Fertigation in Greenhouse Production

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Abstract

Glasshouse horticulture offers possibilities for full process control; nevertheless it is faced by low fertiliser efficiency. Therefore, in areas with a high density of greenhouses, the discharges of N and P contribute significantly to ground- and surface-water pollution. To reduce the environmental impact, the Dutch Government has introduced specific legislation. Since fertigation is common practice with soil-grown crops, improvements in both irrigation strategies and nutrient supply are required. The uneven distribution of sprinkler systems, crop transpiration, and salt accumulation caused by poor water quality constitute bottlenecks. Reuse of drainage water and model-based systems in which irrigation and fertilisation strategies are linked to crop demand provide the best prospects for improving sustainability. Additional improvements could be achieved through reduction of the current N and P target values for the root environment. However, a change in the growers' attitude towards current irrigation and fertilisation strategies is indispensable.

Keywords: fertiliser, irrigation, nitrogen, phosphate, pollution, fertigation model.

Introduction

In general, greenhouse crops are grown intensively. As the mineral uptake is proportional to the total yield, the high physical production levels involve high fertiliser inputs, and the annual fertiliser application is eight to ten times as great as that for open-field vegetable crops (Sonneveld, 1993). Apart from the high crop demand, the high fertiliser inputs are also believed to be necessary to maintain high osmotic pressure levels in the root environment, in order to prevent lush growth and to enhance product quality (Sonneveld, 2000). However, these high fertiliser applications and the high levels in the root environment cause serious leaching and entry of N and P into ground and surface water (Wunderink, 1996).

The accurate control over many processes, and the absence of natural precipitation in protected cultivation offer ample possibilities to improve the sustainability of growing process and techniques, in contrast with the situation presented by open-field cultivation of vegetables. However, a complicating factor is that the costs of fertilisers and water in these intensive growing systems are virtually negligible compared with the total costs (Ruijs, 1995). In general, therefore, savings on these items do not form an incentive to implement concepts and measures regarding sustainability. Therefore, the Dutch government has decided to introduce legislation that includes some comprehensive regulations to reduce pollution.

Nutrient solutions

In present-day greenhouse horticulture fertilisers are applied mainly by fertigation, and specific fertigation programs have been developed for all crops (van den Bos *et al.,* 1999). These are based on a basic nutrient solution, containing NH_4, K, Ca, Mg, NO_3, SO_4 (Table 1), with adjustments for specific conditions such as cropping stage, soil type, soil electrical conductivity (EC), etc. Furthermore, target values and limits are set for individual nutrients, and for Na, Cl, pH and EC levels in the soil (Table 2). For NH_4 the target value is set to zero, because the nitrification process develops very rapidly under greenhouse conditions and usually only negligible NH_4 is found.

Table 1. Composition of the basic nutrient solution for fertigation for some greenhouse crops, in mmol/L.

Crop	Nutrient solution					
	NH_4	K	Ca	Mg	NO_3	SO_4
	---------------------------- *nmol/L* ----------------------------					
Tomato	0.4	5.0	2.0	1.5	9.4	1.5
Cucumber	0.9	3.5	2.0	1.0	8.4	1.0
Sweet pepper	0.4	5.0	2.0	1.0	8.4	1.0
Rose	0.9	3.5	2.0	1.1	8.1	1.1

Table 2. Target values for nutrients and Na, Cl and EC for soil analysis (1:2 volume extract) [1].

Crop	K	Ca	Mg	NO3	SO4	Na	Cl	EC
	-------	-------	-------	*mmol/L*	-------	-------	-------	*dS/m*
Tomato	2.2	2.5	1.7	5.0	2.5	<4	<4	1.4
Cucumber	1.8	2.2	1.2	4.0	1.5	<4	<4	1.0
Sweet pepper	2.0	2.5	1.2	4.5	2.0	<4	<4	1.1
Rose	1.5	2.0	1.2	4.0	1.5	<4	<4	0.9

[1] According to Sonneveld and van den Ende (1971).

The differences between crops mainly concern the K/N, K/Ca and N/S ratios, but the total nutrient concentration, as indicated by the EC-value, may also differ. Micro-elements are not incorporated in the nutrient solution, as there is usually sufficient of them in the soil, the water, or the organic fertilisers used. An exception is B, which is a standard component of the nutrient solution when irrigation is with rainwater. Phosphorus is deliberately not part of the basic nutrient solution formulas, since it is much more effective and also less costly to place P in the soil via base dressings and soil tillage. Only in exceptional situations is P recommended in the fertigation.

For soil analysis the so called 1:2 volume extract is used (Sonneveld and van den Ende, 1971). Soil samples are evaluated by comparison with the target values, and the adjustments to the basis nutrient solution are recommended correspondingly.

The nutrient solution (whether adjusted or not) is converted into a fertiliser recipe for the preparation of tank stocks. For this purpose it is preferable to use single fertilisers, to match the supply of nutrients with the requirements for crop, water quality and soil conditions. In the case of irrigation water such as rainwater, that is low in Ca and/or Mg, the nutrient solution always contains these elements. As a consequence, separate stock tanks are necessary for Ca fertilisers and SO_4 fertilisers. Formulations with compound fertilisers often show a mismatch with the required ratios of individual elements and, as they do not contain Ca, additional calcium nitrate is required.

Environmental problems

In recent years a number of investigations of the water and nutrient balances in greenhouse-grown crops (Voogt, 2003) have clearly shown that there were large excesses of water and minerals, and that, consequently, the emissions of N and, to a lesser extent, of P to the environment were large (Tables 3 and 4). The problem of these low efficiencies can be summarized as follows.

- High EC and nutrient level in the soil are necessary to meet the crop requirements at the high growth rates obtained under protected cultivation (Sonneveld, 1993).
- High EC levels are essential for product quality improvement (Sonneveld, 1988).
- Irrigation is mainly through overhead sprinkler systems, which are characterized by uneven water supply, which necessitates over-irrigation (Heemskerk *et al.*, 1997).
- It is common practice for growers to over-irrigate the crop. (Voogt, 2003).
- In soil-bound crops surface water is often used, and since it contains rather high salt concentrations, leaching is necessary to prevent salinity problems (Sonneveld, 1995).
- The costs of fertilisation are insignificant compared with the total production costs in greenhouse cropping (Ruijs, 1992).

Table 3. Annual water and mineral use of some glasshouse crops.

Crop	Water	N	P	K
	M^3/ha	--------------------	*kg/ha*	--------------------
Tomato	12,950	1,150	205	1,410
Cucumber	10,400	980	240	1,100
Rose	11,500	990	110	910

Table 4. Water and nitrogen efficiency rates for some crops.

Crop	Water	Nitrogen
Tomato	0.80	0.55
Cucumber	0.79	0.54
Sweet pepper	0.88	0.61
Rose	0.78	0.60
Chrysanthemum	0.65	0.52

Improvements

Fertigation is an excellent method to improve the sustainability of greenhouse production, since it enables both the water movement in the soil and nutrient supply to be controlled. Adjustment of the irrigation strategy is necessary in the first place because vertical transport of water in the soil is the driving force behind mineral losses to the groundwater table or the surrounding surface water.

The success of a fertigation strategy will depend on the variations within the greenhouse, which are caused by the nonuniform distribution of the irrigation system and differences in crop transpiration and evaporation (Fig. 1).

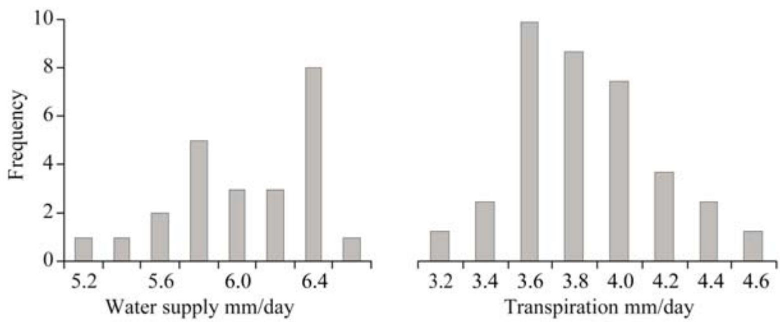

Fig. 1. Frequency distribution of the water supply from drip irrigation, and the water uptake, measured at 32 random spots in a greenhouse tomato crop (van den Burg *et al*., 1987).

Heemskerk *et al.* (1997) listed the distribution variations in a number of sprinkler systems and configurations that are used in practice. With modern wide-broadcasting rotating sprinkler systems the CV (coefficient of variation) can be as low as 5–8%, provided that the appropriate configuration of pipes and emitters is correctly installed and the system is operated at the right pressure. They also found that the CV of new, initially clean systems will increase rapidly, therefore proper filtration and maintenance of the system is important. The same is true of drip irrigation systems, which are widely used for fertigation in greenhouses (van den Burg, 1991).

The water buffering capacity of the soil plays a role in this variation. Moreover, lateral diffusion and horizontal rooting may partly even out spatial variations in moisture content. Assinck and Heinen (2002) simulated root development and water uptake under various conditions of unevenness of irrigation applied to sequential chrysanthemum crops, and concluded that no problems with water stress are to be expected up to a CV of 12%. Moreover, capillary rise and deep root development will supplement the water supply to the crop. These results were found in a practical experiment in which some growers successfully reduced the irrigation surplus (i.e., the irrigation supply minus the calculated evapo-transpiration) to zero or even to negative values, and found that the resulting nutrient losses did not cause any decline in crop performance (Voogt *et al.*, 2002). In this particular case, the water demand by the crop was probably made up from groundwater. Nevertheless this method is not a sustainable solution, because in the long run there will be a threat of salinity problems, since the groundwater always contains salts at higher concentrations than the plant uptake capacity (Sonneveld, 1993). Because of capillary rise, ions will inevitably be transported upwards and so will increase the salt concentration in the topsoil. Eventually severe leaching of the soil is unavoidable, probably with more salts leaching out than would occur under regular low-intensity leaching while the salts are accumulating.

An obvious solution for the problem of mineral emission is the reuse of drainage water, as in the closed-system concept applied in soilless culture (Voogt and Sonneveld, 1997). The majority of protected cultivation in the Netherlands is situated in polder areas where there is a high ground water level. Almost all greenhouses are therefore equipped with drainage systems. These are usually closed systems, with a pump to lower the groundwater level in the greenhouse soil and to drain off the surplus water. As a result of the forced lowering of the groundwater level, the hydrological situation is sometimes complex. The net drainage flow is a combination of percolation of the irrigation surplus from the peripheral soil, seepage from surrounding surface waters and from the groundwater, and leaching to the groundwater. The interpretation of drainage quantity and quality is therefore sometimes difficult. This was illustrated by Voogt (2003), who examined a set of data from 30 greenhouses and showed that it was impossible to correlate the N leaching by drainage with the irrigation or the fertilisation (Fig. 2).

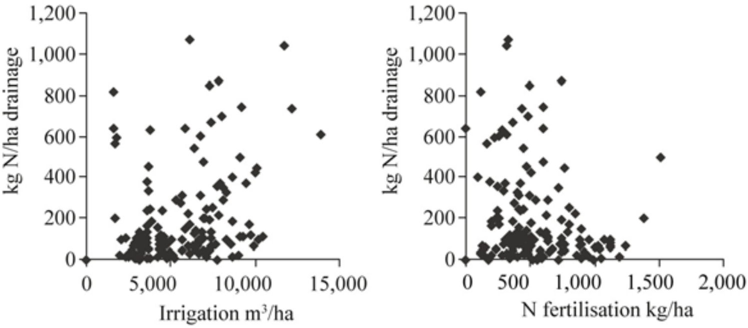

Fig. 2. Relation between the yearly total irrigation (left panel) and the total N fertilisation (right panel) and the total N in the drainage, as monitored in 30 greenhouses during 1996 – 2000 (Voogt, 2003).

However, because of the complex hydrology, mentioned above, a true closed system, based on the standard configurations of drainage systems in soil is virtually impossible. There will always be the risk of diffuse leaching to the shallow groundwater (Boers, 1996). Furthermore, seepage of surface water or adjacent groundwater into drainage pipes must also be considered. Sometimes this causes a quantitative problem (too much drainage in the winter period), and quite often a qualitative problem because of excessive concentrations of ions such as Na, Cl or SO_4. The creation of a closed system, by installing an impermeable layer in the soil is only practicable if the soil layer is deep enough to create sufficient hydraulic pressure to prevent air problems in the root zone. In practical trials, it was shown that depths of 40 cm were insufficient, because of serious problems with soil compaction and air and moisture management (van Emmerik, 1994). Apart from the technical problems, the method is unfeasible from the economic point of view (Ruijs, 1995).

Fertigation model

Systems in which the water and fertiliser supplies are continuously attuned to the demands of the crop will have the best prospects for improving sustainability of soil-grown crops; the “fertigation model” is such a system

(Voogt *et al.*, 2000). The basic principle of this system is that supplies of water and nutrients are determined by the crop demands, which are determined by model calculations. The algorithm for irrigation is based on an evapotranspiration model (de Graaf, 1999) and it contains parameters for irradiation, heating, developmental stage of the crop, and crop- and greenhouse-specific factors. The nutrient uptake is considered to be closely connected with the water uptake and is calculated as uptake concentration, which is derived from empirical data of the average total nutrient and water uptake. For short-term crops such as radish, lettuce and chrysanthemums, one concentration is maintained for the whole cropping period, whereas for long-term crops, such as tomato and sweet pepper, the concentration changes in accordance with the changes in the cropping stage. Fig. 3 presents an example of a long-term tomato crop. Seasonal effects, related to the change in irradiation should be particularly taken into account. Sonneveld and van den Bos (1995) clearly showed with radish that the uptake concentrations of all nutrients in winter (under poor light condition) were four to five times higher than in summer (under abundant light conditions).

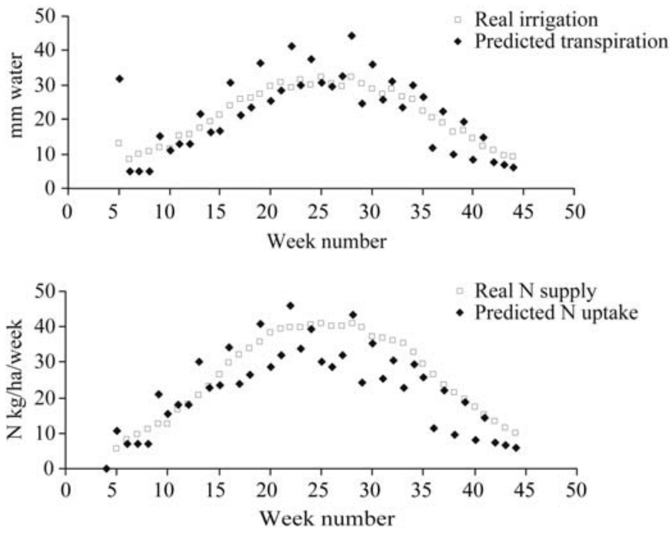

Fig. 3. Predicted irrigation (top) and N supply (bottom) compared with the real irrigation and N-supply in a commercial tomato crop, as recommended by the fertigation model.

To control the model, the moisture content of the soil is measured by means of tensiometers or FD sensors. Feedback on the supply of nutrients can only be obtained through regular soil analysis.

The model was tested in 1999 with satisfactory results (Voogt *et al.*, 2000). Compared with the standard fertigation schedules of the individual growers, the water and N surplus in the test nurseries could be reduced significantly (Fig. 4). However, the results also indicate that zero leaching is difficult to achieve.

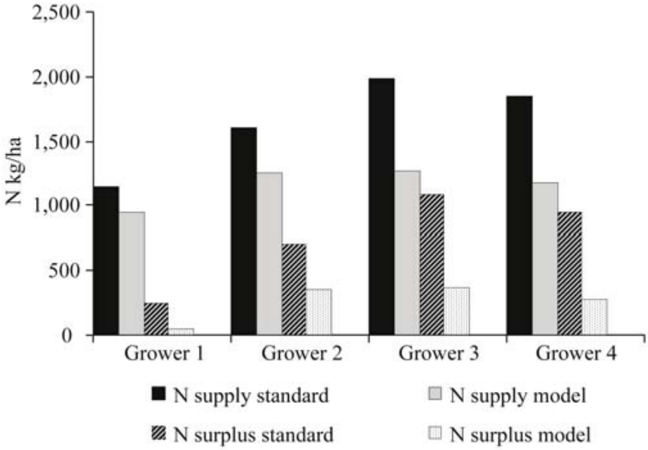

Fig. 4. The yearly N surplus in greenhouse crops of four growers after application of the fertigation model, in comparison with their standard fertigation strategy.

This method enables nutrient leaching to be reduced substantially. In addition to the measures mentioned previously, reduction in the N and P buffer in the soil, i.e., the target values for soil analysis, will improve the result. As already mentioned, the current recommendation system is based on an old concept. Fertilisation schedules were primarily meant to achieve and maintain certain target values in the soil, and it could be deduced from old research results that for the majority of the crops the target values could be reduced without any effect on yield or quality. It was interesting to see that van den Bos (2003) showed clearly that neither yield nor quality of lettuce was negatively affected by lowering the N target values and, consequently, the N supply (Table 5).

Table 5. The average soil mineral N, N supply, yield (average head weight, relative to treatment 1) and N uptake of four successive lettuce crops, in an investigation of lettuce in soil, with four target levels of soil N at the start of the crop (van den Bos, 2003).

Treatment	N target value [(1)]	Mineral N in soil [(1)]	N supply	Yield	N uptake
	-------- *nmol/L* --------		*kg/ha*	*%*	*kg/ha*
1	3	2.1	72	100	138
2	5	3.6	123	103	143
3	7	5.8	189	102	149
4	9	7.4	238	102	147

[(1)] Expressed as the N-min. concentration in the 1:2 volume extract in the top soil (0 - 25 cm depth)

Also with chrysanthemum, reduction in the N-soil buffer was shown to be possible without causing any problems (Voogt *et al.*, 2002). Although the effects on leaching could not be determined in these experiments, one can imagine that a reduction of the N concentration in the soil would at least reduce the risk of N leaching. In specific crops for which the EC value is important for quality, the reduction in N supply must be compensated by application of other salts. For instance van den Bos (pers. comm.) has reported fertiliser trials with radish, in which N was successfully partly replaced by SO_4 and Cl.

van den Bos (2001) also found for P that the recommendation system could be adjusted; in long-term experiments with chrysanthemum and lettuce, he found that even with zero-P treatments there was no effect on crop performance (Table 6). This shows that the vast buffer of P built up in many years over-fertilisation in most greenhouse soils could deliver sufficient P. However, reduction in the P fertilisation will hardly contribute to improvement of the environment, since the leaching of P from greenhouse soils is already very limited. It was shown by Korsten (1995) that the P concentration in drainage water was low, even when the greenhouse soils have a high P content. This is mainly because of the high content of either Fe and Al or $CaCO_3$ in those soils.

Table 6. Results of a 3-year fertiliser trial with 13 successive lettuce crops. Average P-content in the soil expressed as: P in the 1:2 volume extract, Pw value and P-Al content, the P-fertiliser supply, yield (average head weight), P content and P uptake. Treatment 2 is the standard recommended value for P for this soil. (van den Bos, 2001).

Treatment	P supply	P (1:2)	P_w (1)	P-Al (2)	Yield	P cont.	P
	kg/ha	*nmol/L*	*mg/L*	*mg/100 g*	*g/head*	*nmol/kg DM*	*kg/ha*
1	0	0.03	48	122	320	186	641
2	340	0.07	73	133	331	214	739
3	680	0.11	101	146	330	231	789
4	1,020	0.16	132	152	331	242	825
5	1,360	0.22	162	165	332	248	848

(1) P in water extraction, expressed as mg P_2O_5 per liter dry soil
(2) P in extraction of Al-acetate, expressed as mg P_2O_5 per 100 g dry soil

All methods that focus on the reduction of leaching are only successful if water of excellent quality is used. Salinity is a serious problem in the greenhouse industry because of the absence of natural precipitation. Salinity threshold values found for greenhouse crops vary widely among crops and growing conditions (Sonneveld, 1988). Moreover, there is also a considerable interaction between salinity and the fertilisation of crops. It has been shown that when high osmotic pressures are required for certain crops and growing conditions, increasing the levels of nutrients or salts makes no difference. It even appears that in some situations, increased osmotic pressure caused by higher levels of NaCl show advantages above the same increase with nutrients (Adams, 1991). The recommended values for crops grown where there is high osmotic pressure in the soil solution therefore depend on the salinity level. Nevertheless, in spite of the required or acceptable increased salinity levels, water with too high a salt content will, in the long run, lead to salinity problems. In view of the aim of reduced leaching, standards for water quality were drawn up (Table 7).

Table 7. Water quality standards for fertigation with minimum leaching, with respect to salt sensitivity.

Salt sensitivity	EC	Na	Cl	Ca	Mg	SO_4
	dS/m	----------------------		*mmol/L*		----------------------
Sensitivity	<0.5	<1.5	<1.5	<2.0	<1.5	<2.0
Moderate	<1.0	<2.0	<2.5	<3.0	<2.0	<3.0
Tolerant	<1.5	<3.0	<4.0	<4.0	<2.5	<4.0

Conclusion

Because of the complexity of the hydrology of greenhouses, no correlation was found between the amount of irrigation or fertilisation and the quantity of nitrogen leached out by drainage water. Nevertheless, it is clear that the nutrient use efficiency of soil-grown greenhouse crops is low, and the current situation can, therefore, be characterised as unsustainable. Moreover, the intensification of production inevitably leads to further increases in N and P use. Obligatory re-use of drainage water is not applicable to soil-grown crops, because the diversity of hydrological situations makes it too complex. The most promising systems involves the supply of water and nutrients according to crop demand; such systems, like the fertigation model, use model calculations and feedback of soil moisture content. However, such a method can only be applied under restricted conditions. Spatial variations in water supply and crop transpiration should be as low as possible and the method requires irrigation water of perfect quality, to prevent salinity problems. Additional improvements are possible since it was evident that there is a gap between the recommended nutrient levels and the minimum levels for optimal growth. Thus, target values for N and P in the root environment can be reduced.

A complication in the introduction of systems that use reduced supply arises from the current attitude of growers towards irrigation and fertilisation. Since product quality and total yield are much more important to them than water and fertiliser costs, or environmental concerns, modern greenhouse production stimulates fertiliser use rather than reducing it. On the other hand, there is a strong influence from the market, which requires products to be grown under strict licensing conditions which, for instance strictly limit water and fertiliser use.

References

Adams, P. 1991. Effects of increasing salinity of the nutrient solution with major nutrients or sodium chloride on the yield, quality and composition of tomatoes grown in rockwool. Journal of Horticultural Science 66:201-207.

Assinck, F.B.T., and M. Heinen. 2002. Modelverkenning naar het effect van niet uniform verdeelde watergiften op de opname van chrysanten onder glas. Alterra- rapport 393, Wageningen, 36 pp.

Boers, P.C.M. 1996. Nutrient emissions from agriculture in the Netherlands: causes and remedies. *In*: Diffuse pollution '95: Selected proceedings of the 2nd IAWQ International Specialized Conference and Symposia on Diffuse Pollution. Oxford, Pergamon Press, 183-189

de Graaf, R. 1999. Automatic water supply in glasshouse grown crops. Acta Horticulturae 458:103-111.

Heemskerk, M.J., E.A. van Os, M.N.A. Ruijs, and R.W. Schotman. 1997. Verbeteren watergeefsystemen voor grondgebonden teelten. Report 84, Research Station for Glasshouse Vegetables and Floriculture, Naaldwijk, ISSN 1385 3015, 63 pp.

Korsten, P. 1995. Vergelijking orthofosfaat en totaal fosfaat in giet- en draianwater. Research Station for Glasshouse Vegetables and Floriculture. Internal report 6, 12 pp.

Ruijs, M.N.A. 1992. Van grondteelt naar gesloten teelt. Groenten en Fruit vakdeel Glasgroenten 2:64-65.

Ruijs, M. 1995. Economic evaluation of closed production systems in glasshouse horticulture. Acta Horticulturae 340:87-94.

Sonneveld, C. 1988. The salt tolerance of greenhouse crops. Netherlands Journal of Agricultural Science 36:63-73.

Sonneveld, C. 1993. Mineralenbalansen bij kasteelten. Meststoffen 1993:44 – 49.

Sonneveld, C. 1995. Fertigation in the greenhouse industry. *In*: Proceedings of the. 1995 Dahlia Greidinger symposium, Haifa, Technion Institute of technology, Haifa, Israel 121-140.

Sonneveld, C. 2000. Effects of salinity on substrate grown vegetables and ornamentals in greenhouse horticulture. Dissertation, Wageningen University, Wageningen. ISBN 90-5808-190-7. 151 pp.

Sonneveld, C., and J. van den Ende. 1971. Soil analysis by means of a 1:2 volume extract. Plant and Soil 35:506-516.

Sonneveld, C., and A.L. van den Bos. 1995. Effects of nutrient levels on growth and quality of radish (*Raphanus sativus L.*) grown on different substrates. J. Plant Nutr. 18:501-513.

van den Bos, A.L. 2001. Minimale fosfaatbemesting. Research Station for Floriculture and Glasshouse Vegetables, Naaldwijk, Internal report 235. 19 pp.

van den Bos, A.L. 2003. Bemestingsproeven met zware sla. Applied Plant Research, Naaldwijk, Internal Report pp 18.

van den Bos, A.L., de Kreij, C. and Voogt, W. 1999. Bemestingadviesbasis grond. Applied Plant Research, Naaldwijk. ISSN 1387 2427 145 pp.

van den Burg, A.A.M. 1991. Controle druppelsystemen voorkomt verstopping. Vakblad voor de Bloemisterij 46:26, 49.

van den Burg, A.A.M., and P.H. Hamaker. 1987. Variatie in waterafgifte druppelaars en wateropname. Groenten en Fruit vol. 42, 49:30-32.

van Emmerik, P. 1994. Substraatsystemen DENAR op een rij. Vakblad voor de Bloemisterij 49:22-27.

Voogt, W. 2003. Meststofverbruik: realisatie en normverbruik. Applied Plant Research, Naaldwijk Internal Report, 15 pp.

Voogt, W., and C. Sonneveld. 1997. Nutrient management in closed growing systems for greenhouse production in closed ecosystems. *In*: Plant production in closed ecosystems E Goto *et al*. (eds.) Kluwer Academic Publishers, Dordrecht. pp. 83-102.

Voogt, W., J.A. Kipp, R. de Graaf, and L. Spaans. 2000. A fertigation model for glasshouse crops grown in soil. Acta Horticulturae 537:ISHS 2000, 495-502.

Voogt, W., F. Assinck, G. Balendonck, G. Blom-Zandstra, M. Heinen, and F.H. de Zwart. 2002. Minimalisering van de uitspoeling bij teelten in kasgrond. Applied Plant Research, Wageningen, Report 543. 63 pp.

Wunderink, H. 1996. De belasting van het Nederlandse oppervlaktewater met fosfaat en stikstof. Het Waterschap vol. 81, nr 9:304-313.