Crop Specific Application Rates of Nitrogen for Soil-Grown Crops in Greenhouses to Protect the Groundwater

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Abstract

In a desk study, nitrogen (N) fertilizer application rates were studied and N-concentrations at one meter depth or at the drain were estimated for Chrysanthemum grown in twelve greenhouse cropping systems, differing in soil type, supplemental lighting and transmissivity. Two N-saving strategies were also studied of which one estimated the N-concentration in the irrigation water to comply with the EU target value of 11.3 mg N L^{-1}. N-surplus varied between 6 and over 709 kg ha^{-1} yr^{-1}. The N-saving strategies reduced the N-surplus but none of the estimated N-concentrations were below the target value. Growers affect both the N-surplus and the irrigation surplus. Predefined concentrations are therefore not met if only N-fertilizers are regulated through crop specific application rates. Guidelines on irrigation applications need to be provided as well.

INTRODUCTION

In order to comply with the European target value of 11.3 mg N L^{-1} in the shallow groundwater, crop specific N-application rates are introduced by the Dutch government. Specific application rates are developed to ensure maximum nitrate-N surpluses which leach to the groundwater. Under steady state conditions, the nitrate concentration in the percolating soil solution is calculated as this N-surplus divided by the annual winter precipitation surplus, and meets the target value in the shallow groundwater (Schröder et al., 2004). The crop specific application rates are defined for every crop grown outdoors. Among other measures, crop specific application rates contribute to reduce nitrate concentrations for outdoor crops (Jørgensen, 2004). However, questions can be raised if this approach is applicable to soil-grown greenhouse crops as irrigation and fertilization strategies, and conditions of nitrate leaching differ considerably with outdoor crops and there is obviously no precipitation surplus in the autumn/winter period. It is therefore not clear whether the methodology applied to outdoor crops can be used for soil-grown greenhouse crops. A desk study using cut Chrysanthemum (*Dendranthema*) as a model crop was therefore performed.

MATERIALS AND METHODS

Cropping Systems

Twelve greenhouse cropping systems for soil-grown Chrysanthemum, representing the majority of systems in the Netherlands, were defined in this study: dry and wet sandy soils, clay and peaty clay soils were considered, greenhouses with low and high light-transmissivity (65 and 83%) and with or without use of supplemental lighting (130 µmol m^{-2} s^{-1}, 10 to 20 hours per day) (Table 1). For steady state conditions with respect to soil fertility aspects (no change in soil organic matter content), a (nitrate) N-surplus ($N_{surplus}$, kg ha^{-1} yr^{-1}) was calculated for each greenhouse cropping system according to:

$$N_{surplus} = N_{fert} + N_{org} - N_{rem} - N_d \quad (1)$$

where N_{fert} is the applied N-fertilizer (kg ha^{-1} yr^{-1}), N_{org} the amount of N mineralized from organic applications (kg ha^{-1} yr^{-1}), N_{rem} is the N removal by the harvested crop and crop residues at the end of the cropping period (kg ha^{-1} yr^{-1}) and N_d is the N lost through denitrification (kg ha^{-1} yr^{-1}). N_{fert} was based on the fertilizer recommendations of 8 to 11 mmol L^{-1} N in the irrigation water multiplied by the applied irrigation amount (see formula 2). N_{rem} was deduced from measurements of commercial greenhouses throughout the Netherlands from 1994 to 2003 and ranged from 750 to 1000 kg N ha^{-1} (4.5 crops/year, Table 2). Although some cropping systems were not investigated, soil type has a minor effect on N_{rem}. The standardized value of 750 kg N ha^{-1} for systems 3, 6, 9 and 12 may seem high compared to the measured value of 500 kg N ha^{-1}. However, these data were found in 1994 and 1995 and corrected for increased productions for the last decade. The estimated denitrification was taken from Heinen (2006) for Dutch conditions:

$$N_d = N_p * f_N * f_S * f_T \quad (2)$$

in which the potential denitrification rate N_p (kg ha^{-1} year^{-1}) is reduced by dimensionless reduction functions for the nitrate concentration in the soil (f_N), the degree of saturation (f_S) and the temperature (f_T). The temperature was assumed to be 20°C resulting in $f_T = 1$. The potential denitrification rate was soil specific (Heinen, 2006). As denitrification is extremely sensitive for f_S, two soil specific sets of parameter values resulting in a high and a low value for f_S (Heinen, 2006) were used to indicate a range of N_d.

The N-concentration (N_{conc}, mg L^{-1}) in the percolating soil solution was calculated as:

$$N_{conc} = \frac{N_{surplus}}{I_{surplus}} \quad (3)$$

where $I_{surplus}$ is the irrigation surplus (applied irrigation minus the evapotranspiration). The standard evapotranspiration of 721 mm year^{-1} for Chrysanthemum (independent of soil type; Voogt et al., 2002) grown in a greenhouse with low transmissivity of light and no supplemental lighting (cropping system 3, 6, 9 and 12; Table 1) was increased by 18% when the transmissivity was high. In addition, the standard evapotranspiration was increased by 115 mm year^{-1} to correct for additional lighting whereas no corrections were made for soil type.

Standard Fertigation Strategy

Differences in the total amount of N applied by fertilizers N_{fert} usually evolve through different irrigation strategies as N-concentrations in the irrigation water are in agreement with recommendations and irrigation amounts are adjusted to the crop's needs. The irrigation in the standard strategy resembles irrigation in practice and was proportional to the evapotranspiration. In all systems irrigation was 15% higher than estimated evapotranspiration in order to ensure an even distribution of irrigation water. Irrigation was adapted for soil type, +29% for the dry sandy soil, +12.5% for the wet sandy soil, -20% for the peaty clay soil and +8% for the clay soil (Table 1). In case supplemental lighting was applied, irrigation was increased by 115 mm.

N-Saving Strategies

Two N-saving strategies were studied. The first strategy involved a reduction of the irrigation amount by 15%, which subsequently resulted in a reduced N_{fert}. The second strategy was based on reaching the target value of 11.3 mg N L^{-1} in the percolating soil solution. The allowed N-concentration of the irrigation water was calculated from the regulatory limit, provided the irrigation was performed as in the standard strategy.

RESULTS AND DISCUSSION

Standard Fertigation Strategy

N_{fert} ranged from more than 1000 to 1700 kg N ha^{-1} yr^{-1} (Table 3), depending on the cropping system. N_d ranged from 0 to 509 kg N ha^{-1} yr^{-1} from dry sandy soils to clay soils, respectively. $N_{surplus}$ varied between 6 and 709 kg N ha^{-1} yr^{-1} depending on cropping system and a high or low degree of saturation for the denitrification calculations. $N_{surplus}$ was considerably higher than the reported 190 kg N ha^{-1} yr^{-1} in the Netherlands for field grown crops (Fraters et al., 2004). N_{conc} was between 5 and 26 times the European target value. Even with an estimated $N_{surplus}$ of only 101 kg ha^{-1} yr^{-1} for system 12, which is within the range of accepted $N_{surplus}$ values for arable crops on clay soils (Schröder et al., 2004), the N_{conc} exceeded the target value. An annual $N_{surplus}$ of 101 kg ha^{-1} corresponds with only 22 kg ha^{-1} surplus per crop, which is rather low compared to surpluses of horticultural crops grown in the open (Van Dijk and Smit, 2006).

N-Saving Strategies

N_{fert} was reduced by reduced irrigation applications (Table 4). In addition, $I_{surplus}$ was reduced as well. However, N_{conc} was increased and still outranged the target value. Optimized irrigation strategies will not automatically result in N_{conc} which comply with the regulatory limit as was also found by Pronk et al. (2007). The predicted N-concentration in the irrigation water, to comply with the regulatory limit varied between 4.6 to 5.8 mM for cropping systems 1-6 and 10-12 (Table 5). This is considerably lower than the fertilizer recommendations for these cropping systems and will most likely reduce crop production. On peaty clay soils the recommendations may still be followed.

As expected, $N_{surplus}$ was positively related to $I_{surplus}$ (Fig. 1A, regression line fitted through all results). $I_{surplus}$ did not significantly affect N_{conc} (Fig. 1B). In this study, the higher $I_{surplus}$ did not result in N_{conc} in agreement with the regulatory limit. However, this may be the case if $I_{surplus}$ was considerably increased. N_{conc} was also not related to $N_{surplus}$ (Fig. 2).

CONCLUSIONS

In this desk study with Chrysanthemum as a model crop, reduced N_{fert} by reduced irrigation applications lowered total N losses to the groundwater. However, N_{conc} in the percolating soil solution was not automatically reduced as well. Therefore, crop specific application rate on itself for soil grown crops in greenhouses will not guarantee that the EU target concentration will be met. Growers have to adjust both $N_{surplus}$ and $I_{surplus}$. A sound system to meet N_{conc} below any target concentration for soil-grown greenhouse crops should include guidelines on N_{fert} as well as on irrigation.

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Tables

Table 1. Nitrogen removed by the crop (N_{rem}; kg ha^{-1} yr^{-1}), evapotranspiration (mm yr^{-1}) and irrigation (mm yr^{-1}) for the twelve greenhouse cropping systems for soil-grown Chrysanthemum.

System	Soil type	Transmisivity[1]	Lighting[2]	N_{rem}	Evapotranspiration	Irrigation
1	Dry sand	High	Yes	1000	966	1437
2	Dry sand	High	No	900	836	1244
3	Dry sand	Low	No	750	721	1073
4	Wet sand	High	Yes	1000	966	1249
5	Wet sand	High	No	900	836	1082
6	Wet sand	Low	No	750	721	933
7	Peaty clay	High	Yes	1000	966	889
8	Peaty clay	High	No	900	836	769
9	Peaty clay	Low	No	750	721	663
10	Clay	High	Yes	1000	966	1199
11	Clay	High	No	900	836	1038
12	Clay	Low	No	750	721	895

[1]Low and high light transmissivity of the greenhouse (65 and 85%).
[2]Supplemental lighting was used 10-20 hours per day at 130 µmol m^{-2} s^{-1}.

Table 2. Measured annual N removal (N_{rem} kg ha^{-1}) and standard deviation of Chrysanthemum of different growers between 1994 and 2003 (after Pronk et al., 2005).

Soil type	Transmisivity[1]	Lighting[2]	n[3]	N_{rem}	Standard deviation
Clay	high	yes	6	994	121
	high	no	2	856	106
	low	yes	2	770	25
	low	no	6	531	46
Peaty clay	low	yes	2	882	141
Sand	high	no	2	881	103
	low	no	3	439	36
Average	High	yes	6	955	124
	low	yes	4	829	91
	low	no	9	500	61

[1]Low and high light transmissivity of the greenhouse (65 and 85%).
[2]Supplemental lighting was used 10-20 hours per day at 130 µmol m^{-2} s^{-1}.
[3]Number of measurements.

Table 3. Nitrogen application (N_{fert}; kg ha^{-1} yr^{-1}), irrigation surplus ($I_{surplus}$; mm yr^{-1}), nitrogen denitrification (N_d; kg ha^{-1} yr^{-1}), nitrogen surplus ($N_{surplus}$; kg ha^{-1} yr^{-1}) and nitrogen concentration (N_{conc}; mg L^{-1}) for the standard fertigation strategy for high or low degree of saturation (f_S).

			high f_S			low f_S		
System	N_{fert}	$I_{surplus}$	N_d	$N_{surplus}$	N_{conc}	N_d	$N_{surplus}$	N_{conc}
1	1709	471	214	496	105	0	709	151
2	1493	408	181	412	101	0	593	145
3	1301	352	165	387	110	0	551	157
4	1499	284	200	299	106	0	499	176
5	1311	246	176	235	96	0	411	167
6	1145	212	168	226	107	0	395	186
7	1368	-77[1]	393	-	-	362	6	-
8	1184	-67	326	-	-	279	6	-
9	1022	-58	284	-	-	272	-	-
10	1670	234	509	161	69	23	647	277
11	1456	202	444	112	56	0	556	275
12	1266	174	415	101	58	15	500	287

[1]In case of a precipitation shortage no concentration was calculated.

Table 4. Nitrogen application (N_{fert}; kg ha^{-1} yr^{-1}), irrigation surplus ($I_{surplus}$; mm yr^{-1}), nitrogen denitrification (N_d; kg ha^{-1} yr^{-1}), nitrogen surplus ($N_{surplus}$; kg ha^{-1} yr^{-1}) and nitrogen concentration (N_{conc}; mg L^{-1}) for the N-saving strategy through reduced irrigation applications for high or low degree of saturation (f_S).

			high f_S			low f_S		
System	N_{fert}	$I_{surplus}$	N_d	$N_{surplus}$	N_{conc}	N_d	$N_{surplus}$	N_{conc}
1	1500	286	151	355	124	0	506	177
2	1311	260	129	292	112	0	421	162
3	1145	215	116	287	134	0	403	188
4	1316	122	149	174	142	0	323	264
5	1154	107	127	136	127	0	262	245
6	1009	93	126	143	154	0	269	289
7	1290	-193[1]	136	62	-	35	163	-
8	1130	-165	100	38	-	26	112	-
9	988	-143	102	42	-	27	117	-
10	1487	78	359	109	139	7	461	589
11	1300	69	309	75	108	6	378	545
12	1135	60	296	70	117	5	360	601

[1]In case of a precipitation shortage no concentration was calculated.

Table 5. Results on the N-application (N_{fert}, kg ha^{-1} yr^{-1}) and the N-concentration (mM) in the irrigation water to meet the 11.3 mg N L^{-1} target value for high or low degree of saturation (f_S).

	high f_S		low f_S	
System	N_{fert}	N-concentration	N_{fert}	N-concentration
1	1267	5.8	1053	4.7
2	1127	5.9	946	4.9
3	954	5.7	790	4.6
4	1232	6.5	1032	5.3
5	1104	6.6	928	5.5
6	942	6.4	774	5.2
7	1200	9.6	1368	11.0
8	1184	11.0	1184	11.0
9	1022	11.0	1022	11.0
10	1536	8.7	1049	5.8
11	1367	8.9	923	5.8
12	1185	8.9	785	5.7

Figures

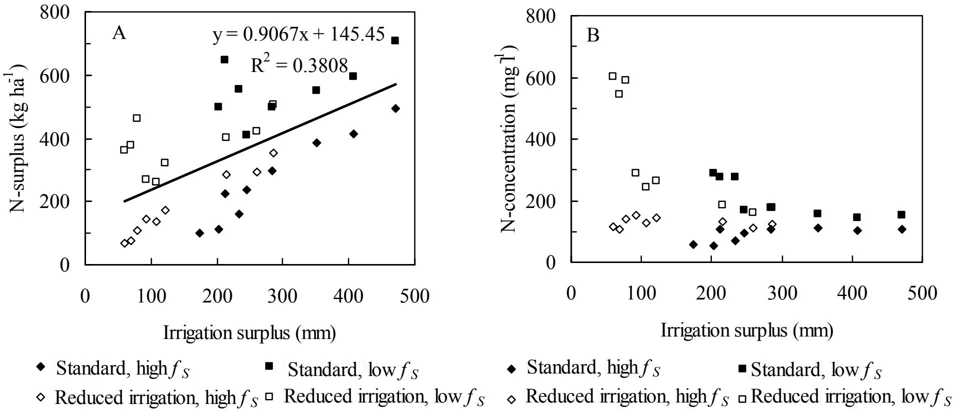

Fig. 1. $N_{surplus}$ (A) and N_{conc} (B) related to $I_{surplus}$ for the standard fertigation strategy and the reduced irrigation strategy for high or low degree of saturation (f_S).

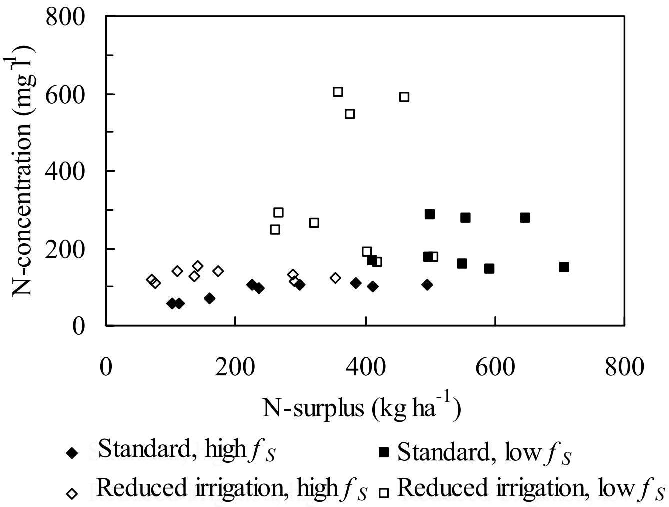

Fig. 2. $N_{surplus}$ related to N_{conc} (concentration in percolating soil solution) for the standard fertigation strategy and the reduced irrigation strategy for high or low degree of saturation (f_S).