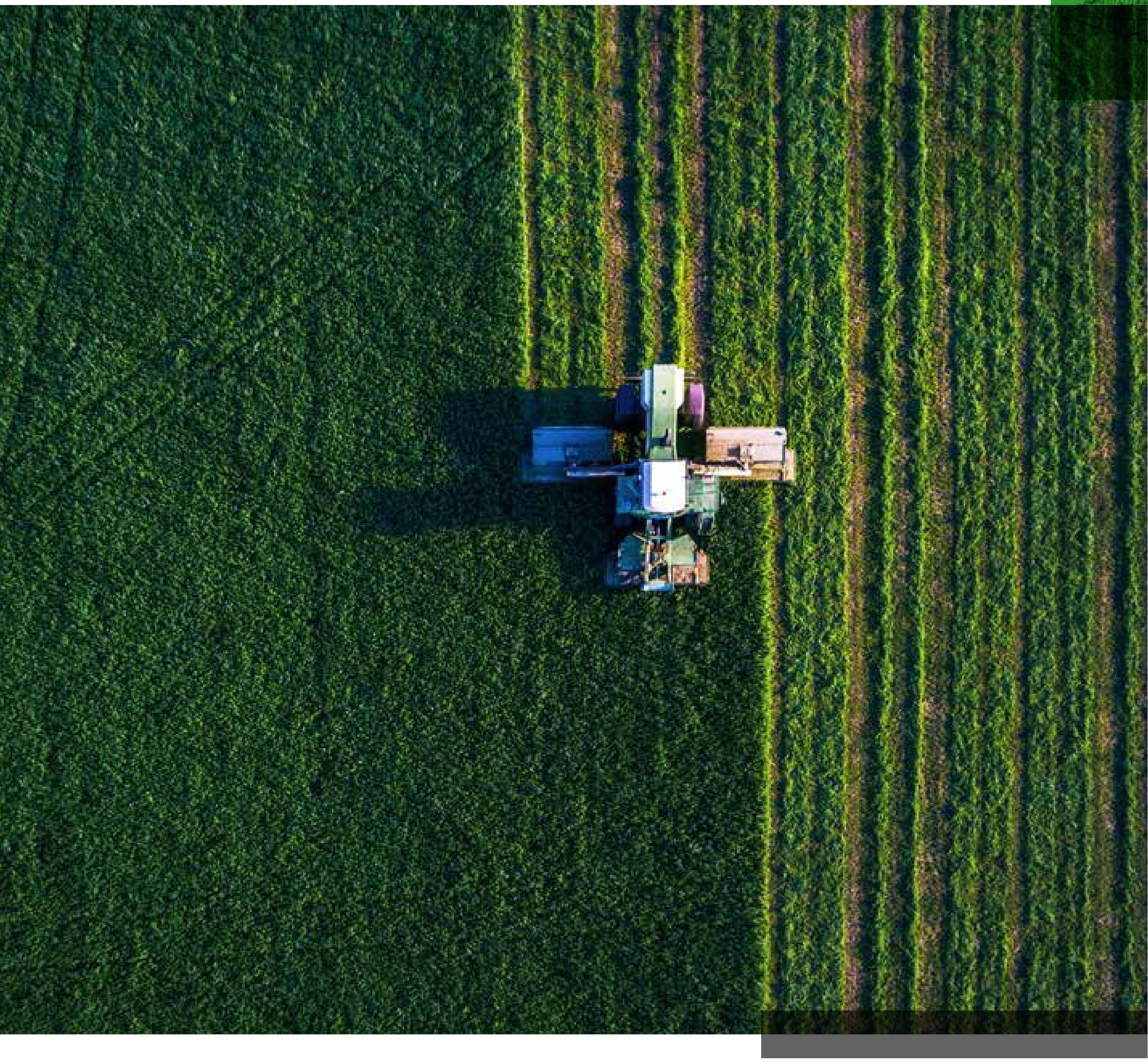
Growing media and the efficient use of nutrients



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Growing on Grodan systems is highly efficient in terms of fertiliser consumption per unit of crop grown when compared to conventional production in soil or other substrates.

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April 2016

Introduction

One of the 15 global challenges formulated by the Millenium project (Glenn *et al.*, 2015) is "How can population growth and resources be brought into balance?" One aspect of this challenge is improving the use efficiency of the global resources e.g. nutrients. These nutrients, e.g. phosphorus, potassium and others, are just as important to agriculture as water. For example, a lack of availability and accessibility of phosphorus is an emerging problem that threatens our capacity to feed the global population (Sciencedaily, 2010). Furthermore, the production of fertilizers is a large energy consumer (Fig. 1), accounting for about a third of energy consumption in US crop production (Gellings and Parmenter, 2004).

Question

Is there scientific proof that growing on mineral wool is more efficient in use of fertilisers than in soil or in organic substrates (coco, depletion – adsorption)?

Introduction

Figure 1.0
The Simplot fertilizer production plant (the Don Plant). Pocatelo, Idaho (http://www.panoramio.com/photo/6525234). Fertilizers are essential for crop growth. Their limited availability, accessibility and the high energy consumption for their production threatens our capacity to feed the global population. Improving the use efficiency of fertilizers is therefore essential and cultivation on mineral wool instead of a soil-based system makes this possible.

Nutrient efficiency in soil-based cultivations is often below 50%, meaning that less than 50% of the applied fertilizers are taken up by the crop (Lassaletta *et al.*, 2014). This low nutrient use efficiency may be attributed to fertilizer overuse and high nutrient loss resulting from inappropriate timing and methods of fertilizer application (Fan *et al.*, 2012). Improved nutrient and irrigation management can reduce these losses significantly (Voogt *et al.*, 2012), but it will not be completely overcome. In principle, soilless cultivation systems can obtain zero nutrient losses, because the nutrient solutions are recirculated (Fig. 2).

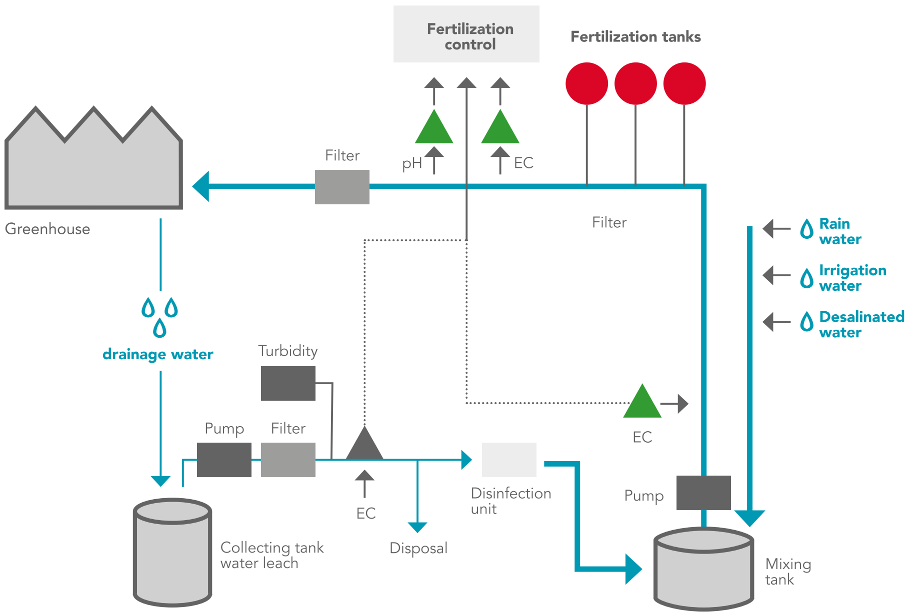

Fig. 2.0
Scheme of a closed system with reuse of drain water after disinfection
Source: International Potash Institute (http://www.ipipotash.org/presentn/rnsigp.html)

Fertilizer use efficiency: soil-based versus soilless cultivation

Sonneveld and Voogt (2009) summarized data about nutrient leaching from greenhouses in the Netherlands. These data are derived from studies carried out under conditions that not yet regulations were issued, roughly 1975-1980. The N efficiency was low, especially for the soil grown situation, resulting in a high discharge of minerals to the environment.

Jovicich *et al.* (2007) estimated water and nutrient efficiencies for cucumbers produced in a greenhouse and for field-grown cucumbers in central Florida. Greenhouse cucumbers were grown in containers filled with pine bark and field cucumbers were grown in sandy soil covered with plastic foil (polyethylene mulch).

Total yield was 270 t/ha in the greenhouse, and 31.2 t/ha for the field crop. With a free drainage system in the greenhouse, a total of 8,190 m^3/ha of nutrient solution were applied to keep drainage between 20% to 30% of the daily irrigation volume. Field drip irrigation delivered 1,406 m^3 water per ha, 160 kg/ha of N, and 243 kg/ha of K. In the greenhouse nitrogen used per kg of fruit was 28% less and K used per kg of fruit was 23% less than in the field (6.5 g N/kg fruit, and 7.8 g K/kg fruit). Greater fruit yields, fruit quality, and nutrient use efficiencies resulted with greenhouse than with field production system (Table 2).

Pronk *et al.* (2007) presented measurements and calculations for nutrient losses in soil and soilless cultivations in greenhouses in the Netherlands. These authors conclude that for soil-based tomato production N emission varied between 200 and 1000 kg N ha^{-1} $year^{1}$, whereas for soilless cultivation on mineral wool (with recirculation) emission is much lower and varies between 64 and 107 kg N ha^{-1} $year^{1}$. P-emission from soilless tomato cultivation varied between 10 and 16 kg P ha^{-1} $year^{1}$. Pronk *et al.* (2007) reported a maximum P-emission for tomato cultivation in soil of 30 kg P ha^{-1} $year^{1}$. However, these authors often found a higher P-uptake than P-supply (negative balance) for soil-grown tomato, of up to 100 kg P ha^{-1} $year^{1}$. This negative balance was calculated for peat and clay soils which often have a high P status. In the Netherlands, the P status of most soils is from both an agricultural and an environmental viewpoint unnecessarily high (Fraters and Boumans, 1997).

Factors	**Soil grown crop**		**Substrate grown crop**	
	Water	N	Water	N
Addition	12950	2269	9691	1935
Uptake by crop	6700	609	7600	1110
Discharge by drainage	6250	1344	2091	825
Residual factor	0	316	0	0
Efficiency	0.52	0.27	0.78	0.57

Table 1.0
Balance sheets of water and nitrogen (N) for tomato growing in greenhouses under free drainage conditions. The quantities of water are expressed as m3 ha-1 year-1 and the N as kg ha-1 year-1 (Sonneveld and Voogt, 2009). Residual factor reflects undetected quantity, added but not traced in the study e.g. as a result of de-nitrification.

	Units	Field (soil-based)	Greenhouse (soilless cultivation)	N
Marketable fruit yield				Increase %
	(t/ha)	31.2	270	765
	(number/ha)	135,693	2.310,000	1600
	(g/fruit)	230	115	
Amount used				Increase %
Water	(m^3/ha)	1,406	8,190	483
Nitrogen (N)	(kg/ha)	203	1,260	521
Potassium (K)	(kg/ha)	243	1,620	567
Efficiency				Reduction %
Water-use	(L/kg fruit)	45	30	33
	(L/fruit)	10	4	60
N-use	(g N/kg fruit)	6.5	4.7	28
	(mg N/fruit)	1,495	545	64
K-use	(g K/kg fruit)	7.8	6.0	23
	(mg K/fruit)	1,789	701	61

Table 2.0
Comparison of field and greenhouse-grown cucumber crops in central Florida (Jovicich et al., 2007).

Fertilizer use efficiency: soil-based versus soilless cultivation

Tüzel *et al.* (2001) compared in an unheated greenhouse in Turkey (Izmir) in 1998 and 1999 different substrates in open and closed systems for tomato production. The tested substrates were perlite, volcanic tuff, perlite + peat (4:1, v/v) and volcanic tuff + peat (4:1, v/v). Substrates were filled into horizontal containers (8 litres per plant). There were no significant yield differences between open (15.7 and 19.0 kg m^{-2}) and closed systems (17.0 and 18.0 kg m^{-2}). However, the closed system did save up to 34 % nutrients.

	Open system	Closed system	% Reduction in closed system
Total water used (L·m^{-2})	44.1	35.5 ± 3.2[z]	20
Total fertilizer used (g·m^{-2})	227.3	42.5 ± 1.7	81
Used water per fruit (L·kg^{-1} fruit)	21.1 ± 5.7	20.1 ± 1.4	5
Used fertilizers per fruit (g·kg^{-1} fruit)	108.9 ± 29.5	24.0 ± 0.9	78

[z]Each value represents mean ± SE (n = 3). In open system, the total amount of water and fertilizer used are the same in 3 replications.

Table 3.0
Total used amounts of water and fertilizer in open and closed soilless culture systems (Ko et al., 2013).

Ko *et al.* (2013) reported for a sweet pepper culture on mineral wool in Korea a reduction in fertilizer use by 80%, comparing a closed system with an open system (Table 3).

Zekki *et al.* (1996) investigated whether recycling of drainage solution would negatively affect tomato yield. Tomato plants were grown in Quebec, Canada, in the three most promising and used soilless cultivation systems using mineral wool and peatmoss substrates and nutrient film technique (NFT), either with or without recycling of the drainage solutions. In the substrate systems without recycling the average volume of drainage (over irrigation) during this experiment was fixed at 25% of the applied irrigation solution. In the substrate systems with recycling drainage solutions were analysed at the end of each week for major and trace elements. The solution then was reused after nutrient adjustments based on mineral analysis. NFT is a hydroponic technique wherein a very shallow stream of water containing all the dissolved nutrients required for plant growth is re-circulated past the bare roots of plants in a watertight gully, also known as channels. Solutions are monitored and adjusted daily for pH and electrical conductivity (EC).The treatment 'NFT without recycling' in this experiment meant that every 4 weeks, nutrient solutions were replaced. The treatment 'NFT system with recycling' means that the solution was not replaced but only adjusted based on pH and EC measurements. Prolonged recycling of nutrient solutions in NFT caused a reduction in fresh weight, dry weight, and yield compared to plants grown in NFT with regular renewal of the nutrient solution. According to Zekki *et al.* (1996) this was most likely due to an accumulation of sulphate ions in the fertigation solutions. There were no differences in growth, productivity, and leaf mineral composition between plants grown in mineral wool and peatmoss systems. Within each system these crop parameters did not differ between recirculated and non-recirculated solution sytems. Zekki *et al.* (1996) concluded that recycling drainage solutions is an economically and environmentally sound horticultural practice that when used correctly does not cause a reduction in yield of tomatoes cultivated in mineral wool or peatmoss. However, prolonged use of the same solution in the NFT cultivation system did negatively affect growth and yield (Zekki *et al.*, 1996).

The discharges of nutrient solution of soilless cultivations with recirculation of cucumber, gerbera and tomato in the Netherlands are on average about 770 m3 ha^{-1} year^{-1}, which is circa 10% of the annually overall used nutrient solution (Beerling *et al.*, 2014). The quantity of discharge differs largely between crops (335 m3 ha^{-1} year^{-1} for tomato and 1308 m3 ha^{-1} year^{-1} for gerbera), but also between greenhouses with the same cultivation system and crop. For example, for the top 20% tomato growers the discharge is almost zero, whereas for the bottom 20% tomato growers it is 746 m3 ha^{-1} year^{-1} (Beerling *et al.*, 2014).

Figure 4.0
Adequate disinfection equipment is needed to prevent discharge of nutrient solution from mineral wool crop-growing systems and hence obtain a fertilizer use efficiency of (almost) 100%. The photograph shows one of the possibilities, disinfection by ultra-violet radiation. http://www.hydroponics.com.au/disinfection-methods-an-australian-perspective/

The key factor in recirculation in soilless cultivation systems is the quality of the irrigation water. Growers (and their advisors) tend to avoid risks especially when costs and other consequences for discarding are relatively low. Thus, when there is the slightest doubt about the drain water quality, it is discarded. However, Beerling *et al.* (2014) estimate that when the tools they developed to tackle obstacles leading to discharge are broadly implemented, discharge and associated emissions will be reduced with approximately 60%. In principle, this can be further improved to 100% by the already known, but not yet broadly implemented solutions to prevent discharge: low sodium irrigation supply water, adequate disinfection equipment (Fig. 4), and especially reuse of filter back-flush water (Beerling *et al.*, 2014).

Pardossi *et al.* (2011) compared open and closed irrigation loops for substrate-grown greenhouse tomato in Italy (Table 4). These authors showed that closed loop could save about 20% of potassium and phosphorus and even 35% of nitrogen, without any loss of production nor quality (°Brix).

	Supply open	Supply closed	Saving	Leaching
Water (m^3/ha)	8632	6831	21%	1682
N (kg/ha)	1591	1032	35%	266
P (kg/ha)	306	244	20%	25
K (kg/ha)	2422	2000	17%	343

Table 4.0
Total use of water and fertilisers for tomatoes grown in mineral wool, either with and without re-use of drain water (closed-loop irrigation). Leaching from the open system was estimated as the difference between supply and uptake, which was independently determined. Commercial yield and quality (oBrix) were the same in the two treatments (Pardossi et al., 2011).

Fertilizer use efficiencies: importance of fertigation strategies

Massa *et al.* (2010) explored in the spring-summer seasons of 2005 and 2006 the influence of three fertigation strategies on the water and nitrogen use efficiency of semi-closed mineral wool culture of greenhouse tomato using saline water (NaCl concentration of 9.5 mol m^{-3}). These authors conclude that by means of EC modulation and/or short-term nutrient starvation, it was possible to prolong the recirculation of nutrient solution in semi-closed soilless cultivations of greenhouse tomato conducted under saline conditions with the aim of reducing the use of water and fertilizers and minimizing N emission with no important effects on fruit yield. Giuffrida & Leonardi (2012) conducted an experiment with pepper in a soilless closed system. They compared the use of two different nutrient solutions, with the same ion ratio, but an electrical conductivity (EC) of 2.5 and 2 dS m^{-1}, respectively. The total yield did not differ between the treatments; However, with reduced strength nutrient solution the amounts of nitrogen, phosphorus and potassium released per ton of marketable peppers were respectively 83%, 80% and 81% lower than the control.

Conclusive summary

In relation to the question whether there is scientific proof that growing on mineral wool is more efficient in use of fertilisers than in soil or in organic substrates (coco, depletion – adsorption) the literature review demonstrates that:

→ Nutrient use efficiency in soilless cultivation (substrates like mineral wool and NFT systems) is potentially much higher than in soil-based (conventional) systems. To what extent this potential is realised depends on the application of recirculation, the quality of the irrigation water and the irrigation strategy. In principle, in soilless cultivation systems zero emission of water, nutrients and plant protection products can be obtained, because the nutrient solutions can be recirculated and there is no interaction with water flows in the soil (Beerling *et al.*, 2014).

→ Low sodium irrigation water is of utmost importance for obtaining zero emission, because sodium will accumulate when recirculating the nutrient solution and hence create the need for discharge of drain water.

→ If high salinity conditions exist, specific irrigation strategies are needed to maintain acceptable EC levels in combination with sufficient nutrients to maintain a good crop and to reduce the emission of fertilizers.

→ Soilless cultivation (open system) has been reported to reduce fertilizer use per kg of product by about 25% compared to a soil-based cultivation and nitrogen use efficiency improved from 27% in soil to 57% in soilless cultivation on mineral wool.

→ For a closed versus an open soilless cultivation system reduction in fertilizer use per kg of product of 20% up to 78% has been observed, without any reduction in yield nor product quality.

→ Nutrient use efficiency largely differs between growers/greenhouses. For example in the Netherlands, for the top 20% tomato growers the discharge is almost zero, whereas for the bottom 20% tomato growers it is 746 m3 ha^{-1} $year^{-1}$ which is about 10% of the annually overall used nutrient solution (Beerling *et al.*, 2014).

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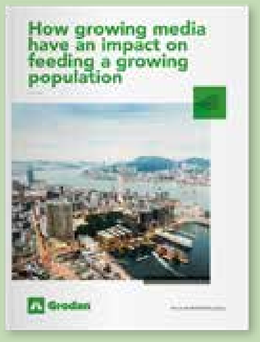

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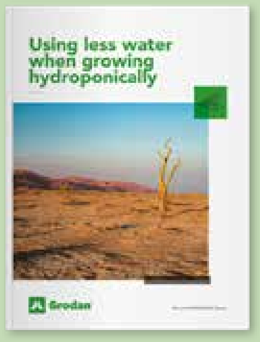

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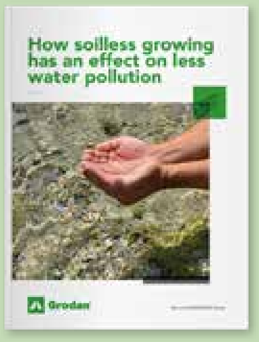

How soilless growing has an effect on less water pollution

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References

Beerling, E.A.M., C. Blok, C., Van der Maas, A.A., and Van Os, E.A., 2014. Closing the Water and Nutrient Cycles in Soilless Cultivation Systems. Acta Horticulturae 1034: 49-55. DOI: 10.17660/ActaHortic.2014.1034.4

Fan, M., Shen, J., Yuan, L., Jiang, R., Chen, X., Davies, W.J., Zhang, F., 2012. Improving crop productivity and resource use efficiency to ensure food security and environmental quality in China Journal of Experimental Botany 63: 13–24. doi:10.1093/jxb/err248

Fraters, B., Boumans, L.J.M., 1997. Fosfaatverzadigde gronden: een overzicht. Deel 1: Technische achtergronden bij de aanpak van de fosfaatverzadigde gronden. Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven, the Netherlands, Report 716601001.

Gellings, C.W., Parmenter, K.E., 2004. Energy efficiency in fertilizer production and use. In: Efficient Use and Conservation of Energy, [Eds. C.W. Gellings, and K. Blok], In: Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford ,UK, [http://www.eolss.net]

Glenn, J.C., Florescu, E., and The Millennium Project Team, 2015. 2015-16 State of the Future. The Millenium Project, Washington DC, USA, 289 pages; ISBN: 978-0-9882639-2-5

Gilinger, P.M., Forray, A., Szlávik, S.Z., Felföldi, J. and Szôriné, Z.A. 1998. Change in quality parameters of the tomato fruit from glasshouse production. Acta Horticulturae 456: 207-214. I
DOI: 10.17660/ActaHortic.1998.456.23

Giuffrida, F. and Leonardi, C. 2012. Nutrient solution concentration on pepper grown in a soilless closed system: yield, fruit quality, water and nutrient efficiency, Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 62:1, 1-6. DOI: 10.1080/09064710.2011.560123

Jovicich, E., J. Cantliffe, D., H. Simonne, E. and J. Stoffella, P. 2007. Comparative water and fertilizer use efficiencies of two production systems for cucumbers. Acta Horticulturae 731: 235-242.
doi: 10.17660/ActaHortic.2007.731.32

Ko, M.T., Ahn, T.I. and Son J.E. 2013. Comparisons of ion balance, fruit yield, water, and fertilizer use efficiencies in open and closed soilless culture of paprika (Capsicum annuum L.). Korean Journal of Horticultural Science & Technology 31: 423-428.

Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., Garnier, J. 2014. 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. Environmental Research Letters 9(10), 9pp.

Massa, D., Incrocci, L., Maggini, R., Carmassi, G., Campiotti, C.A., Pardossi, A. 2010. Strategies to decrease water drainage and nitrate emission from soilless cultures of greenhouse tomato. Agricultural Water Management 97: 971–980. doi:10.1016/j.agwat.2010.01.029

Pardossi A., Carmassi G., Diara C., Incrocci L., Maggini R., Massa D. 2011. Fertigation and Substrate Management in Closed Soilless Culture. Deliverable Report no. 15, EUPHOROS project, 63 pp. www.euphoros.wur.nl

Pronk, A.A., Voogt, W., De Kreij, C., Smit, A.L., Van der Lugt, G.G., Marcelis, L.F.M. 2007. Bouwstenen voor het opstellen van gebruiksnormen voor nutriënten bij teelten onder glas. Plant Research International, Wageningen, the Netherlands, Report 141.

Sciencedaily, 2010. https://www.sciencedaily.com/releases/2010/03/100311092124.htm

Sonneveld, C. and Voogt, W. 2009. Plant nutrition of greenhouse crops. Dordrecht : Springer, ISBN 9789048125319

Tüzel, I.H., Tüzel, Y., Gül, A., Meriç, M.K., Yavuz, O. and Eltez, R.Z. 2001. Comparison of open and closed systems on yield, water and nutrient consumption and their environmental impact. Acta Horticulturae 554: 221-228. doi: 10.17660/ActaHortic.2001.554.23

Voogt, W., Van der Helm, F.P.M., Balendonck, J., Heinen, M. and Van Winkel, A., 2012. Ontwikkeling emissiemanagementsysteem grondgebonden teelt; toetsing in de praktijk. Bleiswijk, Wageningen UR Glastuinbouw, Report GTB 1193.

Zekki, H., Gauthier, L. and Gosselin, A. 1996. Growth, productivity, and mineral composition of hydroponically cultivated greenhouse tomatoes, with or without nutrient solution recycling. Journal of the American Society for Horticultural Science 121:1082–1088.

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