products containing N-NO_3^-) gave rise to an **extraction of NO_3^- from the soil (residual or from irrigation water) by the crop of 3.7 kgNO_3^-/ha** in 3 months (taking into account the total production and the amount of assimilation of NO_3^- of the harvest).

DISCUSSION and CONCLUSION

The fertigation protocol complies with the legislative framework in force (Decree Law 5/2021), and with the precautionary measures imposed by CHS (Segura Hydrographic Confederation), since it does not exceed the maximum number of N fertilizer units per ha allowed. In addition, i) it did not give rise to leaching and drainage processes that would lead to the contamination by nitrates of agricultural origin of the groundwater bodies, ii) it maintained the physical-chemical and biological quality of the soil in good agro-environmental conditions and iii) it obtained a harvest with an economically profitable production and quality. Thus, the ecological cultivation of lettuce in zone 1 of the Mar Menor, already close to 1,500 m, is considered viable from the agronomic, economic and environmental point of view.

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