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1

## 2 **Tracking nitrogen losses i 1 n a greenhouse crop rotation experiment in** 3 **North China using the EU-Rotate\_N simulation model**

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19

### 20 **Abstract:**

21 Vegetable production in China is associated with high inputs of nitrogen, posing a  
22 risk of  
23 losses to the environment. Organic matter mineralisation is a considerable source of  
24 nitrogen (N) which is hard to quantify. In a two-year greenhouse cucumber  
25 experiment with  
26 different N treatments in North China, non-observed pathways of the N cycle were  
27 estimated using the EU-Rotate\_N simulation model. EU-Rotate\_N was calibrated  
28 against  
29 crop dry matter and soil moisture data to predict crop N uptake, soil mineral N  
30 contents, N  
31 mineralisation and N loss. Crop N uptake (Modelling Efficiencies (ME) between 0.80  
32 and  
33 0.92) and soil mineral N contents in different soil layers (ME between 0.24 and 0.74)  
34 were  
35 satisfactorily simulated by the model for all N treatments except for the traditional N  
36 management. The model predicted high N mineralisation rates and N leaching  
37 losses,  
38 suggesting that previously published estimates of N leaching for these production  
39 systems  
40 strongly underestimated the mineralisation of N from organic matter.

41

42

43 *Keywords:* EU-Rotate\_N model; greenhouse; cucumber; fertiliser recommendations;  
44 nitrogen loss

45

### 46 *Capsule*

47 *The EU-Rotate\_N model can satisfactorily simulate crop N uptake and N<sub>min</sub> dynamics in a*

39 *typical greenhouse cucumber production system of North China*

40

#### 41 **1. Introduction**

42 Over the past two decades the area of greenhouse vegetables has greatly increased from

43 20,000 ha to 600,000 ha in China (Li, 2005). Efficient nutrient and water management is

44 crucially important in sustainable vegetable production. Shallow-rooted vegetable production in greenhouses is associated with high inputs of water and nutrients posing a

46 high risk of N losses to the environment in North China. Recent investigations have revealed that excessive N fertiliser applications with less than 10% of fertiliser N being

3

48 recovered are commonly found in the intensive greenhouse vegetable planting systems in

49 northern China (Chen et al., 2004; Zhu et al., 2005). Consequently, high proportions of

50 unused nitrogen are lost to the environment by nitrate leaching, denitrification and  $\text{NH}_3$

51 volatilisation (Cabrera and Chiang, 1994; Fox et al., 1996; Gollany et al., 2004, He et al.,

52 2007; Ramos et al., 2002). The intensification of greenhouse vegetable production has been

53 accompanied by an increase of nitrate concentrations in groundwater. For example, nitrate-N concentrations in shallow wells (<15 m) around greenhouses in Huimin, Shandong Province, ranged from 9 to 274 mg N L<sup>-1</sup>, with 99% of surveyed wells exceeding

56 10 mg N L<sup>-1</sup>, more than half of the samples (53%) exceeding 50 mg N L<sup>-1</sup>, and 26% exceeding 100 mg N L<sup>-1</sup> (Ju et al., 2006).

58 Double-cropping is typical for greenhouse planting systems without supplementary heating or illumination on the North China Plain. The first cucumber crop is grown in the

60 winter-spring (WS) season from February to June and the second in the autumn-winter

61 (AW) season from September until the following January. In the summer season, no crop is

62 grown in the greenhouse due to hot weather conditions. Fertiliser applications are not based

63 on official recommendation systems as none are available. However, different methods are

64 at hand to optimise the N fertiliser input for maximum yield with minimum environmental

65 impact.

66 Root zone N management based on the measurement of soil mineral N ( $\text{N}_{\text{min}}$ ) before N

67 side-dressing ( $N_{\min}$  method) and on the N uptake pattern of the plants is considered  
to be a  
68 key method to improve N use efficiency. Using this strategy N fertiliser application  
could  
69 be reduced by 73% in a continuous three-season greenhouse tomato cropping  
system (He et  
70 al., 2007) in Shouguang and by 50% in a continuous four-season greenhouse  
cucumber  
4  
71 cropping system (Guo et al., 2008a) in Beijing suburb without yield reduction. The N  
72 balance between N input (fertiliser N + initial  $N_{\min}$  + N in irrigation water) and N output  
73 (crop N uptake + residual  $N_{\min}$  at harvest) confirmed that N loss was greatly reduced  
by  
74 root zone N management. A catch crop planted during the summer fallow period  
further  
75 reduced apparent N loss in a greenhouse cropping system (Guo et al, 2008b). N  
leaching  
76 was considered the most important pathway of N loss (Zhu et al. 2005), although it  
was  
77 never measured. For this reason, a reliable process based model for N cycling under  
78 vegetable production was utilised to facilitate better estimation of N leaching from the  
79 greenhouse system. The EU-Rotate\_N model (Rahn et al. 2010) was developed with  
the  
80 help of European Commission funding to simulate N utilisation and cycling in  
rotations of  
81 field vegetable crops. Losses of N by leaching together with crop growth and root  
82 development, the release of N from soil organic matter and crop residues and their  
83 subsequent fate are simulated. Nendel (2009) demonstrated that the model is a  
useful tool  
84 to improve N management in rotations of field grown vegetables with minimal effect  
on  
85 yield whilst greatly reducing nitrogen losses. The objective of this study was (i) to test  
the  
86 model performance in greenhouse vegetable cropping systems in North China Plain  
by  
87 comparing model predictions of crop N uptake and soil mineral N with experimental  
data  
88 testing different strategies of N management in a continuous four-season  
greenhouse  
89 cucumber cropping system, and (ii) to estimate N mineralisation and N losses of the  
90 production systems to help developing Best Management Practices (BMP) for N  
91 fertilisation to protect groundwater resources.

92

## 93 2. Materials and methods

5

### 94 2.1. The EU-Rotate\_N simulation model

95 EU-Rotate\_N was developed as a tool to optimise nitrogen use in rotations of field

96 crops across Europe. The dynamic and process-based simulation model was extensively  
97 revised from the N\_ABLE model (Greenwood et al., 1996) upon which it is based.  
The  
98 model has been described in detail by Rahn et al. (2010). The EU-Rotate\_N  
simulation  
99 model has been tested against a number of organic and conventional vegetable crop  
rotation  
100 experiments across Europe and demonstrated fitness for purpose. In the present  
101 investigation the model is tested against data from a greenhouse cropping system  
for the  
102 first time. The version number of the model used in this study is 1.6, which was  
released in  
103 2007.

104

#### 105 2.2. *Model input variables*

106 The model requires a set of input variables for weather, soil characteristics,  
fertilisation  
107 and irrigation (Table 1). Mean air temperature and mean relative humidity were  
measured

108 on-site on a daily basis. Precipitation data was obtained from a local weather  
station.

109 Maximum and minimum temperature and daily sum of global radiation was  
estimated from

110 data outside the greenhouse using transfer functions.

111 Soil organic matter content and particle size distribution was measured from soil  
112 samples taken prior to the experiment. The soil water content at field capacity,  
permanent

113 wilting point and saturation for the 0 – 0.3, 0.3 – 0.6 and 0.6 – 0.9 m soil layers were  
114 derived from soil texture classes (AG Bodenkunde 1994). Water infiltration into the  
soil

115 largely depends on the position within the furrow system and its distance to the  
water inlet.

116 Measured soil water contents were used to calibrate the model in order to inversely  
estimate

6

117 the water flux at the simulated position in the greenhouse. The parameter describing  
the

118 wetted surface area of the furrow system (Guo et al. 2008a) was used as adjustable  
119 parameter in this procedure.

120

121 ((Table 1))

122

#### 123 2.3. *Model output*

124 Water and N dynamics were simulated for 0.3 m soil layers down to 0.9 m depth.

125 Cumulative daily crop N uptake from the soil was simulated using target cucumber  
and

126 sweet corn yields. Cumulative N mineralisation was simulated from soil and added organic

127 matter pools for manure and sweet corn residues respectively. Cumulative N leaching was

128 predicted for the profile boundaries below 0.3 cm and 0.9 cm soil depth. Simulated gaseous

129 N losses are presented both on daily basis and as a cumulative total figure.

130

#### 131 2.4. *Experimental site*

132 A typical five-year-old commercial greenhouse was selected for the field experiment in

133 the Changping County, in the suburbs of Beijing from 2005 to 2006. The greenhouse is of

134 typical design with loam back and side walls and a quadrant metal frame supporting a

135 removable polyethylene cover facing south. Crops are grown in soil and the cover is

136 removed completely during the summer period. The maximum height is 4 m and the

137 ground area is 6 m × 72 m. No supplementary lighting or heating is provided. Before the

138 beginning of the experiment, the greenhouse soil, a silty loam, had a five-year history of

139 traditional N fertilisation characterised by high inputs (1200 – 1500 kg ha<sup>-1</sup> N per year) of

7

140 manure and fertiliser N. The surface soil in the greenhouse (0 – 0.3 m layer) had a pH (in

141 water) of 6.1, an electrical conductivity (EC) value of 214 s cm<sup>-1</sup> (1:5 ratio soil/water), a

142 density of 1370 kg m<sup>-3</sup>, an initial N<sub>min</sub> of 255 kg N ha<sup>-1</sup> and an organic matter content of

143 24.0 g kg<sup>-1</sup> prior to the experiments. Total N, Olsen-P and NH<sub>4</sub>OAc-K were 1.78 g kg<sup>-1</sup>,

144 305 mg kg<sup>-1</sup> and 470 mg kg<sup>-1</sup>, respectively. Soil texture and soil bulk density in the soil

145 profile to 1.8 m are shown in Table 2.

146

147 ((Table 2))

148

149 Total precipitation of 299 mm and 491 mm were recorded at a local weather station in

150 2005 and 2006, respectively. Effective precipitation (during the period in which the

151 greenhouse was uncovered between 21 July and the harvest of sweet corn)

amounted 270

152 mm and 244 mm in 2005 and 2006, respectively.

153

#### 154 2.5. *Crop establishment and management*

155 Cucumber seedlings (*Cucumis sativus* L. cv. Jinglu No. 3 in 2005 and cv. Zhongte No.

156 25 in 2006) were transplanted by hand at the two-leaf stage, into double rows of 0.9  
m row  
157 spacing and 0.3 m seedling spacing on 11 March 2005 and 15 February 2006 (WS  
season),  
158 and 8 September 2005 and 10 September 2006 (AW season), respectively. Fruit  
harvesting  
159 started on 21 April and 18 October in 2005 and 9 April and 9 October in 2006. Once  
the  
160 final harvest was completed, cucumber vines were quickly removed from the  
greenhouse in  
161 order to reduce the risk of root fungal diseases in future crops. Sweet corn  
seedlings at the  
162 three-leaf stage were transplanted on 28 June 2005 and 30 June 2006,  
respectively, with 0.6  
8  
163 m row spacing and 0.3 m plant spacing in the treatments with summer catch crop.  
Sweet  
164 corn harvest was conducted on 28 August 2005 and 2 September 2006,  
respectively.

165

#### 166 2.6. *Experimental treatments*

167 The treatments were designed as follows:

168 (1) **N00**: The control treatment where neither manure nor fertiliser N was applied.

169 (2) **Nm0**: Chicken manure was broadcast at rates of 75, 22.5, 11 and 18 t ha<sup>-1</sup> (with  
total

170 N inputs of 671, 200, 146 and 205 kg N ha<sup>-1</sup>), before transplanting in the four  
growing

171 seasons, respectively. Organic matter, total P and total K contents of the organic  
manure

172 used in 2006 were 30.9%, 12.6 g kg<sup>-1</sup> (P<sub>2</sub>O<sub>5</sub>) and 2.45 g kg<sup>-1</sup> (K<sub>2</sub>O), respectively. No  
173 additional N fertiliser was used.

174 (3) **Nmt**: Chicken manure was applied before transplanting as in the *Nm0* treatment.  
In

175 addition, N fertiliser was side-dressed in the cucumber growing period following  
176 conventional practice in the region. The total N rates applied by side-dressing were  
710,

177 675, 666 and 590 kg N ha<sup>-1</sup> in the WS and AW seasons of 2005 and WS and AW  
seasons

178 of 2006, respectively.

179 (4) **Nmr**: Chicken manure was applied before transplanting as in the *Nm0* treatment.  
In

180 addition, mineral N side-dressing was applied, based on the following approach:

*rec uptake buffer initial N N N N min* 181 Eq. 1

182 where  $N_{rec}$  is the recommended N fertiliser dosage,  $N_{uptake}$  is the expected amount of  
N

183 taken up by the crop until harvest,  $N_{buffer}$  is the minimum soil mineral N content in the

184 rooting zone to maintain optimum crop growth and  $N_{min\ initial}$  denotes the soil mineral  
N

185 content in the rooting zone at planting.  $N_{buffer}$  was set to 200 kg N ha<sup>-1</sup>, according to  
9

186 substrate cucumber experiments carried out by Kotsiras (2002). N uptake in  
cucumber

187 shoot was based on the following function describing the relationship between  
growth and

188 uptake (Pei, 2002).

189 WS season:

$$190 N_{uptake} = -0.0337 \cdot DAT^2 + 8.2533 \cdot DAT - 216.04 \text{ Eq. 2}$$

191 AW season:

$$192 N_{uptake} = -0.0174 \cdot DAT^2 + 4.1953 \cdot DAT - 79.94 \text{ Eq. 3}$$

193 where DAT denotes days after transplanting.

194 In 2005 the total side-dressing N rates in Nmr were 152 kg N ha<sup>-1</sup> in the WS season  
195 and 405 kg N ha<sup>-1</sup> in the AW season. In 2006, the total side-dressing N rates in Nmr  
were

196 319 kg N ha<sup>-1</sup> in the WS season and 310 kg N ha<sup>-1</sup> in the AW season.

197 (5) **Nmr+C**: Based the Nmr treatment, but with a sweet corn catch crop planted  
198 during the summer fallow period. The residue of sweet corn shoots were removed  
from soil

199 after harvest.

200 (6) **Nmr+CS**: based on the Nmr+C treatment, but with the sweet corn shoot residue  
201 incorporated into the soil after harvest.

202 The experiment had a completely randomised block design with three replicates and  
the

203 size of each replicate plot was 4.8 m x 5.5 m. The furrow irrigation system and the  
204 irrigation schedule were carried out according to normal commercial practice. The  
side

205 dressings of nitrogen were made by dissolving Urea in water which was distributed  
to the

206 plots in the irrigation water. The water input which included irrigation during covered  
and

207 precipitation during uncovered periods is shown in Fig 1. No irrigation or fertiliser  
was

208 applied during the summer period except for 35 mm at the transplanting of sweet  
corn.

10

209

210 ((Fig. 1))

211

### 212 2.7. *Sampling and analysis*

213 Soil samples were taken from the top 0.9 m in each plot in 0.3 m layers two or three  
214 days before N side-dressing during the cucumber growing season. In the sweet  
corn

215 growing and fallow periods soil samples were collected from the 0 – 0.3, 0.3 – 0.6  
and



216 0.6 – 0.9 m soil layers every 2 – 3 weeks. Six soil cores were taken from each plot, which  
217 were thoroughly mixed before being passed through a 4 mm sieve. Sub-samples of  
12 g  
218 soil were extracted at a ratio of 1:10 (dry soil weight/extractant volume) with 0.01  
mol L<sup>-1</sup>  
219 CaCl<sub>2</sub>, shaken for 1 h and filtered. The filtrates were analysed for mineral N with a  
220 TRAACS 2000 continuous-flow auto-analyser (Houba et al. 1986). Water contents  
in the  
221 soil samples were determined gravimetrically by drying the soil at 105°C and  
determining  
the water loss by weighing. NH<sub>4</sub>  
222 + concentration always corresponded to values below 17.6  
kg N ha<sup>-1</sup>, indicating that NH<sub>4</sub>  
223 + fixation would not significantly affect N dynamics. A 2 mol  
224 L<sup>-1</sup> KCl extraction was carried out additionally for some samples. However, this  
extraction  
225 method yielded comparable results (maximum 11.4 kg N ha<sup>-1</sup>).  
226 Samples of whole crop were taken at intervals of 2 – 3 weeks to assess dry matter  
yield  
227 and N content of cucumber crop. Commercial fruits (2.5 – 3.0 cm in diameter and 25  
– 30  
228 cm long) were picked and weighed from 24 plants in each plot every one to three  
days  
229 following commercial harvest practice. Sweet corn was sampled when soil sampling  
was  
230 conducted. Fresh shoot samples were collected and dried at 70°C to constant  
weight. The  
231 dried shoots were ground before determination of total N content. A modified  
Kjeldahl  
11  
232 method with addition of salicylic acid was used to analyse total N including NO<sub>3</sub>-N in  
the  
233 plant samples.

234

### 235 2.7. Model evaluation

236 The following four statistical indices were chosen to evaluate the model  
performance:

237 The mean bias error (*MBE*, Addiscott and Whitmore, 1987), the root mean square  
error

238 (*RMSE*, Fox 1981), Modelling Efficiency (*ME*, Nash and Sutcliffe, 1970) and  
Willmott's

239 Index of Agreement (*d*; Willmot, 1982). *MBE* provides information on any systemic  
over240

or underprediction of the model (Eq. 4). *RSME* describes the average absolute deviation

241 between observed and predicted values (Eq. 5). *ME* compares the difference  
between

242 predicted and observed values against the variance of the observed values during  
 the period  
 243 under investigation (Eq. 6). It ranges between  $-1.0$  (no correlation) and  $1.0$  (perfect  
 fit). An  
 244 efficiency of lower than zero indicates that the mean value of the observed time  
 series  
 245 would have been a better predictor than the model.  $d$  represents the ratio of the  
 mean square  
 246 error and the potential error (Eq. 7). It ranges between  $0$  (no correlation) and  $1$   
 (perfect fit).

$$\frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (P_i - \bar{O})^2}$$

247 (Eq. 4)

$$\frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (P_i - \bar{O})^2}$$

248 (Eq. 5)

$$\frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (P_i - \bar{O})^2}$$

249  $ME$  ) ( Eq. 6)

$$\frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (P_i - \bar{O})^2}$$

250  $d I$  (Eq. 7)

251 where  $n$  is the number of samples,  $P_i$  and  $O_i$  are the predicted and observed values,  
 and

252  $O$  is the mean of the observed data.

253

### 254 3. Results

#### 255 3.1. Nitrogen uptake and soil mineral nitrogen content simulations

256 The seasonal differences in N uptake of cucumber in this experiment have been

257 reported in Guo et al. (2008a). The N uptake of cucumber at harvest averaged 207 (N00),  
258 257 (Nm0), 294 (Nmt), 304 (Nmr), 304 kg (Nmr+C), and 304 kg N ha<sup>-1</sup> (Nmr+CS),  
259 respectively, in WS season while the N uptake was on the average of 125 (N00),  
157  
260 (Nm0), 184 (Nmt), 190 (Nmr), 176 (Nmr+C) and 187 kg N ha<sup>-1</sup> (Nmr+CS),  
respectively in  
261 winter-autumn season. Model simulations of the N uptake of cucumber and sweet  
corn  
262 were compared with observed values for a range of treatments (Fig 1 – 6). In  
general, the  
263 model produces the observed value well, showing  $d$  between 0.94 and 0.98, and  $ME$   
of  
264 between 0.80 and 0.92 (Table 3).  
265 For N<sub>min</sub> content in the 0 – 0.3, 0.3 – 0.6 and 0.6 – 0.9 m soil layers the model  
266 performed with  $d$  ranging between 0.58 and 0.92 and  $ME$  between –0.35 and 0.74.  
The  
267 model overestimated N<sub>min</sub> with Nmt treatment in the 0 – 0.3 m soil layer. In general,  
both  
268 observed and simulated N<sub>min</sub> in the 0 – 0.9 m soil profile was lower in the Nmr  
managed  
269 treatments as compared to Nmt.  
270  
271 ((Fig 1 – 6))  
13  
272 ((Table 3))  
273  
274 3.2. *Simulation of nitrogen mineralisation*  
275 The model simulated that 339 kg N ha<sup>-1</sup> N would be mineralised from soil organic  
276 matter per year over two continuous experimental years, where no fertiliser or  
manures had  
277 been applied. It predicted an additional 105 kg N ha<sup>-1</sup> being released from  
decomposing  
278 roots of the cucumber plants (Fig 7). The total being close to the total N uptake of  
279 cucumber shoot during the four seasons. Simulations of total N mineralisation were  
280 dramatically increased by 41% and 92% with the application of chicken manure,  
281 respectively, reaching 748 kg ha<sup>-1</sup> per year. The application of N fertiliser had little  
effect  
282 on the simulated amount of soil N mineralisation. Sweet corn cropping reduced total  
N  
283 mineralisation by 140 kg N ha<sup>-1</sup> over two years (Fig 8), with lasting impact on the  
284 subsequent AW season. The incorporation of sweet corn residues had marginally  
smaller  
285 effect on soil N mineralisation compared with Nmr+C treatment.  
286  
287 ((Fig 7))  
288 ((Fig 8))

289

### 290 3.3. *Simulation of gaseous nitrogen losses*

291 Annual gaseous N loss simulated by the model for the different treatments were  
0.41

292 (N00), 1.78 (Nm0), 21.7 (Nmt), 9.9 (Nmr), 9.9 (Nmr+C) and 10.0 (Nmr+CS) kg N ha<sup>-1</sup>

293 (Table 4). Gaseous N losses were simulated to be larger for the WS season than for  
the AW

294 season. Fertiliser and manual N inputs greatly increased simulations of N gaseous  
losses.

14

295 Comparing Nmt and Nmr treatments gaseous losses could be reduced by 54%  
where lower

296 amounts of fertiliser were applied. Sweet corn cropping and incorporation of sweet  
corn

297 straw had little effect on gaseous N losses. Fertiliser greatly increased the  
percentage of

298 gaseous N losses in WS season. Gaseous N losses predicted with conventional  
and

299 recommended N management in WS season account for 72% – 83% of total  
gaseous N loss

300 per year while gaseous N losses in AW season accounted for 14% – 24%.

301

302 ((Table 4))

### 303 3.4. *Simulations of nitrate leaching.*

304 The simulations of N leaching below 0.3 m and 0.9 m (Table 5) were greatly  
increased

305 by N inputs. Compared with Nmt treatment, N leaching loss was reduced by 34%  
(below

306 0.3 m) and 37% (below 0.9 m) with Nmr treatment and 49% (below 0.3 m) and by  
44%

307 (below 0.9 m) with the treatment of Nmt+C. The reduced losses of N below 0.3 m  
indicated

308 the benefits of sweet corn in reducing N leaching in both the summer fallow period  
and in

309 the subsequent AW season. However, nitrate leaching simulated by model below  
0.9 m was

310 reduced by sweet corn cropping only in AW season but not in summer fallow period.

311 Incorporation of sweet corn residues had little effect on N leaching losses.

312

313 ((Table 5))

314

## 315 4. Discussion

### 316 4.1. *Simulated nitrogen mineralisation*

317 Model-predicted N release from soil organic matter in the manure treatments (Nm0)

15

was always higher than 318 the predicted release from soil organic matter in the  
unfertilised

319 treatment (N00). This is due to the fact that the model assumes a fraction of added  
organic  
320 manure to be transformed into soil organic matter, which in turn mineralises and  
releases N.  
321 Model-predicted cumulative N mineralisation from soil organic matter and added  
322 organic manure was high with an average of 15.5 kg N ha<sup>-1</sup> week<sup>-1</sup>. For those  
treatments  
323 with manure, N mineralisation only from soil organic matter averaged 9.9 kg N ha<sup>-1</sup>  
week<sup>-1</sup>  
324 in the experimental period (2005 – 2006). These high N mineralisation rates are  
explained  
325 by the long-term history of high N inputs into intensive vegetable production  
systems. He  
326 et al. (2005) reported N mineralisation rates from a 28-day lab incubation  
experiment with  
327 soils used for vegetable production being in the range of 9.9 to 14.1 mg kg<sup>-1</sup> per  
week,  
328 which is 1.5-1.7 times than that found in soils with a grain crops history. In 2007, an  
in-situ  
329 experiment was conducted by Wang et al. (2008) at the same experimental site in  
Beijing to  
330 measure soil N mineralisation of soils with different histories of N management  
using  
331 micro-lysimeters (Nendel et al. 2005). No fertiliser was applied to the soils in the  
332 micro-lysimeters. From this experiment, weekly soil N mineralisation was measured  
as 3.4,  
333 4.7, 6.9 and 5.7 kg N ha<sup>-1</sup> with N00, Nm0, Nmt and Nmr treatment, respectively  
(Wang,  
334 2008). The observed N mineralisation rate with the N00 treatment in 2007 was low  
335 compared with the rate predicted by model in 2005 and 2006 but no manure or  
fertiliser had  
336 been applied since 2005 exhausting of the soil organic matter pool. The observed N  
337 mineralisation rate was high in the Nmt treatment reflecting the history of high  
fertiliser  
338 and manure applications (Wang, 2008), indicating that high N mineralisation rates  
339 predicted by the model from 2005 to 2006 were in the range of measured values in  
a  
340 greenhouse cropping system.

16

341

#### 342 4.2. *Simulation of nitrogen losses*

343 The results of the simulations showed that gaseous N loss was only a small fraction  
of  
344 the total N losses in the greenhouse cropping system, similar to the results reported  
by Zhu  
345 et al. (2005) and He et al. (2009). The EU-Rotate\_N model does not distinguish  
between

346  $\text{NH}_3$  or  $\text{N}_2\text{O}$  forms of gaseous N emissions which limits the evaluation of the  
simulation  
347 results. Zhu et al. (2005) reported that seasonal ammonia volatilisation in a  
greenhouse  
348 experiment with organic manure input of 178 kg N ha<sup>-1</sup> and urea input of 600 kg N  
ha<sup>-1</sup> was  
349 just 9 kg N ha<sup>-1</sup>. Low pH and high soil moisture contents were assumed to be the  
350 explanation for low ammonia volatilisation (Zhu et al. 2005). He et al. (2009)  
reported an  
351 annual  $\text{N}_2\text{O}$  emission rate of 8.8 kg N ha<sup>-1</sup> with traditional N treatment, applying N  
fertiliser  
352 rates similar to our experiment. According to Zhu et al. (2005) and He et al. (2009),  
the  
353 sum of  $\text{N}_2\text{O}$  losses and  $\text{NH}_3$  volatilisation was 29 kg N ha<sup>-1</sup> per year in Shouguang,  
354 Shandong Province, which was only marginally higher than the gaseous loss  
predicted by  
355 the model (22 kg N ha<sup>-1</sup>) for the Beijing region. Furthermore, the model was able to  
predict  
356 seasonal variations in gaseous N losses. Higher gaseous N losses were simulated  
in the WS  
357 season compared to the AW season, similar to the findings of He et al. (2009).  
358 N leaching was predicted to be the main source of N losses in our experiment  
according  
359 to the result of the simulations. N leaching predicted for the Nmt treatment added up  
to 590  
360 kg N ha<sup>-1</sup> per season below 0.3 m and 684 kg N ha<sup>-1</sup> per season below 0.9 m in  
average of  
361 four growing seasons, with an average N application rate of 305 kg N ha<sup>-1</sup> as  
chicken  
362 manure and 660 kg N as urea. A lysimeter experiment conducted in Shouguang  
measured  
363 231 kg N ha<sup>-1</sup> leaching below 0.9 m during WS season with 178 kg N ha<sup>-1</sup> from  
chicken  
17  
manure and 600 kg 364 N ha<sup>-1</sup> from urea in a greenhouse hot pepper cropping system  
(Zhu et al,  
365 2005). This suggests that N leaching predicted by model in our simulations may be  
366 overestimated. However, there was still 392 kg N ha<sup>-1</sup> unaccountable in the hot  
pepper  
367 cropping system according to the calculation of N balance. Dissolved organic N,  
which was  
368 neither considered in the experiment nor in the simulation model, may help  
explaining part  
369 of this gap.  
370 In this experiment and that reported by Zhu et al. (2005), a furrow irrigation system  
371 with double-row cropping was used, so water and nitrogen input into the soil was  
not

372 distributed evenly in the greenhouse area. The model simulations apply to a single  
point in  
373 the furrow, where water infiltration and N input is much higher than in other zones of  
the  
374 greenhouse. A set of simulations will be needed to represent the whole greenhouse  
375 including spatial information on water infiltration and N distribution. However,  
beneath the  
376 furrow, high N leaching losses are still expected.  
377 N management based on the approach given in Eq. (4) reduced fertiliser N input by  
378 53% for the experiment. Consequently, the simulated leaching of N in this treatment  
was  
379 reduced by 37%. However, nitrogen leaching under the Nmr treatment still  
accounted for  
380 81% of total fertiliser and manure N input, which was similar to the traditional N  
treatments.  
381 Sweet corn could further reduce N leaching loss by prolonging the period of crop N  
uptake.  
382 Total N mineralisation was reduced by sweet corn cropping as summer catch crop,  
383 presumably by lowering the soil water content due to transpiration and thus  
impairing the  
384 conditions for soil organic matter mineralisation. The main effect of sweet corn was  
to  
385 intercept rainfall and thus reduce infiltration and the downward movement of nitrate  
in the  
386 soil. This was observed in a labelled  $^{15}\text{N}$  experiment conducted in 2006, where more  
 $^{15}\text{N}$   
18  
387 was kept in the 0-0.3 m soil layer as organic nitrogen under sweet corn cropping as  
388 compared with a fallow treatment (Data unpublished).  
389 Although the simulation study indicates that the amount of N released from organic  
390 matter in the soil is high and greatly contributes to N leaching losses, an  
experimental  
391 verification of this hypothesis would be desirable to quantify the fluxes in the system  
with  
392 more accuracy and validate the predictions of the EU-Rotate\_N model.  
393

#### 394 *4.3. Deriving nitrogen fertiliser recommendations*

395 In the past fifteen years, several research groups have reported on the effects of  
396 conventional N input on soil mineral N accumulation, groundwater condition and  
397 greenhouse gas emission in the intensive greenhouse vegetable cropping areas of  
the  
398 North China Plain (Chen et al., 2004; He et al., 2009; Ju et al., 2006, 2007; Shen et  
al.,  
399 2009; Zhang et al., 1996). It has been commonly recognized that uncontrolled N  
losses to  
400 groundwater and atmosphere are a serious problem and closely related to high N  
input

401 from either fertiliser or manure. Improved N management is urgently required for  
402 environmentally sound and sustainable vegetable production. Among the possible  
403 approaches to improve N management, both crop rotation planning (Zhou et al.,  
2008) and  
404 root zone N management have become increasingly popular. Modified root-zone N  
405 management based on  $N_{\min}$  method proved to reduce N fertilizer input and N loss  
406 efficiently (Guo et al., 2008a; He et al., 2007, 2009). However, in their experiments  
the  
407 impact of mineralisable N from soil organic matter and manure is ignored in deciding  
408 upon fertiliser recommendations. The results of the EU-Rotate\_N model suggest a  
409 significant N input from soil organic matter and manure over the growing season not  
19  
410 previously accounted for. Consequently, the recommended N rate for our  
experiment  
411 could be further reduced.

412

### 413 **5. Conclusion**

414 It can be concluded that EU-Rotate\_N, which was initially designed for the use in  
415 European outdoor field conditions, can be applied in typical greenhouses in China  
without  
416 major modifications. The model-predicted leaching of N supports the hypothesis that  
N  
417 losses of vegetable production systems can be large and cannot easily be  
estimated from  
418 observed  $N_{\min}$  data alone. It also suggested that the mineralisation of N from soil  
organic  
419 matter as well as N release from organic amendments need to be considered to  
improve  
420 fertiliser recommendations. Furthermore, the EU-Rotate\_N model could be  
considered as a  
421 tool for deriving N fertiliser recommendations, since it works without the requirement  
for  
422 frequent soil sampling and analysis, and thus is less expensive and laborious for  
agricultural  
423 advisors and policy-makers in contrast to the system of recommended N  
management that  
424 we used for this experiment. Future codes of BMP for greenhouse vegetable  
production in  
425 China could be developed with the help of EU-Rotate\_N.

426

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20

433

434 **Reference**

435 Addiscott, T.M., Whitmore, A.P., 1987. Computer simulation of changes in soil  
mineral

436 nitrogen and crop nitrogen during autumn, winter and spring. *Journal of Agriculture  
437 Science, Cambridge* 109, 141-157.

438 Arbeitsgemeinschaft Bodenkunde, 1994. *Bodenkundliche Kartieranleitung*, fourth  
ed., E.

439 Schweizerbartsche Verlagsbuchhandlung, Hanover, Germany (in German)

440 Cabrera, M.L., Chiang, S.C., 1994. Water content effect on denitrification and  
ammonia

441 volatilisation in poultry litter. *Soil Science Society of America Journal* 58, 811-816.

442 Chen, Q., Zhang, X. S., Zhang, H. Y., Christie, P., Li, X.L., Horlacher, D., Liebig, H.  
P.,

443 2004. Evaluation of current fertiliser practice and soil fertility in vegetable production  
444 in the Beijing region. *Nutrient Cycling in Agroecosystems* 69, 51-58.

445 Fox, D.G., 1981. Judging air quality model performance: a summary of the AMS  
446 Workshop on dispersion model performance. *Bulletin of American Meteorological  
447 Society* 62, 599-609.

448 Fox, R.H., Piekielek, W.P., MacNeal, K.E., 1996. Estimating ammonia volatilisation  
losses

449 from urea fertilisers using a simplified micrometeorological sampler. *Soil Science  
450 Society of America Journal* 60, 591-601.

451 Gollany, H.T., Molina, J.E., Clapp, C.E., Allmaras, R.R., Layese, M.F., Baker, J.M.,  
Cheng,

452 H.H., 2004. Nitrogen leaching and denitrification in continuous corn as related to  
453 residue management and nitrogen fertilisation. *Environmental Management* 33  
454 (Supplement 1), S289-S298.

455 Greenwood, D.J., Rahn, C.R., Draycott, A., Vaidyanathan, L.V., Paterson, C., 1996.  
21

456 Modelling and measurement of the effects of fertiliser-N and crop residue  
incorporation

457 on N-dynamics in vegetable cropping. *Soil Use and Management* 12 (1), 13-24.

458 Guo, R.Y., Li, X.L., Christie, P., Chen, Q. and Zhang, F.S., 2008a. Seasonal  
temperatures

459 have more influence than nitrogen fertiliser rates on cucumber yield and nitrogen  
460 uptake in a double cropping system. *Environmental Pollution* 151 (3), 443-451.

461 Guo, R.Y., Li, X.L., Christie, P., Chen, Q., Jiang, R.F., Zhang, F.S., 2008b. Influence  
of

462 root zone nitrogen management and a summer catch crop on cucumber yield and  
soil

463 mineral nitrogen dynamics in intensive production systems. *Plant and Soil* 313, 55-  
70.

464 He, F.F., Chen, Q., Jiang, R.F., Chen, X. P., Zhang, F.S., 2007. Yield and nitrogen balance  
465 of greenhouse tomato (*Lycopersicum esculentum* Mill.) with conventional and  
466 site-specific nitrogen management in Northern China. *Nutrient Cycling in*  
467 *Agroecosystems* 77, 1-14.

468 He, F.F., Jiang, R.F., Chen, Q., Zhang, F.S., Su, F., 2009. Nitrous oxide emission  
469 from an  
470 intensively managed greenhouse vegetable cropping systems in Northern China.  
471 *Environmental Pollution* 157 (5), 1666-1672.

471 He, Y.F., Yin, B., Cai, G.X., Jin, X.X. and Li, H.X., 2005. Comparison of nitrogen  
472 mineralisation and nitrification in upland soils grown with vegetables and food crops.  
473 *Chinese Journal of Soil Science* 36 (1), 41-44 (in Chinese with English summary).

474 Houba, V.J.G., Novozamsky, I., Huybregts, A.W.M., 1986. Comparison of soil  
475 extractions  
476 by 0.01 M CaCl<sub>2</sub>, by EUF and some conventional extraction procedures. *Plant and*  
477 *Soil*  
478 96, 433-437.

477 Ju, X.T., Kou, C.L., Christie, P. Dou, Z.X., Zhang, F.S., 2007. Changes in the soil  
479 environment from excessive application of fertilizers and manures to two contrasting  
480 intensive cropping systems on the North China Plain. *Environmental Pollution* 145,  
481 497-506.

481 Ju, X.T., Kou, C.L., Zhang, F.S., Christie, P., 2006. Nitrogen balance and  
482 groundwater  
483 nitrate contamination: Comparison among three intensive cropping systems on the  
484 North China Plain. *Environmental Pollution* 143, 117-125.

484 Kotsiras, A., Olympios, C.M., Drosopoulos, J., and Passam, H. C., 2002. Effects of  
485 nitrogen form and concentration on the distribution of ions within cucumber fruits.  
486 *Scientia Horticulturae* 95, 175-183.

487 Li, T.L., 2005. Current situation and prospects of greenhouse industry development  
488 in  
489 China. *Journal of Shenyang Agricultural University* 36 (2), 131-138.

489 Nash, J.E, Sutcliffe IV, 1970. Riverflow forecasting through conceptual model.  
490 *Journal of*  
491 *Hydrology* 273, 282-29.

491 Nendel, C., 2009. Evaluation of Best Management Practices for N fertilisation in  
492 regional  
493 field vegetable production with a small-scale simulation model. *European Journal of*  
494 *Agronomy* 30 (2), 110-118.

494 Nendel, C., Reuter, S., Kersebaum, K.C., Kubiak, R., Nieder, R., 2005. Nitrogen  
495 mineralisation from mature bio-waste compost in vineyard soils II. Test of  
496 N-mineralisation parameters in a long-term in situ incubation experiment. *Journal of*  
497 *Plant Nutrition and Soil Science* 168 (2), 219-227.

498 Pei, X.B., 2002. Studies on regularity of water and solute transfer of cucumber  
499 growing in  
500 solar greenhouse. PhD Dissertation, China Agricultural University, Beijing, China (in  
501 Chinese with English summary).

501 Rahn, C.R., Zhang, K., Lillywhite, R.D., Ramos, C., De Paz, J.M., Doltra, J., Riley, H.,  
23  
502 Fink, M., Nendel, C., Thorup-Kristensen, K., Pedersen, A., Piro, F., Venezia, A., Firth,  
503 C., Schmutz, U., Rayns, F., Strohmeyer, K., 2010. A European Decision Support  
504 System, EU-Rotate\_N to predict environmental and economic consequences of the  
505 management of nitrogen fertiliser in crop rotations. European Journal of Horticultural  
506 Science, in press.

507 Ramos, C., Agut, A., Lidon, A.L., 2002. Nitrate leaching in important crops of the  
508 Valencian Community region (Spain). Environmental Pollution 118 (2), 215-223.

509 Shen, J.L. Tang, A.H., Liu, X.J. Fangmeier, A., Goulding, K.T.W., Zhang, F.S.. 2009.  
High  
510 concentrations and dry deposition of reactive nitrogen species at two sites in the  
North  
511 China Plain. Environmental Pollution 157, 3106–3113.

512 Verma, P., George, K.V., Singh, H.V., Singh R.N., 2007. Modeling cadmium  
accumulation  
513 in radish, carrot, spinach and cabbage. Applied Mathematical Modelling 31 (8),  
514 1652-1661.

515 Wang, X.Q., 2008. Studies on soil organic nitrogen mineralisation in greenhouse  
vegetable  
516 field in Beijing Suburb. Master Dissertation, China Agricultural University, Beijing,  
517 China (in Chinese with English summary).

518 Willmott, C.J., 1982. Some comments on the evaluation of model performance.  
Bulletin of  
519 American Meteorological Society 64, 1309-1313.

520 Zhang, W.L., Tian, Z.X., Zhang, N., Li, X.Q., 1996. Nitrate pollution of groundwater  
in  
521 northern China. Agriculture, Ecosystems and Environment 59, 223-231.

522 Zhou, S.L., Wu, Y.C., Wang, Z.M., Lu, L.Q., Wang, R.Z., 2008. The nitrate leached  
below  
523 maize root zone is available for deep-rooted wheat in winter wheat summer maize  
524 rotation in the North China Plain. Environmental Pollution 152, 723-730.

24  
Zhu, J.H., 525 Li, X.L., Christie, P., Li, J.L., 2005. Environmental implications of low  
nitrogen  
526 use efficiency in excessively fertilised hot pepper (*Capsicum frutescens* L.) cropping  
527 systems. Agriculture, Ecosystems and Environment 111, 70-80.

528  
529  
25  
530 Table 1: Model input variables  
Variable Unit Data source  
**Daily weather parameter**  
Mean air temperature °C Measured on site  
Maximum air temperature °C Estimated from daily air temperature

outside the greenhouse  
Minimum air temperature °C Estimated from daily air temperature  
outside the greenhouse  
Precipitation mm Obtained from local weather station  
Mean relative humidity % Daily measured on site  
Global radiation MJ m<sup>-2</sup> day<sup>-1</sup> Estimated from data outside the  
greenhouse and data inside the  
greenhouse in 2007

### **Soil**

Texture kg kg<sup>-1</sup> Measured  
Total organic carbon kg kg<sup>-1</sup> Measured  
Bulk density g cm<sup>-3</sup> Measured  
Field capacity m<sup>3</sup> m<sup>-3</sup> Estimated from soil texture  
Permanent wilting point m<sup>3</sup> m<sup>-3</sup> Estimated from soil texture  
Saturation m<sup>3</sup> m<sup>-3</sup> Estimated from soil texture  
pH Measured  
Soil C/N Measured  
Initial N<sub>min</sub> content kg N ha<sup>-1</sup> Measured  
Initial soil water content m<sup>3</sup> m<sup>-3</sup> Measured

### **Fertilization**

Fertilization rate (manure and  
chemical fertilizer)  
kg N ha<sup>-1</sup> Measured  
Characteristics of fertilizer Defined in model

### **Irrigation**

Irrigation amount mm Assessment from measurement and soil  
moisture content predicted by model  
N concentration in irrigation  
water  
mg l<sup>-1</sup> Measured

### **Crop**

Crop dry matter at planting kg ha<sup>-1</sup> Measured  
Fruit dry matter at harvest t ha<sup>-1</sup> Measured  
N concentration in transplant % Measured

531

532

26

533 Table 2: Soil texture and soil bulk density at different soil depths in Changping  
534 experimental field

Soil depth  
(m)

Soil bulk density  
kg m<sup>-3</sup>

Soil texture classes (%)

20-2000 μm 2-20 μm <2 μm

0 – 0.3 1420 38.57 60.55 0.87

0.3 – 0.6 1620 38.95 59.38 1.68

0.6 – 0.9 1510 27.80 69.06 3.14

0.9 – 1.2 1510 12.09 84.76 3.15

1.2 – 1.5 1550 9.07 86.63 4.30

1.5 – 1.8 n.d.a 21.09 75.95 2.97

535 a n.d., not done

536

27

537 Table 3: Model performance indices (*MBE* = Mean Bias Error, *RMSE* = Root Mean Squared Error, *d* = Index of Agreement and *ME* = Modelling Efficiency) for soil mineral N

539 in different layers and crop N uptake for different N treatments in a greenhouse cucumber-sweet corn rotation system

541

Treatment Parameter MBE RMSE d ME

N00 Soil N<sub>min</sub> 0 – 0.3 m –33.65 57.69 0.79 0.40

Soil N<sub>min</sub> 0.3 – 0.6 m –33.92 54.09 0.89 0.64

Soil N<sub>min</sub> 0.6 – 0.9 m –24.19 43.48 0.92 0.72

Crop N uptake –8.57 19.50 0.98 0.92

Nm0 Soil N<sub>min</sub> 0 – 0.3 m 5.02 45.58 0.91 0.74

Soil N<sub>min</sub> 0.3 – 0.6 m –1.24 54.67 0.90 0.49

Soil N<sub>min</sub> 0.6 – 0.9 m 11.92 55.81 0.89 0.64

Crop N uptake –10.30 25.30 0.98 0.92

Nmt Soil N<sub>min</sub> 0 – 0.3 m 130.02 209.12 0.69 –0.35

Soil N<sub>min</sub> 0.3 – 0.6 m 25.37 117.61 0.61 –0.01

Soil N<sub>min</sub> 0.6 – 0.9 m 35.13 110.68 0.58 –0.49

Crop N uptake –16.77 28.88 0.97 0.91

Nmr Soil N<sub>min</sub> 0 – 0.3 m 40.78 102.64 0.68 0.24

Soil N<sub>min</sub> 0.3 – 0.6 m 10.47 65.29 0.82 0.52

Soil N<sub>min</sub> 0.6 – 0.9 m 20.69 66.75 0.76 0.34

Crop N uptake –19.15 29.65 0.97 0.91

Nmr+C Soil N<sub>min</sub> 0 – 0.3 m 10.00 71.29 0.86 0.62

Soil N<sub>min</sub> 0.3 – 0.6 m –0.08 65.82 0.84 0.55

Soil N<sub>min</sub> 0.6 – 0.9 m 15.16 53.90 0.83 0.54

Crop N uptake –8.46 28.71 0.97 0.90

Nmr+CS Soil N<sub>min</sub> 0 – 0.3 m 17.61 74.48 0.83 0.55

Soil N<sub>min</sub> 0.3 – 0.6 m 3.51 53.04 0.88 0.64

Soil N<sub>min</sub> 0.6 – 0.9 m 18.65 59.02 0.80 0.46

Crop N uptake –13.94 40.54 0.94 0.80

542

543

28

544 Table 4: Model simulations of gaseous N loss in different treatments (Unit: kg N ha<sup>-1</sup>)

Treatment 2005

WS<sub>a</sub>

2005

SF

2005

AW

2005

WF

2006

WS

2006

SF

2006

AW

Total

N00<sub>b</sub> 0.16 0.14 0.11 0.01 0.17 0.14 0.10 0.82

Nm0 1.77 0.71 0.30 0.24 0.21 0.35 0.14 3.55

Nmt 21.20 0.70 3.50 0.20 14.00 0.40 3.30 43.30

Nmr 7.54 0.70 1.86 0.30 6.60 0.50 2.30 19.80

Nmr+C 7.54 0.14 1.86 0.22 7.24 0.50 2.30 19.80

Nmr+CS 7.54 0.14 1.92 0.23 7.27 0.50 2.30 19.90

545 <sup>a</sup>WS, SF, AW and WF denoted winter-spring season, summer fallow period, autumn-winter season and winter

546 fallow season.

547 <sup>b</sup>N00, Nm0, Nmt, Nmr, Nmr+C and Nmr+CS denote control treatment, N from organic manure treatment,

548 conventional N management, reduced-N management, reduced-N management with sweet corn as catch crop

549 and reduced-N management with sweet corn as catch crop with residue incorporation after sweet corn harvest.

550

551

29

552 Table 5: Model simulations of N loss through leaching with different treatments below

553 0.3 m and 0.9 m (Unit: kg N ha<sup>-1</sup>)

Treatment

2005

WS<sub>a</sub>

2005

SF

2005

AW

2006

WS

2006

SF

2006

AW

Total

Below 0.3 m

N00<sub>b</sub> 170 96 90 52 14 101 522

Nm0 339 175 197 177 5 236 1129  
Nmt 408 688 467 683 19 800 3065  
Nmr 342 288 330 452 65 470 1947  
Nmr+C 342 196 229 411 51 322 1552  
Nmr+CS 342 196 232 408 50 321 1549  
Below 0.9 m  
N00 177 175 208 67 0 99 728  
Nm0 181 256 402 209 -1 216 1263  
Nmt 208 372 858 796 4 872 3110  
Nmr 208 308 533 503 15 547 2114  
C+Nmr 208 329 378 429 23 375 1741  
C+CNmr 208 329 380 426 23 375 1740

554 <sup>a</sup>WS, SF, AW and WF denoted winter-spring season, summer fallow period, autumn-winter season and winter

555 fallow season.

556 <sup>b</sup>N00, Nm0, Nmt, Nmr, Nmr+C and Nmr+CS denote control treatment, N from organic manure treatment,

557 conventional N management, reduced-N management, reduced-N management with sweet corn as catch crop

558 and reduced-N management with sweet corn as catch crop with residue incorporation after sweet corn harvest.

559

560

30

561 Figure captions

562

563 Figure 1: Simulated (lines) and observed (dots) dynamics of crop nitrogen uptake (A) and

564 soil mineral nitrogen contents in the 0 – 0.3 m (B), 0.3 – 0.6 m (C) and 0.6 – 0.9 m (D) soil

565 layer of the N00 treatment. Error bars indicate the standard deviation of the observations;

566 WS, SF, AW and WF denote the winter-spring season, summer fallow period, autumn-winter season and winter fallow period.

568

569 Figure 2: Simulated (lines) and observed (dots) dynamics of crop nitrogen uptake (A) and

570 soil mineral nitrogen contents in the 0 – 0.3 m (B), 0.3 – 0.6 m (C) and 0.6 – 0.9 m (D) soil

571 layer of the Nm0 treatment. Error bars indicate the standard deviation of the observations;

572 WS, SF, AW and WF denote the winter-spring season, summer fallow period, autumn-winter season and winter fallow period.

574

575 Figure 3: Simulated (lines) and observed (dots) dynamics of crop nitrogen uptake (A) and

576 soil mineral nitrogen contents in the 0 – 0.3 m (B), 0.3 – 0.6 m (C) and 0.6 – 0.9 m (D) soil

577 layer of the Nmt treatment. Error bars indicate the standard deviation of the observations;

578 WS, SF, AW and WF denote the winter-spring season, summer fallow period, 579 autumn-winter season and winter fallow period.

580

581 Figure 4: Simulated (lines) and observed (dots) dynamics of crop nitrogen uptake (A) and

582 soil mineral nitrogen contents in the 0 – 0.3 m (B), 0.3 – 0.6 m (C) and 0.6 – 0.9 m (D) soil

583 layer of the Nmr treatment. Error bars indicate the standard deviation of the observations;

31

584 WS, SF, AW and WF denote the winter-spring season, summer fallow period, 585 autumn-winter season and winter fallow period.

586

587 Figure 5: Simulated (lines) and observed (dots) dynamics of crop nitrogen uptake (A) and

588 soil mineral nitrogen contents in the 0 – 0.3 m (B), 0.3 – 0.6 m (C) and 0.6 – 0.9 m (D) soil

589 layer of the Nmr + C treatment. Error bars indicate the standard deviation of the 590 observations; WS, SF, AW and WF denote the winter-spring season, summer fallow period,

591 autumn-winter season and winter fallow period.

592

593 Figure 6: Simulated (lines) and observed (dots) dynamics of crop nitrogen uptake (A) and

594 soil mineral nitrogen contents in the 0 – 0.3 m (B), 0.3 – 0.6 m (C) and 0.6 – 0.9 m (D) soil

595 layer of the Nmr + CS treatment. Error bars indicate the standard deviation of the 596 observations; WS, SF, AW and WF denote the winter-spring season, summer fallow period,

597 autumn-winter season and winter fallow period.

598

599 Figure 7: Model predictions for nitrogen mineralised from soil organic matter and from all

600 organic sources for different nitrogen treatments in the period from 2005 to 2006.

The

601 treatments were: no fertiliser (N00), organic manure application (Nm0), conventional N

602 management (Nmt), reduced N management (Nmr), reduced N management with sweet

603 corn as catch crop (Nmr + C) and reduced N management with sweet corn as catch crop

604 with residue incorporation after harvest (Nmr + CS)

605

606 Figure 8: Model predictions for total mineralised nitrogen for different nitrogen treatments

32



607 in the winter-spring season (WS), the summer fallow period (SF), the autumn-winter season  
608 (AW) and the winter fallow period (WF). The treatments were: no fertiliser (N00),  
organic  
609 manure application (Nm0), conventional N management (Nmt), reduced N  
management  
610 (Nmr), reduced N management with sweet corn as catch crop (Nmr + C) and  
reduced N  
611 management with sweet corn as catch crop with residue incorporation after harvest  
612 (Nmr+CS)