Evaluation of the 'Fertigation Model', a Decision Support System for Water and Nutrient Supply for Soil Grown Greenhouse Crops

W. Voogt*, A. van Winkel and F. Steinbuch
Applied Plant Research, Glasshouse Horticulture, Wageningen-UR
P.O. Box 8, 2670 AA Naaldwijk
The Netherlands

* Corresponding author

Keywords: soil, evapotranspiration, irrigation, fertiliser supply, chrysanthemum, *Dendranthema grandiflorum*, irrigation surplus, nitrogen surplus

Abstract

Soil grown greenhouse crops require high fertilisation rates. Combined with the common practice of over-irrigation, leaching of nutrients is a serious problem. In order to reduce the environmental impact, a 'fertigation' model was developed as a decision support system for irrigation and fertiliser supply. The applicability in growers practice was evaluated during two years on commercial nurseries, growing chrysanthemum (*Dendranthema grandiflorum*). The evaluation was performed by comparison of the actual water and irrigation strategy of the growers with the strategy recommended by the model in a specific section within the same greenhouse. At one chrysanthemum grower a lysimeter was installed to measure water and nutrient leaching. The model performed well in general, without any yield or quality decline by using the model. The irrigation and the nitrogen surplus were decreased significantly compared to the growers standard and consequently reduced the environmental impact. The results indicate also that application of this model depends highly on the growers' attitude towards the environmental impact of irrigation and fertilisation at one hand and the avoidance of risks at the other.

INTRODUCTION

In contradiction with substrate grown greenhouse crops, soil-grown greenhouse crops in the Netherlands contribute to the pollution by nutrients (N and P) of surface and groundwater substantially (Wunderink, 1996; Boers, 1986). The main reason is the open character of the root environment, with either free leaching of the irrigation surplus to ground water or to drainage systems with discharge directly to surface waters. Drainage water is (partly) re-used at some nurseries but is not a solution in many cases (Voogt and Korsten, 1995). The main cause of the important nutrient emission is the high fertiliser supply, not only for the crop demand but also to achieve high nutrient levels in the root environment. Combined with the common practice of over-irrigation and the fact that in the Dutch soil-grown greenhouse crops fertigation is the standard for fertilisation, leaching of nutrients is a serious problem (Sonneveld, 1995). An apparent solution is to bring down the over-irrigation, to avoid or at least reduce leaching. For this purpose a so-called 'fertigation' model was developed. This is a decision support system for irrigation and fertiliser supply, aiming at supply in match with the crop demand (Voogt et al., 2000). The objective of this work is to investigate the applicability in growers practice. Chrysanthemum was chosen because this crop is the major soil grown greenhouse crop in the Netherlands, moreover the crop at which the nutrient emission appeared to be severe (Baltus and Volker Verboom, 2005). The evaluation was performed by assessing the water and irrigation strategy of three chrysanthemum growers during two years, comparing the growers' own strategies with those recommended by the model in a specific section within the same greenhouse. At one nursery a lysimeter was installed to measure water and nutrient leaching. Specific attention was paid to the applicability of the model in the grower's perception of irrigation and fertilization management for their specific growth concept.

MATERIALS AND METHODS

Three year-round chrysanthemum nurseries, situated in a river clay polder in the centre of the Netherlands, each in the vicinity of 10 km from each other were under investigation. The greenhouses were modern and 7, 2 and 1 year old, with a light transmission of 72, 79 and 80% for grower A, B and C respectively. All greenhouses were equipped with supplementary lighting. All three were more or less heavy clay soils, with 21 till 28% clay (< µm) respectively and a ground water level between 80 and 90 cm below field level.

Treatments

Two treatments: Standard and Model were compared at all growers, in adjoining irrigation sections of the greenhouses, both sections differed at maximum only 3 days in planting and the average harvesting date. **Standard**, the growers' own strategy on irrigation and fertilization was used; **Model**, irrigation and fertilization was applied according to the model calculations, with the following restrictions: irrigation frequency was performed according to the growers' judgement, for decisions on irrigation quantity and nutrient concentrations the output of the model was leading, however the grower was free to adjust the recommended supply to his own judgment.

The fertigation model used is an empirical model and consists of separate algorithms for the estimation of evaporation and nutrient uptake (Voogt et al., 2000).

As a consequence of the incomparability of the three nurseries (time, place, growing conditions), no statistical analysis were performed on the data. The yield results of each individual crop were analysed by ANOVA.

Evapotranspiration Model

A linear regression model is used based on variables routinely recorded by climate computers (de Graaf and van den Ende, 1981; de Graaf, 1988). The total evapotranspiration integrated over time in mm is defined as

$$T_c = (a_t R_o + b_t DM)\, s \qquad (1)$$

where R_o = global radiation measured outside the greenhouse integrated over time (J cm^{-2}), DM = temperature difference between the heating pipes and the greenhouse air temperature in °C, integrated over time in 'degree minutes', a_t, b_t = empirical crop factor: 2.0×10^{-3} (mm (J cm^{-2})$^{-1}$) and 0.18×10^{-4} (mm (°C min)$^{-1}$) for factor a_t and b_t respectively for chrysanthemum, s = plant size factor, defined as the ratio of the actual plant length (cm) to mature plants (LAI > 3). Equation (1) was modified to the situation in modern greenhouses, with artificial lighting, to introduce the effect of light transmission in and the effect of screening:

$$T_c = (a_t (c\, s_t R_o + R_a) + b_t DM)\, s \qquad (2)$$

where R_a = effective radiation from supplementary lighting during operating hours, c = factor for light transmission of the greenhouse, expressed as the ratio of the actual transmission to 0.68 (being the factor of the greenhouses the empirical crop factors a and b were derived from) and s_t = factor for opening (1) or closure (0) of the screen.

During the cropping period, T_c was computed continuously by the climate computers. The necessary driving variables were measured every minute; global radiation was measured with solarimeters; Platinum resistance Thermometers and NTC sensors were used to measure temperature from the greenhouse air and the heating pipes; plant length was determined by an empirical growth curve for chrysanthemum and was weekly checked by observations.

Nutrient Uptake

A simple approach was used, given the fact that nutrient uptake is closely related to the water uptake and that the soil buffer is very large in relation to the daily uptake

(Voogt, 2001). The total estimated nutrient uptake of one cropping cycle was derived from the linear relationship between expected yield and uptake (Voogt, 2003). For simplification, the water uptake was assumed to be equal to the evapotranspiration. The total expected water uptake was calculated using eq. (2) and average climatical conditions and development stages of the crop. The total N and K uptake per crop was allocated to weekly periods linearly, based on T_c. Subsequently the uptake concentration per period for N and K was calculated by dividing the weekly N and K uptake by the water uptake. Concentrations of Mg, Ca, SO_4 were derived from the calculated N and K concentration and fixed ratios of these elements towards N and K corresponding with the standard recommendation system, from which eventually the basic nutrient solution and the fertiliser recipe were calculated, according to the standard procedure (van den Bos et al., 1999).

Lysimeter

At grower B a simple lysimeter was installed in the section of the model treatment. A pit of 2.1 * 2 * 0.80 m was made and coated with 1.5 mm polypropylene foil, covering 4.2 m^2 of representative cropping area. The soil was removed in three layers (0-25, 25-50 and 50-80 cm) and after installation carefully replaced. The bottom was funnel shaped and provided with a layer of 10 cm expanded clay granules (fraction 20-50 mm), connected with a drainage reservoir. Drainage water was pumped out by a peristaltic pump provided with an automatic level switch and collected in a tank, for further analysis. The pump flow was logged at the central computer.

Data Collection and Crop Observations

Growers were visited every two-three weeks: for sampling, data collection and exchange judgments of irrigation and fertiliser strategy. Soil samples were taken from soil layers: 0-25 cm and 25-50 cm, analysed for macro elements. At harvest of each crop, plant length, weight and quality class was observed from 5 random spots with each 5 plants, plant samples were dried and analyzed for dry matter and macro-element content by total according to the method described by de Bes (1986). From all crops observed the irrigation surplus S_w,with respect to the model prediction, was determined as

$$S_w = I_t - T_c \tag{3}$$

where I_t = total irrigation in mm. S_w was calculated for each individual crop using total I_t and T_c of the whole cropping period. Furthermore S_w was calculated as the cumulative irrigation surplus using the cumulative data during the cropping period where I_t and T_c were reset to zero at te start of each crop.

The nitrogen surplus S_N was calculated in two ways, as

$$S_{Nc} = N_{It} - N_c \tag{4}$$

where N_c = total N uptake predicted by the model calculations and N_{It} = total N supplied by fertigation in kg ha^{-1}, or as

$$S_{Nm} = N_{It} - N_m \tag{5}$$

where N_m = total N determined by dry matter analysis and yield in kg ha^{-1}.

The output of the three climate computers was compared and verified with off-line calculations, using the datasets from the growers.

Irrigation Strategy

In all greenhouses overhead sprinklers were used. The irrigation frequency was to the judgment of the grower and varied from once a week in winter to every two days during peaks in summer. During the last 2 weeks (winter) or 10 days (summer) of a cropping cycle irrigation was stopped to avoid damage on the flowers. The accumulated water shortage was compensated at the start of the next crop, coinciding with the common practice to apply a large initial irrigation right after planting. The growers' own strategy was based on experience, the actual weather, soil condition and expectancies of the oncoming period, sometimes they used additional information like the actual soil moisture content (tensiometers, manual judgement).

Fertilisation

All fertilisers were supplied by fertigation, except for phosphate. The nutrient solution used differed among the growers, mainly because of differences in K management in connection with site specific soil conditions. The growers' strategy was based on experience and judgement of recent soil analysis. Mainly the EC of the supply was used for adjustments to correct the deviation from the growers' standard. Adjustments to the fertiliser recipe were secondary. At grower B 500 T ha^{-1} green-compost was supplied in the second year in his whole greenhouse.

RESULTS AND DISCUSSION

No significant differences were found in the observed yields or in flower quality between both treatments in all crops.

The T_c over equal periods differed among the three growers (Table 1). Grower A was approximately 15% lower in transpiration than the other two. This is obviously caused by the lower transmission rate of his older greenhouse. Comparison of the greenhouse computer output and the off-line calculations, showed sometimes unexpected differences. It turned out that these were mainly due to errors in the data registration, however, sometimes parameters were erroneously changed by the grower. This illustrates the need for improvements in the robustness of the application. The irrigation was lower in the model treatment compared to the standard at all three growers. The difference was largest for grower B. Additionally, the total water supply among the three growers was quite different. This is likely to be connected with the growers' own judgments as is demonstrated by the irrigation strategy which is rather different among the growers (Table 2). The lowest irrigations per event were found at grower A, the highest at grower B, in particular the maximum and the initial irrigation, right after planting. These results illustrate the differences in perception towards irrigation management in practice, as was reported also in Baltus and Volker-Verboom (2005).

As irrigation events are carried out in a 2 till 4 days frequency, the cumulative S_w oscillates considerably (Fig. 1). In agreement with common practice, the irrigation was stopped 10 days till 2 weeks before harvest of each crop, causing a negative S_w and so depletion of the soil moisture content during the remaining days (Fig. 1). The maximum quantity depleted was about 60 mm for crops in summer, which is within the range of available water in the soil profile, nevertheless the shortage is likely to be compensated by capillary rise from the groundwater table, or deeper rooting. The negative accumulated water shortage in a cropping cycle was compensated by the initial and next irrigations at the start of the successive crop. However, the approach of the compensation appeared to be quite different among the growers (Table 2).

I_t was higher than T_c in both years for all three growers, but S_w was significantly lower in the model treatments than in the standard. S_w was higher in year 2 at grower A and B, in particular in the standard. Both growers deliberately decided to the higher irrigation, for grower A it was because of his opinion that the soil profile was drying out too strongly, whilst with grower B, the high compost application had increased the salt content of the soil too much. For both growers there is still a significant difference in S_w between the standard and the model treatment. For grower C the results in the first year were satisfying and convincing which moved him to application of the model for his entire greenhouse.

The variation in the results between the growers could not be attributed clearly to differences in greenhouse, soil, hydrology or other characteristics but mainly to their individual attitude. Since they were free in interpretation and actions upon the model output, adjustments were made regularly, based on their own interpretation and experience.

The leaching from the lysimeter matched with the calculated irrigation surplus from grower B in the model treatment over the same period. However because of the bulky volume of the lysimeter, the time delay for drainage is obviously high. A peak in the estimated irrigation surplus can be observed > 24 hr later in the leachate. Moreover, due to the hysteresis effect of depletion and re-saturation of the soil the time constant for the system will be unstable. So the data cannot be used for quantitative validation of the model and are only useful for evaluation on the long run. Over a period of 16 months, the progression of the measured leaching shows a good resemblance with the calculated irrigation surplus (Fig. 2) and eventually the difference is only 10%. Periods of depletion of the soil moisture are obviously not present in the leaching and only visible as a flat period in the curve of the leachate.

Taking into account the variability in conditions of the individual crops, the N uptake as approached by eq. (4) and (5), N_c and N_m show a acceptable match (Fig. 3), nevertheless, the result for individual crops varied considerably over two years. According to Zerche (1997) and Gonzalez and Bertsch (1989) the discrepancy will be - next to stochastical variation in the tissue analysis - probably connected with site specific conditions (e.g. soil, greenhouse, cultivars) and these parameters are not yet part of the nutrient uptake module. N_c and N_m are lower for grower A compared to the others in both years and this is likely caused by the lower light transmission of the greenhouse.

As expected, N_{It} was considerably higher in the control than in the fertigation treatment for all growers, due to the higher irrigation in the control. The differences in N supply between the individual fertigation treatment plots should match up with those in the water supply. However, due to specific adjustments in the N concentrations made by the growers, the differences in N and water supply between specific growers or years diverge. Particularly for grower B the contrast between year 1 and 2 is large and is due to a general reduction in the fertiliser supply as a consequence of the additional heavy compost application.

Except for grower B in the 2nd year (for obvious reasons) the N surplus is positive and clearly much higher in the standard treatments than in the model treatments, irrespective of considering S_{Nc} or S_{Nm} as parameter (Table 3). Thus, in general the use of the fertigation model reduces excessive N fertilisation, nevertheless in some cases the N-surplus is still pretty high. Main steps in further improvements are likely to be made if the decisions for actual are more tuned to the results of the fertigation model calculations.

Furthermore, the applicability of the fertigation model has shown to depend highly on the growers attitude towards the problem of nutrient leaching.

Literature Cited

Baltus, C.A.M. and Volkers-Verboom, L.W. 2005. Onderzoek naar emissies van N en P vanuit de glastuinbouw. RIZA, rapport 2005.007, Lelystad. 54p.

Boers, P.C.M. 1996. Nutrient emissions from agriculture in the Netherlands causes and remedies. Diffuse pollution '95. Proc. 2nd IAWQ Intl. Specialized Conf. and Symp. on Diffuse Pollution, Oxford, Pergamon Press. p.183-189.

de Bes, S.S. 1986. A summary of methods for analysing glasshouse crops. PBG, Internal report, Naaldwijk, the Netherlands. 5p.

de Graaf, R. and van den Ende, J. 1981. Transpiration and evapotranspiration of the glasshouse crops. Acta Hort. 119:147-157.

de Graaf, R. 1988. Automation of the water supply of glasshouse crops by means of calculating the transpiration and measuring the amount of drainage water. Acta Hort. 229:219-231.

Gonzalez, P. and Bertsch, F. 1989. Nutrient absorption by chrysanthemum (*Chrysanthemum morifolium*) cv. 'Super White' throughout one life cycle in a greenhouse. Agronomia-Costarricense 13(1):51-60.

Sonneveld, C. 1995. Fertigation in the greenhouse industry. Proc. 1995 Dahlia Greidinger Symposium, Haifa, Israel. p.121-140.
van den Bos, A.L., de Kreij, C. and Voogt, W. 1999. Bemestingadviesbasis grond. Applied Plant Research, Naaldwijk, ISSN 1387 2427. 145p.
Voogt, W., Kipp, J.A., de Graaf, R. and Spaans, L. 2000. A fertigation model for glasshouse crops grown in soil. Acta Hort. 537:495-502.
Voogt, W. and Korsten, P. 1995. Complicaties bij hergebruik drainwater. Vakblad voor de Bloemisterij 50(43):108-109.
Voogt, W. 2001. Improving the nitrogen efficiency in soil grown glasshouse crops, by using the fertigation model. Proc. Int. Fert. Soc. & Dahlia Greidinger Symp., Lisbon, 4-7 March 2001. p.551-554.
Voogt, W. 2003. Nutrient management in soil and soil-less culture in the Netherlands: towards environmental goals. Proc. Int. Fert. Soc. & the 2003 Dahlia Greidinger Symp., Izmir, 7-10 Dec. 2003. p.1-27.
Wunderink, H. 1996. De belasting van het Nederlandse oppervlaktewater met fosfaat en stikstof. Het waterschap 81(9):304-311.
Zerche, S. 1997. Nitrogen uptake and total dry matter production of cut chrysanthemum (*Dendranthema grandiflorum*-hybrids) in relation to shoot height and planting date. Gartenbauwissenschaft 62(3):119-128.

Tables

Table 1. The calculated evapotranspiration (T_c), the total irrigation (I_t) and the calculated irrigation surplus, in l m^{-2} $year^{-1}$, and the relative water use efficiency (WUE) of the model treatment (M) and the control (C).

Grower	Year	Evapo-transpiration T_c	Irrigation I_t		Irrigation surplus S_w		WUE %	
			M	C	M	C	M	C
A	1	687	756	769	69	83	91	89
	2	779	874	1026	95	247	89	76
B	1	799	918	1254	119	455	87	64
	2	850	1076	1165	227	315	79	73
C	1	785	972	1051	187	266	81	75
	2	843	868	893	25	50	97	94

Table 2. The irrigation strategy of the three growers, expressed as the average and the range of the irrigation per event and the average initial irrigation performed right after each new planting.

Grower	Year	Irrigation per event (l m^{-2})			
		Initial	Average	Min	Max
A	1	13	8	4	15
	2	9	10	4	18
B	1	11	12	4	24
	2	28	12	2	28
C	1	18	10	5	14
	2	15	10	5	14

Table 3. N uptake derived from the model calculations (N_c) and from yield and dry matter determination (N_m), N supply, N surplus calculated from eq. (4) (S_{Nc}) and from eq. (5) (S_{Nm}), from the model treatment plots (M) and the control plots (C), in kg N ha^{-1} $year^{-1}$.

Grower	Year	N-uptake		N-supply N_{It}		N-surplus S_{Nc}		N-surplus S_{Nm}	
		N_c	N_m	M	C	M	C	M	C
A	1	714	855	769	969	55	254	-86	113
	2	704	680	890	1174	186	470	210	494
B	1	881	772	935	1515	54	634	163	743
	2	949	947	718	815	-231	-134	-229	-132
C	1	894	979	990	1268	96	375	11	289
	2	862	944	883	1216	21	353	-61	271

Figures

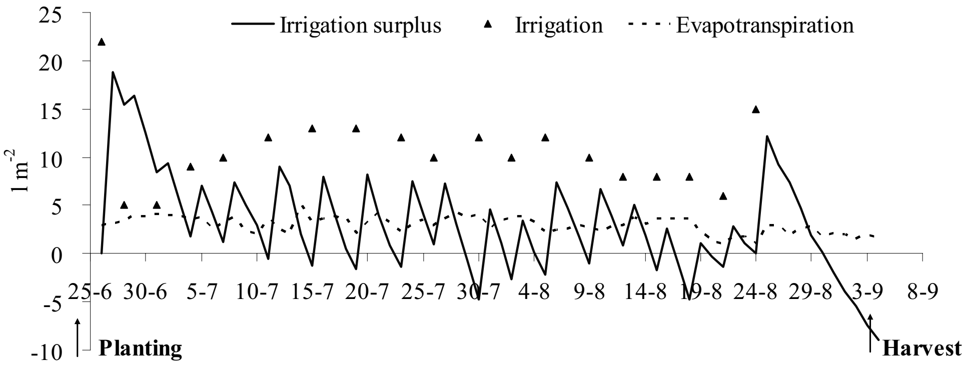

Fig. 1. The realized irrigation (l m^{-2} per event), the calculated evapotranspiration (l m^{-2} day^{-1}) and the cumulative irrigation surplus (l m^{-2}) (S_w) during one cropping cycle (Grower A).

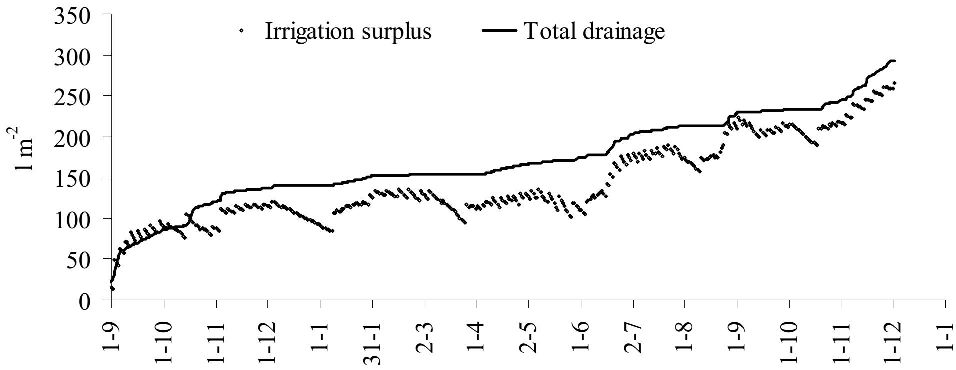

Fig. 2. The cumulative irrigation surplus (S_w) in the model treatment and the measured drainage in the lysimeter cumulated over 15 months, in l m^{-2} (Grower B).

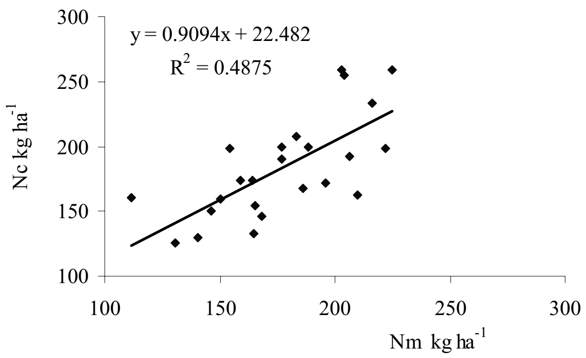

Fig. 3. Comparison of the measured N-uptake (*Nm*) and predicted uptake by the model (*Nc*) of the individual crops of all growers in two years.