Performance of the NPK sensor in 'CascadeReUse Systems' and guidelines for best management practices

Deliverable D5.3

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List of abbreviations

AGRINUPES	Integrated monitoring and control of water, nutrients and plant protection products towards a sustainable agricultural sector
BMP	Best Management Practices
CRUS	CascadeReUse System
EC	Electrical Conductivity
NPK	Nitrogen (N), phosphorus (P) and potassium (K)
PPP	Plant Protection Products
WP	Work Package

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Summary

This report encloses the performance assessment of the optical NPK sensor – for determination of nitrogen (N), phosphorus (P) and potassium (K) in aqueous solutions – developed in the framework of the AGRINUPES Project and presents guidelines for its implementation in horticultural production systems in which a semi-open irrigation system is applied (so-called Cascade ReUse Systems, 'CRUS'). This sensor allows the monitoring of those main plant macronutrient in nutrient/drainage solutions utilized in cultivation, despite its development is still ongoing for final adjustments. After laboratory and semi-practical testing and validation, here we present the results from testing under field conditions in two demonstration events that were conducted in Portuguese commercial CRUS, where the NPK sensor was presented to the growers managing those farms. This comprised a thorough explanation of the composition of the device, its functioning and potentials in supporting decision-making regarding fertigation management in CRUS, and a series of tests with on-site collected drainage samples. For these purposes, CRUS were selected for growing different crops with representativeness in terms of soilless cultivation in Portugal (rose and strawberry) and using different growing media in soilless production system, namely coconut peat (rose CRUS) and mixed substrate (mixture of humus, coco peat, blond peat and coconut fiber; strawberry CRUS). Guidelines for best management practices for utilization of the NPK sensor, here presented, were developed based on research and knowledge acquired under the scope of AGRINUPES, compiled in two public Deliverables (D5.1 and D5.2), available at www.agrinupes.eu. For further information, stakeholders or any other interested readers are invited to visit the project website, where other reports and research articles are made available.

1. Introduction

In horticultural production systems without utilizing soil (soilless cultivation), plants are grown by supplying nutrient solution which is distributed through a fertigation[1] system. In those soilless production systems in which growing media (substrates) are used, it is generated, in each fertigation cycle, a considerable amount of drainage solution [1]. This effluent results from the common practice of supplying nutrient solution above the water holding capacity of substrates [2]. For the majority of crops, drainage volumes ranging from 20 % to 40 % are commonly applied [2, 3]. As such, for an efficient use of water and nutrients, which are supplied through fertilizers, the use of drainage becomes fundamental. This is the case of closed systems in which drainage

[1] Fertigation is the plants' irrigation enriched with nutrients that were injected in the irrigation system.

is recycled through its incorporation in subsequent fertigation cycles, after disinfection and further correction of the nutrient solution for the electrical conductivity (EC) and pH [4, 5].

An alternative that has been adopted, consists in drainage use for fertigation of other crops (considered "secondary crops") that are not the core business of the farm, where growers dedicate more efforts in the management of the crop(s) grown in the soilless production system ("main crop") and from where the drainages are originated. These are called semi-open systems or Cascade ReuSe Systems (CRUS), because of this aspect of using drainage from soilless cultivation, in the growth of crops of a lesser level of importance for the grower. In CRUS, those secondary crops receiving the drainage are typically grown on soil, either in protected cultivation (e.g., greenhouse) or in open-field. Although these systems are seen as being frankly more efficient than the totally obsolete systems with free drainage (open systems), also the adequacy of CRUS has been called into question, particularly when including soil cultivation, as is the most common scenario. Aiming at adequate utilization of CRUS, it is essential to achieve a more informative monitoring of the drainages. In this respect, knowing the nutrient profile of drainages or, in other words, the concentration of each particular nutrient they contain, will clearly represent a crucial step in improving sustainability in horticultural production [6]. In practical terms, this would translate into higher accuracy of nutrient correction, higher water- and nutrient use efficiencies, safer utilization of drainages in agricultural soils or in CRUS exclusively dedicated to soilless crops or, ultimately, it could lead to generalization of closed systems. These aspects have been addressed by the AGRINUPES project (www.agrinupes.eu), which has been developing, since 2017, an optical sensor conjoined with artificial intelligence for measuring nitrogen (N), phosphorus (P) and potassium (K) in aqueous solutions, to represent an innovative technological tool to support fertigation management in horticultural production [7]. The development of this NPK sensor has gone through a series of steps, which have comprised its i) design, ii) technical specifications and assessment of its iii) operational performance under laboratory conditions (lab calibration) and iv) operational performance under field conditions (field operation). The latter is addressed in this report, in which are presented and discussed the performance of the NPK sensor in two demonstration events, carried out in two Portuguese commercial CRUS, in December 2020. Furthermore, here we briefly describe the CRUS, summarize several features of drainage from soilless cultivation and present guidelines for Best Management Practices (BMP) for using the NPK sensor in CRUS. The development of these guidelines was supported by knowledge acquired from Work Package (WP) 5 of AGRINUPES, which aimed at a general characterization of CRUS regarding fertigation management and at assessing their suitability and impacts on irrigation water, soil an at plant level [8, 9].

1.1. General description of Cascade ReUse Systems (CRUS)

Cascade ReUse Systems are horticultural cropping systems in which the drainage originated from greenhouse soilless cultivation is used for fertigation of other crops, typically of lesser economic importance to the grower. In the soilless component of this combined production system, plants are grown in semi-hydroponics since a physical medium (substrate) is used to support plant growth.

Regarding the second component in CRUS, the most common scenario is that those "user" crops or, in other words, the crops receiving the drainage coming from the semi-hydroponic system, are grown on soil, either in protected cultivation (e.g., greenhouses) or in open-field. As such, CRUS are typically a combination of greenhouse soilless production, with soil-based production system [10, 11], as graphically represented in Figure 1. Although much less common, CRUS can also be exclusively based on soilless cultivation, in production systems in which drainage is sequentially used in fertigation of crops with increasing salinity tolerance [12]. CRUS are commonly adopted by growers from regions where increasing water salinity, higher pressure from phytopathogens, lesser technological level of greenhouses and lack of technical knowledge makes implementation of closed systems more difficult, as is the case of Portugal and several other countries from the Mediterranean region [9, 10, 12-14]. Given the prevalence of those CRUS which include soil cultivation, this was the modality addressed in WP5 of AGRINUPES and their main components (semi-hydroponic + soil cultivation) are briefly described in the following sub-sections. For more details on aspects related to CRUS in Portugal, you should refer to Deliverable 5.1 [9], which addressed the fertigation management and application of PPP in two of the most important Portuguese horticultural regions.

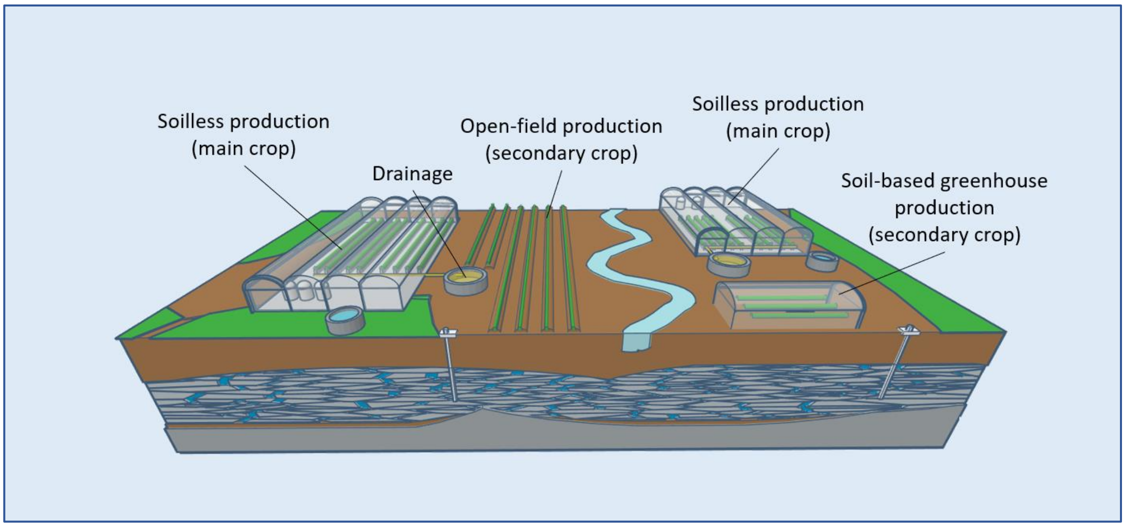

Figure 1. Graphical representation of typical Cascade ReUse Systems (CRUS) in which soilless production in greenhouse (main crop) is combined with soil-based cultivation system for growing secondary crops (either in open-field or soil-based protected cultivation) using drainage in fertigation.

1.1.1. 'Soilless production' component of CRUS

In soilless production, irrigation/fertigation systems are typically composed by an automated fertigation unit, stock tanks, filtration system (e.g., sand filters), pipes, pumps and valves (for mixing, circulation and pressurization), injectors, drippers (or micro-sprinklers) and reservoirs (storage tanks, basins or irrigation ponds) [15].

In general, plants are installed in elevated structures where they are cultivated in growing media (substrate). Those substrates are containerized in bags, pots or other types of containers to facilitate installation, handling and crop management [16]. Moreover, the substrate and typology of containerization to be used are chosen considering the crop and preference of growers [16, 17]. Constituent materials of substrates can be of organic or inorganic origin, and the final product can be composed by a single constituent or a mixture of materials. Most commonly used organic constituents include peat (e.g., peat from mosses belonging to the genus *Sphagnum*), coconut fiber (coir), bark and wood fiber. Regarding inorganic materials used in substrates, amongst most utilized are vermiculite, perlite, rockwool, sand, pumice and expanded clay [17, 18].

Through the pipes, the fertigation system circulates the nutrient solution until they reach the substrates where plants are cultivated. For elaboration of nutrient solutions, proportions of stock solutions, prepared in high nutrient concentrations, are mixed with irrigation water at each fertigation cycle [19]. These nutrient solutions are prepared according to the crop, developmental stage of plants and growth conditions (e.g., temperature, radiation), which implies that they must be modify in terms of nutrient concentration, electrical conductivity (EC) and pH [20]. Naturally, all these aspects in crop cultivation should be optimized, with the goal of combining high yield with better use efficiency of water and nutrients in greenhouse horticulture.

As in any other agricultural production system, irrigation water quality is of critical importance. In greenhouse semi-hydroponics, rainwater, surface- or groundwater are the most commonly used types of irrigation water, whereas the use of mains water is less common due to its cost [11, 21]. Application of PPP via fertigation is practically universal in soilless cultivation [22], as this greatly facilitates the logistics and also because many phytopharmaceuticals have systemic action, thus allowing them to effectively play their role in protecting the whole plant, despite their application be localized at the root zone. Nevertheless, PPP residues in the drainages is one of the main aspects related to drainage quality degradation, not only caused from intentional inclusion of PPP in nutrient solutions, as also from run-off resulting from other application methods, such as aspersion. Another important aspect regarding drainage quality is related to the accumulation of toxic ions to the plants, namely sodium (Na^+) and chloride (Cl^-), which are introduced by irrigation water and some materials used as substrate [16, 23]. Concerning the optical properties of nutrient/drainage solutions there is to consider their turbidity, frequent proliferation of microalgae (Figure 2-C) and coloration of the solutions mainly resulting from addition of ferric salts used as iron source, which gives the solutions a yellow-brown coloration [24, 25], and from substances present in organic substrates, such as humic substances in peat [26].

Drainage resulting from each fertigation cycle is conducted by gravity flow through slightly inclined irrigation troughs or tubing to one or more drainage reservoirs, generally placed outside the greenhouse, which remain either covered or uncovered. These reservoirs can be storage tanks, basins or irrigation ponds, and be made of diverse materials, as for example galvanized steel or concrete (Figure 2). Thus, the drainage is retained in these deposits until its utilization for fertigation of secondary crops, in CRUS.

Figure 2. Reservoirs in Cascade ReUse Systems (CRUS), namely (A) galvanized steel tanks, (B) underground concrete reservoir and (C) irrigation pond, where drainages originated from fertigation of soilless production are retained to be used for fertigation of soil-grown crops.

1.1.2. 'Soil-based' component of CRUS

In CRUS which include soil cultivation, secondary crops are cultivated in land parcels contiguously to the greenhouse where the soilless crop is installed. Depending on the land available, crop or local edaphoclimatic conditions, growers can opt to cultivate these secondary crops in open-field, in protected cultivation, or even in a combination of both production modalities.

Generally, the drainage retained in the outdoor reservoirs is distributed to the soil-grown crop through plastic tubing (e.g., PVC) or hoses, after a simple filtration to prevent clogging of the irrigation system [27]. Drainage application to the soil can be made with or without its dilution with irrigation water and, generally, this procedure is realized using a common irrigation system and with low or absent monitoring of the drainage being used for fertigation of secondary crops [10].

Given the soil-based component of CRUS is essentially a strategy based in reusing drainage (either total or partial) in other crops as complementary part of the growers´ economic activity, in the choice of secondary crops, irrigation method and mode of crop management, possibilities are virtually the same as other soil-based production system we could find for similar edaphoclimatic conditions. In Portugal, for example, we found that amongst the most common secondary crops in CRUS are maize, cabbage, several ornamental species, lettuce, tomato, bell pepper, garlic and onion [9].

2. Operational performance of the NPK prototype sensor

A diversity of tests was performed with increasing complexity, starting from reference lab solutions, Hoagland solutions, solutions prepared from the precursor fertilizers of the growers, to real samples collected *in situ*. These tests allowed to continuously fine tune the prototype, both in terms of hardware and control and processing software. Finally, in December 2020, the final prototype was taken to local greenhouse growers (rose and strawberry soilless cultivation) in the outskirts of Porto (Portugal) for on-site testing/demonstration. No sample filtration was required since no obvious particles were suspended in the drainage solution. No counter analysis of the chemical parameters was performed except for EC and pH. The latter was confirmed to be approximately 6.00, in agreement with the average of the obtained values (5.70). A more detailed description of these tests is available in Deliverable D2.3 of this report.

Overall it was observed that the sensor presented a very good performance while operating with the reference solutions and Hoagland solutions, which were used to establish the Artificial Intelligence reference database. When moving to more complex solutions, it was observed that the spectral feature space was expanded outside the reference. For those solutions within the feature space, good predictions were obtained (error < 10 %). However, for those samples laying well outside the reference feature space, the prediction was not sufficiently reliable. In spite of this, it was shown that, if the new solutions are measured with a reference method and thereafter this information is incorporated in the database, the new extended system will recover its performance to meaningful levels.

In conclusion, the results demonstrate the feasibility of real-time NPK measurement. However, for a real operation to be successful, the system has to be trained with the real samples from the target location (which for this purpose have to be characterized with a reference method).

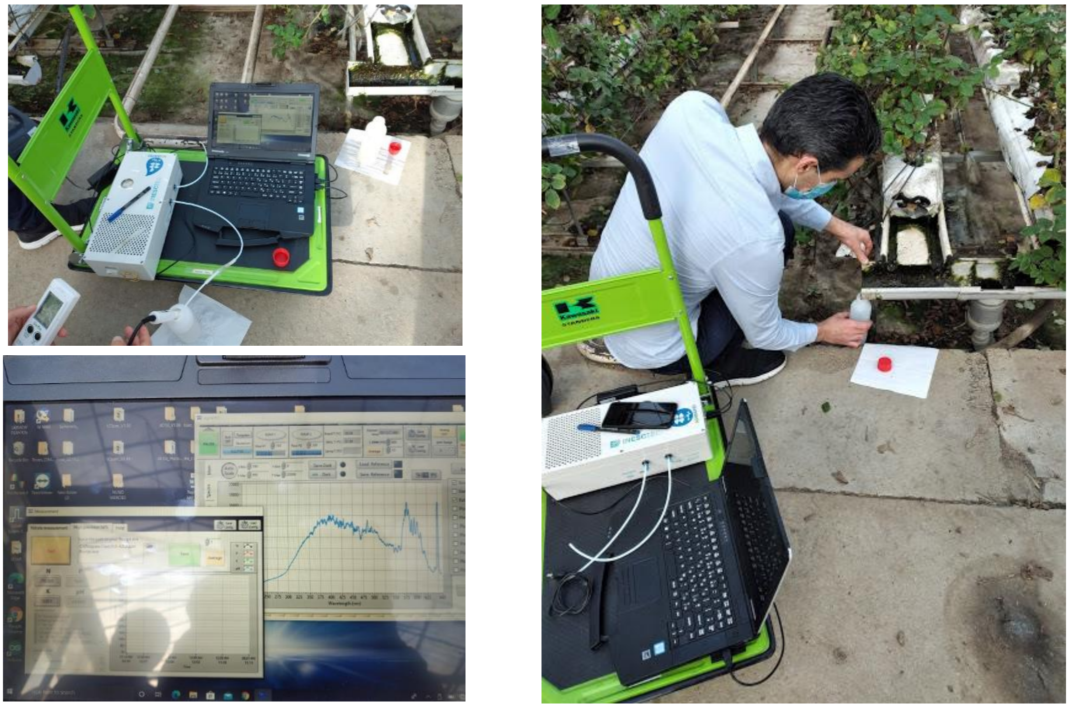

Figure 3. Details on the on-site data acquisition/ testing and demonstration using the final NPK prototype.

3. Best Management Practices (BMP)

In the development of any technological equipment, it is fundamental the assessment of its applicability and operational performance *in situ*. At the time of preparation of this report, the prototype NPK sensor was already able to operate within the ranges of EC, pH and nutrient concentrations that can be found for nutrient/drainage solutions from soilless production systems. To some extent, the sensor was already able to cope with color of the solutions utilized in fertigation and presence of solid material in suspension (e.g., substrate debris) and microalgae. Nonetheless, further development is still required before the device can be fully able to operate, under field conditions, with the same consistency and reliability that has already demonstrated in the laboratory and semi-practical conditions (real samples appropriately cleaned to use in training and calibration of the equipment).

In order to obtain maximum benefit from the NPK sensor in CRUS and to meet the expectations of end-users, the installation of the NPK sensor should be made considering specific goals of growers, the layout of each CRUS and conditions at the site where the device will operate.

As an equipment with electronic components, the performance and durability of the NPK sensor can be affected by adverse operational conditions, such as prolonged exposure to direct sunlight, high temperatures, high moisture and rain, so its installation and use should consider all these aspects. Furthermore, it is necessary for drainages to be filtered prior to their passage through the sensing system, so to prevent clogging, damages to the device or reading interferences.

In CRUS, the most intuitive situation is the installation of the sensor in the outlet of the drainage reservoir, as this is the point in the production system preceding drainage application to soil-grown crops. From the reservoir, the drainage can be circulated through pumping or it can flow by gravity for its application to soil-grown crops, after being monitored by the sensing system. In this case, it is advisable to install the sensor in an outdoor compartment, where the pump and filtration unit can also be placed, offering good access, ease of handling and adequate operational conditions (Figure 4). Moreover, reservoirs should be kept covered, both to prevent additional debris to end-up in the drainage and to minimize microalgae growth.

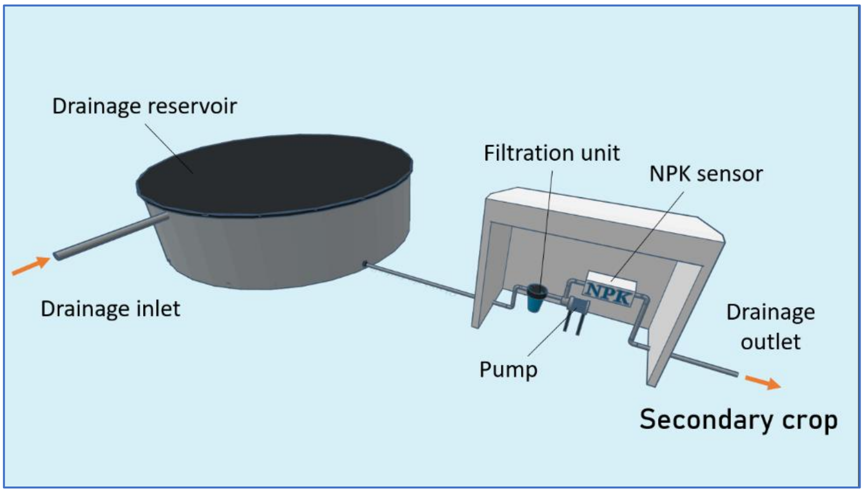

Figure 4. Graphical representation of placement of the NPK sensor in an outdoor compartment where drainage is pumped from a reservoir, filtered and monitored for N, P and K, for its application to secondary crops.

Another possibility consists in installing the NPK sensor at the fertigation room, as an integrative component of the mixing unit in the fertigation system (Figure 5). This option allows to increase versatility in the utilization of the NPK sensor, as it can be used for determination of main macronutrients not only in drainages, but also in fresh nutrient solutions destined to fertigation of the soilless main crop. From the fertigation room, drainage could be circulated to the secondary crop either in full (100 % drainage) or after its dilution with irrigation water, as well as with or without incorporation of stock solutions and possibly corrected for pH and EC. However, the most common situation is that reservoirs are placed distant to the fertigation room, generally at lower levels in the farm, thus not allowing drainage to flow by gravity. For this reason, costs associated to drainage pumping should be taken into account, when considering this possibility of sensor installation.

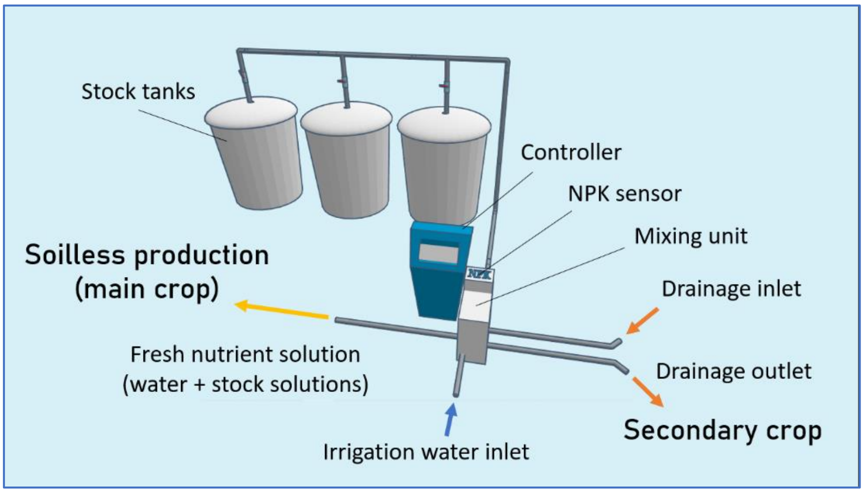

Figure 5. Graphical representation of integration of the NPK sensor in the mixing unit of the fertigation room.

The sensor can also be installed in a cultivation row within the soilless component of CRUS (Figure 6), selected either at random or according to any specific criterium defined by growers. This can be done in a fixed or movable site in the greenhouse and include, for instance, monitoring of a particular irrigation section within the greenhouse or a particular cultivation row due to criteria such as integration of other sensors, crop species, cultivar or plant developmental stage. Although, in this case, representativeness of drainage monitoring is clearly limited when compared with other possibilities, this option offers the advantage of collecting useful information in supporting fertigation management, mainly regarding the soilless component in CRUS.

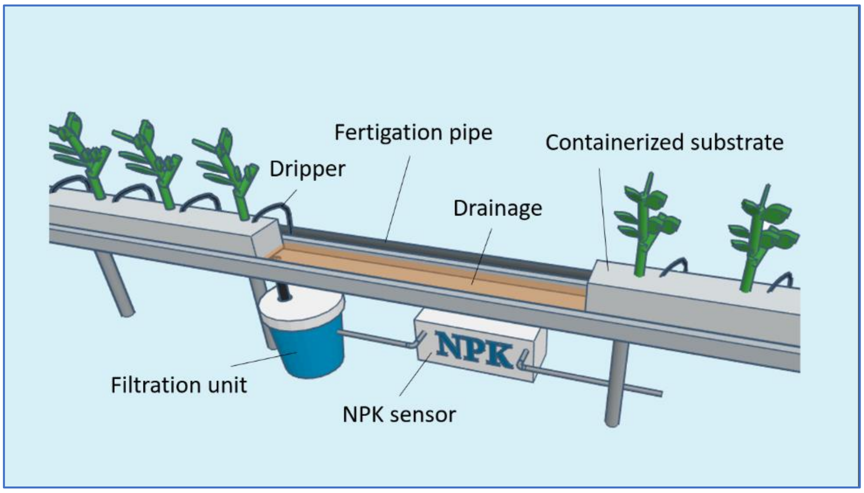

Figure 6. Graphical representation of placement of the NPK sensor in a cultivation row of the soilless production system, for monitoring drainage immediately after its passage through the containerized substrate.

In sum, any of the aforementioned possibilities, either implemented alone or in their combination with multiple NPK sensors installed, should be subject of consideration in the decision on the type of usage and installation site in CRUS, with the ultimate goal of using this technological tool to optimize use efficiency of water and nutrients in horticultural production.

4. References

1. Rouphael, Y.; Raimondi, G.; Caputo, R.; De Pascale, S. Fertigation strategies for improving water use efficiency and limiting nutrient loss in soilless *Hippeastrum* production. *HortScience*. **2016,** *51* (6), 684–689. DOI: 10.21273/HORTSCI.51.6.684.
2. Giuffrida, F.; Argento, S.; Leonardi, C.; Lipari, V. Methods for controlling salt accumulation in substrate cultivation. *Acta Horticulturae 614*. **2003**. DOI: 10.17660/ActaHortic.2003.614.117.
3. Signore, A.; Serio, F.; Santamaria, P. A Targeted Management of the Nutrient Solution in a Soilless Tomato Crop According to Plant Needs. *Frontiers in Plant Science*. **2016,** *7*. DOI: 10.3389/fpls.2016.00391.
4. Ehret, D.; Alsanius, B.; Wohanka, W.; Menzies, J.; Utkhede, R. Disinfestation of recirculating nutrient solutions in greenhouse horticulture. *Agronomie*. **2001,** *21* (4), 323–339. DOI: 10.1051/agro:2001127.
5. Pardossi, A.; Malorgio, F.; Incrocci, L.; Carmassi, G.; Maggini, R.; Massa, D.; Tognoni, F. Simplified models for the water relations of soilless cultures: what they do or suggest for sustainable water use in intensive horticulture. *Acta horticulturae 718*. **2006**, 425–434.
6. Marcelis, L.; Dieleman, J.; Boulard, T.; Garate, A.; Kittas, C.; Buschmann, C.; Brajeul, E.; Wieringa, G.; de Groot, F.; van Loon, A.; Kocsanyi, L. CLOSYS: Closed System for Water and Nutrient Management in Horticulture. *Acta Horticulturae 718*. **2006**, 375–382.
7. Monteiro-Silva, F.; Jorge, P.; Martins, R. Optical sensing of nitrogen, phosphorus and potassium: a spectrophotometrical approach toward smart nutrient deployment. *Chemosensors*. **2019,** *7*. DOI: 10.3390/chemosensors7040051.

8. Santos, M. G.; Pereira, R.; Aguiar, A.; Carvalho, S. M. P. *Suitability and impacts of 'CascadeReUse Systems' on irrigation water, soil and at plant level*. Deliverable D5.2 (Version 2); A Report prepared within the framework of the AGRINUPES Project: **2021**; 36 pp. Available at: http://www.agrinupes.eu/index.php/documents/
9. Santos, M. G.; Pereira, R.; Aguiar, A.; Carvalho, S. M. P. *Report on general characterization of the 'CascadeReUse Systems'*. Deliverable D5.1; A Report prepared within the framework of the AGRINUPES Project: **2017**; 20 pp. Available at: http://www.agrinupes.eu/index.php/documents/
10. Muñoz, P.; Flores, J. S.; Antón, A.; Montero, J. I. Combination of greenhouse and open-field crop fertigation can increase sustainability of horticultural crops in the Mediterranean region. *Acta Horticulturae 1170*. **2017**.
11. Santos, M.; Roncon, I.; Pereira, R.; Carvalho, S. Caracterização da gestão da fertirrega e aplicação de produtos fitofarmacêuticos em culturas sem solo em Portugal. In: *I Congresso Luso-Brasileiro de Horticultura*, Lisbon, 1-4 November 2017; Paulo César Tavares de Melo (ESALQ/USP); António Calado (APH), Eds. Associação Portuguesa de Horticultura (APH): Lisbon, **2017**; pp 611-619.
12. García-Caparrós, P.; Llanderal, A.; Maksimovic, I.; Lao, M. T. Cascade Cropping System with Horticultural and Ornamental Plants under Greenhouse Conditions. *Water* **2018,** *10* (125). DOI: 10.3390/w10020125.
13. Garcia-Martinez, M. C.; Balasch, S.; Alcon, F.; Fernandez-Zamudio, M. A. Characterization of technological levels in Mediterranean horticultural greenhouses. *Spanish Journal of Agricultural Research*. **2010,** *8* (3), 509–525.
14. Incrocci, L.; Pardossi, A.; Malorgio, F.; Maggini, R.; Campiotti, C. A. Cascade Cropping System for Greenhouse Soilless Culture. *Acta Horticulturae 609*. **2003**, 297-300.
15. Van Os, E.; Gieling, T.; Lieth, J. Technical equipment in soilless production systems. In *Soilless Culture: Theory and Practice*; 2nd ed.; Raviv, M.; Lieth, J.; Bar-Tal, A., Eds. Elsevier: **2019**; pp 587–635. ISBN: 978-0-444-63696-6. DOI: 10.1016/B978-0-444-63696-6.00013-X.
16. Savvas, D.; Gruda, N. Application of soilless culture technologies in the modern greenhouse industry – A review. *Eur. J. Hortic. Sci.* **2018,** *83* (5), 280-293. DOI: 10.17660/eJHS.2018/83.5.2.
17. Papadopoulos, A.; Bar-Tal, A.; Silber, A.; Saha, U.; Raviv, M. Inorganic and synthetic organic components of soilless culture and potting mixes. In *Soilless Culture: Theory and Practice*; Raviv, M.; Lieth, J., Eds. Elsevier: Amsterdam, the Netherlands, **2008**; pp 505–544. ISBN: 978-0-444-52975-6.
18. Gruda, N. Increasing sustainability of growing media constituents and stand-alone substrates in soilless culture systems. *Agronomy*. **2019,** *9*. DOI: 10.3390/agronomy9060298.
19. Van Os, E.; Gieling, T.; Lieth, J. Technical equipment in soilless production systems. In *Soilless culture: Theory and Practice*; Raviv, M.; Lieth, J., Eds. Elsevier: Amsterdam, the Netherlands, **2008**; pp 157–207. ISBN: 978-0-444-52975-6.
20. Tsukagoshi, S.; Shinohara, Y. Nutrition and nutrient uptake in soilless culture systems. In *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*; Toyoki Kozai, G. N., Michiko Takagaki, Ed. Elsevier: **2016**; pp 165–172. ISBN: 978-0-12-801775-3. DOI: 10.1016/C2014-0-01039-8.
21. Schnitzler, W. Pest and disease management of soilless culture. *Acta Horticulturae 648*. **2004**, 191– 203. DOI: 10.17660/ActaHortic.2004.648.23.
22. Alsanius, B. W.; Bergstrand, K. J.; Burleigh, S.; Gruyer, N.; Rosberg, A. K. Persistence of fenhexamid in the nutrient solution of a closed cropping system. *Agricultural Water Management*. **2013,** *127*, 25-30. DOI: 10.1016/j.agwat.2013.05.008.
23. Lee, S. G.; Choi, E. Y.; Lim, G. H.; Choi, K. Y. Yield and Inorganic Ion Contents in Drained Solution by Different Substrate for Hydroponically Grown Strawberry. *Horticultural Science and Technology*. **2018,** *36* (2), 337-349. DOI: 10.12972/kjhst.20180033.

24. Steiner, A. A.; van Winden, H. Recipe for ferric salts of ethylenediaminetetraacetic acid. *Plant Physiology*. **1970,** *46*, 862–863.
25. Bawiec, A.; Garbowski, T.; Pawęska, K.; Pulikowski, K. Analysis of the algae growth dynamics in the hydroponic system with LEDs nighttime lighting using the laser granulometry method. *Water, Air, & Soil Pollution* **2019,** *230*. DOI: 10.1007/s11270-018-4075-8.
26. Smith, D. G.; Lorimer, J. W. An examination of the humic acids of *Sphagnum* peat. *Canadian Journal of Soil Science*. **1964,** *44*, 76–87.
27. Lieth, J.; Oki, L. Irrigation in soilless production. In *Soilless Culture: Theory and Practice*; 2nd ed.; Raviv, M.; Lieth, J.; Bar-Tal, A., Eds. Elsevier: **2019**; pp 381–423. ISBN: 978-0-444-63696-6. DOI: 10.1016/B978-0-444-63696-6.00013-X.