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## Limiting factors for yields of field tomatoes grown by smallholders in tropical regions

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► **To cite this version:**

Joël Huat, Thierry Doré, Christine Aubry. Limiting factors for yields of field tomatoes grown by smallholders in tropical regions. *Crop Protection*, 2013, 44, 10.1016/j.cropro.2012.11.003. hal-01186809

**HAL Id: hal-01186809**

**<https://hal.science/hal-01186809>**

Submitted on 14 Aug 2019

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1 Crop Protection, 44, 120-127

2 <http://dx.doi.org/10.1016/j.cropro.2012.11.003>

3

4 **Title:** Diagnosis of limiting factors of field-grown tomato yield in smallholder farms under  
5 tropical conditions

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14

## 15 **Abstract**

16 Tomatoes are widely cultivated in developing countries and are a major source of income for  
17 small-scale farmers. Yields of field-grown tomatoes vary considerably under tropical

18 conditions but the main factors that limit yields remain to be identified. To this end, we

19 conducted an on-farm survey in 22 fields in 2003 and in 28 fields in 2005 in a range of socio-  
20 economic settings typical of smallholder farms on the island of Mayotte (Indian Ocean). Data

21 on crop management, fulfillment of water requirements, weed density, nitrogen absorption by  
22 the crop and nutrient availability in the soil, as well as the sanitary status of the crop were

23 recorded at two-week intervals throughout the crop cycle. The data were analysed by

24 principal component analysis, and multiple linear regression. Yields varied between years and

25 sites from 0.7 to 45.3 t ha<sup>-1</sup> in 2003 and from 8.1 to 89.1 t ha<sup>-1</sup> in 2005. In 2003, the number of

26 fruits per m<sup>2</sup>, fruit weight, the health status of the crop, and the cation exchange capacity of  
27 the soil explained 84.7% of yield variability among fields. In 2005, the number of fruits per  
28 m<sup>2</sup> and the health status of the crop explained 84% of yield variability. In 2003, 61.8% of the  
29 variability of the number of fruits per m<sup>2</sup> was explained by health status and the number of  
30 plants per m<sup>2</sup>, whereas in 2005, 65.6% of the variability was explained by health status, the  
31 number of pesticide applications, and planting density. The results of this study indicate that  
32 tomato yield could be increased by improving the health status of the crop by improving the  
33 efficiency of crop protection practices and by increasing planting density.

34

35 **Keywords:** tomato; yield variability; pesticides; farmers' fields; tropical area; multiple linear  
36 regression.

37

## 38 **1. Introduction**

39 Tomatoes (*Lycopersicon esculentum* Mill.) are widely cultivated both in the open field and in  
40 greenhouses for fresh consumption and/or for processing. The crop is grown in temperate  
41 regions, humid and hot tropical regions, and dry Sahelian regions, which together represent a  
42 total area of about 5.22 billion ha and a total estimated production of 129.6 billion tonnes  
43 (FAO, 2011). Potential yields can be evaluated by total achievable biomass, biomass  
44 distribution between fruits, stems, leaves, roots, and by the dry matter content of fruits  
45 (Heuvelink and Dorais, 2005). Yields of field tomatoes usually range between 40 and 100 t  
46 ha<sup>-1</sup> depending on the location, growing season, the cultivar used and crop management  
47 practices (Heuvelink and Dorais, 2005). A very wide range of cropping systems exist which  
48 vary according to the type of cultivar (determinate or indeterminate growth), mechanized or  
49 manual land preparation, weeding, irrigation and harvesting, the irrigation system (furrow,  
50 drip irrigation, sprinkle ring, garden hose), fertilization and crop protection (integrated pest  
51 management, conventional pest management), and management of the vegetation (with or  
52 without staking, pruning, disbudding, deleafing).

53 The main reasons for differences in yield in greenhouse tomato crops are well known  
54 (Heuvelink, 2005; Peet and Welles, 2005). However, fewer studies have focused on field-  
55 grown tomato crops for fresh consumption and/or processing, and those that did were mostly  
56 conducted in temperate regions in developed countries (Dumas et al., 1998; Clark et al., 1999;  
57 Scholberg et al., 2000; Csizinszky, 2005). Few studies have dealt with the factors that affect  
58 the production of field-grown tomatoes in tropical areas including water, nitrogen, weeds, and  
59 insect pests (Riahi et al., 2009; Asgedom et al., 2011). Special attention needs to be paid to  
60 tomato pests and diseases as the climate conditions in tropical areas are favourable for  
61 numerous insects including *Helicoverpa armigera*, *Bemisia tabaci* (vector of Tomato Yellow  
62 Leaf Curl Virus), mites *Tetranychus urticae*, *Tetranychus evansi*, *Aculops lycopersici*, fungi

63 *Phytophthora infestans*, *Leveillula taurica*, *Fusarium oxysporum* f. sp. *lycopersici*, *Alternaria*  
64 *solani*, bacteria *Ralstonia solanaceum*, *Xanthomonas campestris* pv. *vesicatoria*, nematodes  
65 *Meloidogyne incognita*, *M. arenaria*, *M. javanica*, *M. mayaguensis* (Csizinszky et al., 2005).

66 The damage to tomato leaves caused by pests and diseases is known to negatively affect the  
67 production of assimilates and filling of the fruits in soilless conditions by decreasing overall  
68 plant photosynthetic capacity (Stacey, 1983; Bertin and Heuvelink, 1993), but their real  
69 influence on the determination of yield in field conditions remains unclear. In addition, in  
70 developing countries, because farmers with limited financial and labour resources often grow  
71 several different vegetable crops (tomato, aubergine, onion, hot pepper, carrot, okra, leafy  
72 vegetables) over the course of the growing season (N'Dienor et al., 2004; Temple and  
73 Moustier, 2004; Huat, 2006), they face different constraints including lack of access to  
74 improved seeds, pesticides, organic manure, mineral fertilizers, water, and land, which impact  
75 technical crop management and consequently influence the yield.

76 Using a regional diagnosis method that has already been successfully applied on many crops  
77 and in a wide range of soil and climate environments, and social and economic conditions  
78 (Meynard and David, 1992; Doré et al., 1997; Doré et al., 2008), our aim was to identify the  
79 major factors which limit yields of field-grown tomatoes and the main cultivation practices  
80 connected with limiting factors in smallholder tropical agriculture.

81

## 82 **2. Materials and methods**

### 83 *2.1. Study sites*

84 Our study was carried out in 2003 and in 2005 in Mayotte, a small (374 km<sup>2</sup>) French island  
85 situated in the Indian Ocean (12° 45' S, 45° 05' W) (Fig. 1). Mayotte has a tropical climate  
86 with a cool dry season from April to October (average temperature 21 °C) and a hot rainy  
87 season from November to March (average temperature 28 °C). Annual average rainfall ranges

88 from 1 000 mm to 2 300 mm, and most rain falls in the north and north-western parts of the  
89 island, which are directly exposed to the monsoon (Raunet, 1992). During the growing period  
90 in our study (April to December), the monthly average temperature varied slightly across  
91 areas and years (Fig. 1). The monthly average rainfall ranged from 0 to 154 mm depending on  
92 the location of the farmers' fields. The driest months were July and August. The soils used for  
93 the cultivation of vegetables are usually of alluvial origin and are clay loam (Raunet, 1992).  
94 Farmers' fields were selected in five major areas covering a wide range of climates, soils and  
95 technical management (Fig. 1; Table 1) Sixteen farmers and a total of 22 tomato fields were  
96 surveyed in 2003, and 20 farmers and 28 fields in 2005; six of the farmers were surveyed in  
97 both years. Data were collected through short in-depth interview with farmers at two-weekly  
98 intervals.

99 The size of the tomato fields ranged from 110 m<sup>2</sup> to 2000 m<sup>2</sup> (average 360 m<sup>2</sup>). Except for  
100 land preparation, which was sometimes by tractor (19 cases), all the other fields were  
101 cultivated by hand. The most variable practices were planting density (11 000 to 54 200 plants  
102 ha<sup>-1</sup> in both years, the amounts of organic manure (0 to 23.3 t ha<sup>-1</sup>) and NPK fertilizers applied  
103 (0 to 2 638 t ha<sup>-1</sup>), the number of pesticide applications (0 to 23) (Table 1), the variety of  
104 tomato, crop rotation and planting date (May 2 to October 6).

105 In 29 cases out of 50, the tomato crop was preceded by a short fallow period. In the other  
106 cases, cereals such as maize or rice, root crops such as cassava, and vegetables (cucumber,  
107 courgette, melon, tomato, French beans) preceded the tomato crop. The main tomato cultivars  
108 used were determinate: Mongal F1 and Calinago F1 because of their tolerance to bacterial  
109 wilt (*Ralstonia solanacearum*). In 48 out of 50 cases, the farmers used either NPK chemical  
110 fertilizers (15-12-24 or 10-20-20) or organic poultry manure, or both. All the farmers irrigated  
111 the plants by hand with a garden hose. At the flowering stage, all farmers except one staked  
112 and pruned their plants to maintain two or three vigorous stems, and disbudded the plants

113 several times before harvest. Sanitary deleafing was practised 8-10 days after planting and  
114 consisted in removing all the leaves in contact with the soil. This operation was repeated at  
115 each disbudding by removing all leaves with disease symptoms from the whole plant. The  
116 number of leaves removed was based on each individual farmer's perception of the damage.  
117

## 118 *2.2. Measurements*

119 Five representative sub-samples of soil were collected from each field at depths of 0-20 cm  
120 and 20-40 cm at the beginning of the cropping season. P-Olsen modified Dabin, total carbon  
121 and nitrogen (Dumas), cation exchange capacity (hexamine cobalt chloride), pH (soil: H2O  
122 ratio = 1:2.5), water content at pF4.2 and pF2.5 were measured on each sample.

123 In each field, three plots (4 m x 3 m) were randomly chosen, each including at least 24 plants.  
124 Every two weeks, weed infestation was recorded using a visual scale corresponding to the  
125 percentage of soil surface covered with weeds. The proportion of plants whose leaves and  
126 fruits showed symptoms of attacks by pests or diseases was recorded, and an  $M_i$  ( $i=1$  to 5)  
127 index calculated at each date; M1: < 10% of plants attacked; M2: 10-30% plants attacked;  
128 M3: 31-50% plants attacked; M4: 51-75% plants attacked; M5: > 75% plants attacked. The  
129 interval between planting and the M3 stage (P-M3) was calculated in days. Pests and diseases  
130 were recorded, along with the number of pesticide applications (NbPA) during the cropping  
131 period.

132 The density of tomato plants per  $m^2$  was determined by counting the plants 8-10 days after  
133 planting and again at the beginning of the harvesting period. Yield components (number of  
134 stems, number of trusses, and total number of fruits) were measured at flowering (i.e. when  
135 the first truss on the main stem had started flowering on at least 50% of plants per plot) and at  
136 harvest and expressed per  $m^2$ . Individual fruit weight was calculated from the total number  
137 and total weight of fruits harvested per  $m^2$ .

138 In 2005 only, three plants were randomly sampled in each plot at four different dates: 8-10  
139 days after planting (P), at flowering (F), two weeks after flowering (F+15), and at the  
140 beginning of the harvesting period (Ri). The aerial parts (stems, leaves, and fruits) were  
141 separated and dry matter determined after drying at 70 °C for 48 h. Plant total N, P, and K  
142 contents were measured on a 1 g sub-sample of dry matter taken separately from each aerial  
143 part. We calculated the nitrogen nutrition index (NNI; [Lemaire et al., 1997](#)) as the ratio of the  
144 N content of the aboveground parts of the plant to critical N content, using the reference  
145 values of critical N content for field-grown processing tomato proposed by [Tei et al. \(2002\)](#):  
146  $\%N = 4.53DM^{-0.327}$  (DM = dry matter, g).

147

### 148 2.3. Data analysis

149 For each field, we used the mean values calculated from measurements made in the three  
150 plots, and also calculated the standard deviation error and the coefficient of variation for each  
151 type of measurement. We identified all the correlated variables by principal component  
152 analysis (PCA). Yield was considered as a supplementary variable. The correlated variables  
153 (number of stems m<sup>-2</sup>, number of trusses m<sup>-2</sup>) were not included in the linear models. The  
154 relationships between yield, yield components, crop status and management practices were  
155 determined by multiple linear regression analysis with forward stepwise variable selection.  
156 The variables selected were the number of fruits per m<sup>2</sup> (NbF m<sup>-2</sup>), number of plants per m<sup>2</sup> at  
157 Ri (DP), mean fruit weight (FW), interval in days from the planting date to the M3 stage (P-  
158 M3), number of pesticide applications (NbPA), the quantity of total nitrogen applied (QtotN),  
159 cation exchange capacity (CEC) and the nitrogen content of the soil (Nsoil). In 2005, we  
160 added two extra variables: the number of trusses per m<sup>2</sup> and the nitrogen nutrition index. The  
161 Akaike information criterion (AIC) was chosen to determine the stopping point (i.e. the  
162 number of variables included):  $AIC = n \log (RSS/n) + 2p$ , where  $n$  is the number of



163 observations, RSS is the model residual sum of squares, and  $p$  is the number of parameters.  
164 The minimum AIC is commonly used to identify the parsimonious model that has both a low  
165 error rate and few parameters.

166 All analyses were performed with the software XLSTAT 2012.1. As different fields were  
167 sampled in the two years of our survey, we analyzed data from the two years separately.

168 Although we planned to survey the same tomato fields in the two years, this proved to be  
169 impossible, because in 2005, several farmers decided to not cultivate tomatoes and also  
170 because some farmers were obliged to cultivate different fields than those they had used in  
171 2003.

172

### 173 **3. Results and discussion**

#### 174 *3.1. Variability in yield and yield components*

175 Measured yield was highly variable, ranging from 0.7 to 45.3 t ha<sup>-1</sup> in 2003 (mean 19.9 t ha<sup>-1</sup>),  
176 and from 8.1 to 89.1 t ha<sup>-1</sup> in 2005 (mean 34.2 t ha<sup>-1</sup>). These average yields were relatively  
177 high compared to yields in other developing countries such as Madagascar (8.8 t ha<sup>-1</sup>), India  
178 (18.2 t ha<sup>-1</sup>), West Africa (7 t ha<sup>-1</sup>) and Central Africa (7.7 t ha<sup>-1</sup>) (FAO, 2011) where  
179 tomatoes are also mainly cultivated by hand. Planting density, number of fruits, stems, and  
180 trusses at harvest were also highly variable (Table 2). The key question is why yields were so  
181 low in some fields and high in others.

182 Results of the PCA showed that around 71.7% of the variability in 2003 (Fig. 2A), and 72.3%  
183 in 2005 were expressed by the three first axes (Fig. 2B). The yield components (number of  
184 fruits m<sup>-2</sup> and number of stems m<sup>-2</sup>) were correlated with the number of trusses m<sup>-2</sup> and  
185 number of plants m<sup>-2</sup> respectively and expressed by the first axis. In 2005, the NNI and QtotN  
186 variables were also linked to axis 1. In 2003, yields were closer to P-M3, FW and NbPA  
187 variables and correlated with the second axis, whereas in 2005, this axis expressed the NbPA

188 and FW variables. The third axis mainly expressed Q<sub>tot</sub>N in 2003, and CEC and N<sub>soil</sub> in  
189 2005.

190 Given that yield variability was correlated with the number of fruit per m<sup>2</sup>, and was close to  
191 limiting factors which played a role during the growing and fruit setting period, we focused  
192 our investigations on the biotic factors and cultivation practices that could influence the yield  
193 components before harvest, and on the final yield.

194

### 195 3.2. Characteristic of biotic limiting factors

#### 196 3.2.1. Incidence of pests and diseases

197 The incidence of pest and diseases varied with the growth stage and with the year. In 2003,  
198 the index of parasitism was rather low at flowering (59% of fields scored M1, 27% M2, 9%  
199 M3, and 5% M4), whereas at the beginning of harvesting period, 64% of the plots already  
200 scored M5 and 5% M4. In 2005, at flowering, the health status of the tomato crop had already  
201 deteriorated in 46% of the fields: 18% scored M3, 7% M4 and 21% M5. At the beginning of  
202 the harvesting period, all the fields expressed the maximum index M5. The difference  
203 between 2003 and 2005 in terms of the length of the P-M3 interval (23 to 94 days in 2003 and  
204 18 to 67 days in 2005), suggested that disease incidence was higher in 2005, but this may be  
205 due either to higher pest pressure or to differences in the major pests, or to the fact that crops  
206 were more sensitive to pests in 2005 because of the cultivars or the technical management  
207 practices used.

208 In 2003, three fields were severely attacked by bacterial wilt (*Ralstonia solanacearum*), black  
209 marrow disease (*Pseudomonas corrugata*), tomato yellow leaf curl virus and nematodes  
210 (*Meloidogynous* spp.), and the farmers argued that they had no effective means to control  
211 these diseases. The yield components (number of plants and number of fruits m<sup>-2</sup>) were  
212 seriously affected, and the yields of these fields were respectively 2.7, 6.1 and 0.7 t ha<sup>-1</sup>. Two

213 other fields suffered serious fruit losses due to blossom end rot and late attacks by cut worms  
214 (*Helicoverpa armigera*) during the harvesting period, which resulted in low yields (4.0 t ha<sup>-1</sup>  
215 and 11.7 t ha<sup>-1</sup>) despite a relatively long P-M3 interval (72 and 60 days, respectively).

216 In 2005, Tephritidae *Neoceratitis cyanescens* and the plant pathogen *Corynespora cassicola*  
217 were the cause of the main problems observed in the fields.

218

### 219 3.2.2. Nitrogen nutrition

220 In 2005, NNI measured at four crop stages varied considerably among fields, ranging from  
221 0.41 to 1.26 at 8-10 days after planting, from 1.43 to 3.24 at flowering, from 2.00 to 3.68 two  
222 weeks after flowering, and from 1.59 to 3.27 at the beginning of the harvest period. An  
223 increasing NNI trend over the cropping cycle revealed an improvement in nitrogen nutrition,  
224 perhaps the result of improved availability of N in the soil due to N-mineral fertilization and  
225 the mineralization of organic matter. At planting, the mean mineral N content of the network  
226 of fields and the mean organic matter content at a depth of 0-20 cm were respectively 2.02 g  
227 kg<sup>-1</sup> and 3.08% in 2003, and 2.43 g kg<sup>-1</sup> and 4.2% in 2005, revealing satisfactory nitrogen  
228 content and soil organic matter content with respect to the standard values of [Latrille \(1981\)](#)  
229 and [Odet \(1989\)](#).

230 A total of 80% of the fields received from 3.3 to 23.8 t ha<sup>-1</sup> of organic poultry manure at  
231 planting, corresponding to 24.7 to 178.5 kg ha<sup>-1</sup> of nitrogen according to the standard values  
232 developed by [Chabalier et al. \(2006\)](#). Consequently, most of the fields appeared to receive  
233 correct amounts of N with respect to tomato N requirements.

234 In 2005, the variation in the nitrogen nutrition index (NNI) was weakly correlated with the  
235 increasing doses of nitrogen fertilizers supplied to the crop (data not shown). The farmers  
236 usually irrigate their tomato plants once or twice a day, so nitrogen leaching probably caused

237 a variation in N uptake in the field network, and consequently a variation in NNI for a given  
238 quantity of nitrogen applied.

239

### 240 *3.2.3. Climatic conditions over the two years and at the different sites*

241 We observed that the best yields (56 to 89 t ha<sup>-1</sup>) were obtained in the central part of the island  
242 where the average temperature for the whole study period (24.2 °C) was 0.5 °C to 2.9 °C  
243 lower than in the other areas. Yields of more than 40 t ha<sup>-1</sup> were obtained in the southern,  
244 south-eastern, and central zones, suggesting a beneficial effect of cooler temperatures on  
245 yield. However, as the surveys were conducted separately in 2003 and 2005, and spanned  
246 only two years, we cannot conclude if the best yields were due to the effect of climatic  
247 conditions at regional scale.

248

### 249 *3.3. Limiting factors of yield components and yield*

250 We performed several stepwise regression analyses to investigate the factors that might  
251 negatively affect yield throughout the crop cycle. Theoretically, yield can be broken down  
252 into the following components: yield = number of plants per m<sup>2</sup> x number of stems per plant x  
253 number of trusses per stem x number of fruits per truss x mean fruit weight.

254 For 2003, forward linear regression selected a model with four variables and with an  
255 explanatory power of 84.7% of yield variability (Table 3A). In this model, the number of  
256 fruits per m<sup>2</sup> (NbF m<sup>-2</sup>), fruit weight (FW), P-M3, and CEC variables were deemed to be  
257 positively correlated with yield. The health status of the crop (P-M3) explained 55% of the  
258 yield. In 2005, only two variables were selected for the regression model (Table 3B), with P-  
259 M3 and NbF m<sup>-2</sup> explaining 84% of yield variability. All the variables exhibited similar  
260 effects with greater effect of NbF m<sup>-2</sup> in 2003 and of P-M3 in 2005.

261 Consequently, we performed a stepwise regression analysis of the number of fruits per m<sup>2</sup>  
262 which appeared to be the main yield component correlated with yield. For 2003, forward  
263 linear regression selected a model with two variables (DP and P-M3) and with an explanatory  
264 power of 61.8% of the variability of number of fruits per m<sup>2</sup> (Table 4A). In 2005, three  
265 variables were selected for the regression model (Table 4B) and P-M3, the number of  
266 pesticide applications and DP explained 65.6% of NbF m<sup>-2</sup> variability. All the variables had  
267 similar effects with a high contribution of P-M3 to NbF m<sup>-2</sup> variability in both years.

268

### 269 *3.4. Effect of crop management on limiting factors*

270 As the health status of the crop (expressed by P-M3) and the number of plants per m<sup>2</sup>  
271 appeared to be the main factors involved in yield variability, we investigated the effects of  
272 tomato crop management on these limiting factors.

273

#### 274 *3.4.1. Pest and disease management*

275 The P-M3 interval (in days) was weakly correlated with the number of pesticide applications  
276 ( $r^2 = 0.29$  in 2003;  $P < 0.05$ ; no effect in 2005) which calls into question the use and  
277 efficiency of such applications. Moreover, under the cropping conditions studied here, we  
278 found no significant relationship between the sanitary index (Mi) and the number of pesticide  
279 applications (data not shown), either at the flowering stage, or later, at the beginning of the  
280 harvesting period. However, none of the farmers used the pesticides correctly, as both too  
281 small and too large doses of pesticide were applied in both years (Table 5). Overuse of  
282 insecticides and fungicides was less marked in 2003 than in 2005, and major differences  
283 among farmers were observed. Farmers undertook an average of 9 pesticide applications ( $\pm$   
284 4.3) in 2003 and 9.5 ( $\pm$  3.5) in 2005. They usually used a knapsack sprayer, and wore no  
285 protective clothing even though they were aware of pesticide hazards. In 2003, the doses of

286 Deltamethrin used by all the farmers ranged between 43% and 267% and of Lambda-  
287 cyhalothrin between 87% and 533% of the recommended doses, and in 2005, doses of  
288 Deltamethrin ranged between 22% and 360% and those of Lambda-cyhalothrin between  
289 113% and 480% of the recommended doses (Table 5), evidence for the absence of appropriate  
290 pesticide management.

291 The positive relationship between the P-M3 interval (in days) and yield revealed a major  
292 impact of pest and diseases and the need to prevent their attacks at the beginning of the crop  
293 cycle to avoid high yield losses. However, the chemical control measures implemented by the  
294 farmers had very limited effects on pests. Although all the farmers used pesticides, all their  
295 fields were nevertheless subject to severe attacks at the beginning of the harvesting period.

296 The Lepidoptera *Helicoverpa armigera*, the Tephritidae *Neoceratitis cyanescens* and the  
297 foliar disease *Corynespora cassiicola* were the main problems recorded in the fields. In a field  
298 trial with processing tomatoes at UC Davis, California, Wilson et al. (1983) reported that  
299 fruits less than 2.5 cm in diameter abort when fed on by *Helicoverpa zea*, and Brevault and  
300 Quilici (2009) observed in field-grown tomatoes in Reunion Island that *N. cyanescens*  
301 attacked small developing fruits 2-3.5 cm in diameter, primarily from 10 to 20 days post-  
302 flowering. These fruits are completely damaged when they ripen and may drop off the plant.  
303 In the absence of insecticide application during the fruiting period, these authors observed that  
304 40% of a given generation of fruits were damaged by the tomato fruit fly. In islands in the  
305 Indian Ocean and particularly in Mayotte, *N. cyanescens* is a major constraint for tomato  
306 production (Bordat, 2008) and the efficacy of chemical control has been neither validated nor  
307 demonstrated in the field (Ryckewaert et al., 2010).

308 The absence of a relationship between the number of pesticide applications and the crop  
309 sanitary index Mi at the beginning of the harvesting period could be explained by under  
310 dosing of pesticide in some of the fields (Table 5) or the inefficacy of the insecticides

311 (Deltamethrin and Lambda-cyhalothrin) used by the farmers to control the major insect pests  
312 *H. armigera* and *N. cyanescens* during the post flowering period. These insects were probably  
313 involved in the variation in the number of fruits per truss per m<sup>2</sup>, and in the number of fruits  
314 per m<sup>2</sup> in both years, as fruits that aborted or dropped prematurely were not recorded. The  
315 inefficacy of the pesticides may also be explained by under and overuse, or the use of  
316 inappropriate pesticides, as already observed in other rural, urban and peri-urban vegetable  
317 cropping systems in developing countries (Kanda et al., 2009; De Bon et al., 2010; Lund et  
318 al., 2010). Our survey showed that the famers did not have a thorough understanding of the  
319 different types of pests and of appropriate control measures, and highlighted the problems that  
320 can arise from inappropriate use of pesticides by farmers and the risk of environmental  
321 degradation as well as sanitary risks for the users. There is thus an urgent need to increase  
322 farmers' understanding and use of safe plant protection practices (Barman, 2007; Snelder et  
323 al., 2008).

324 In addition to applying pesticides, 25 farmers out of 26 practiced different degrees of sanitary  
325 deleafing several times during the post-flowering period. Their objective was to decrease the  
326 propagation of pests in the field, to reduce the number of applications of chemicals, and to  
327 facilitate the penetration of the chemical products within the vegetation. However, no  
328 measurement was made to assess the effectiveness of this practice for pest and disease  
329 control.

330

### 331 3.4.2. *Planting and stem density*

332 The number of fruits m<sup>-2</sup> was influenced by the number of plants m<sup>-2</sup>, but there was no effect  
333 of the number of stems plant<sup>-1</sup> (data not shown). This result could be linked to the practice of  
334 pruning and disbudding which consisted in keeping two to three fruit-bearing stems per plant  
335 from flowering to harvesting. The survey confirmed that farmers based their control of the

336 vegetation on the individual plant unit and not on the unit area, and by choosing the same  
337 number of stems per plant whatever the planting density. We could argue that manual pruning  
338 and disbudding also influenced the variation in the number of stems  $\text{m}^{-2}$  and therefore the  
339 number of fruits  $\text{m}^{-2}$ . These practices also reduced the influence of the variety on the number  
340 of fruits per  $\text{m}^2$ , consequently the varietal diversity in the field network was not a constraint  
341 for carrying out the agronomic diagnosis. [Figure 3](#) shows links as a function of plant density,  
342 and the highest points suggest that the only limiting factor was density. As pest attacks  
343 increase with plant density (at least fungi under tropical conditions), there is probably an  
344 optimal threshold beyond which yield will decrease. These results indicate that yields of field-  
345 grown tomatoes could be increased by increasing the planting density.

346 An on-station trial implemented in Mayotte in 2005, two treatments with pruning and one  
347 without ([Huat, 2008](#)), confirmed the positive relationship between the number of fruits  $\text{m}^{-2}$   
348 and increasing the number of stems  $\text{m}^{-2}$ . The same relationship was observed by [Ece and](#)  
349 [Darakci \(2007\)](#) with indeterminate field-grown tomato varieties in Turkey.

350 In 2003, the average density of tomato plants in the farmers' fields was lower than the  
351 densities usually recommended (2.5 to 3.0 plants  $\text{m}^{-2}$ ) for determinate varieties in tropical  
352 areas and managed without pruning and disbudding ([Messiaen, 1998](#)). Although small-scale  
353 farmers in Mayotte Island considered that pruning and disbudding make it possible to obtain  
354 better marketable yields and to limit pest infestations in the crop, (which has not been  
355 demonstrated), most small scale farmers in Africa are reluctant to apply these operations  
356 because they are very demanding in terms of labour and associated costs ([Asgedom et al.,](#)  
357 [2011](#)). As the number of fruits appears to be the main determinant of the dry mass partitioning  
358 between fruits and the vegetative parts of tomato plants ([Heuvelink and Dorais, 2005](#)), a  
359 certain number of fruits can be removed to obtain the desired average fruit weight. Individual  
360 fruit mass increases with a decrease in the number of fruits per plant, as competition between



361 fruits for assimilates is reduced. Nevertheless, determinate cultivars need light pruning: only  
362 the first or two three axillary shoots should be removed, because heavier pruning reduces  
363 marketable yields (Csizinszky, 2005).  
364 Yield could be increased by increasing planting density and pruning the plants down to 2-3  
365 stems, or by increasing the number of stems per plant (i.e. the number of trusses and fruits per  
366 plant) by not pruning the plants. One practical solution would be to measure the effect of  
367 several medium and high plant densities combined with different modes of pruning and  
368 disbudding on yield, and in other cropping conditions, to help small-scale farmers improve  
369 their yield based on their own cropping system.

370

#### 371 *3.4.3. Limitations of the study*

372 The fraction of the variability of the number of fruits per m<sup>2</sup> not explained by the linear model  
373 (around 38% in 2003 and 34% in 2005) can be attributed to several factors. At the beginning  
374 of the study, we planned to survey the same tomato fields in 2003 and 2005, but this proved to  
375 be impossible, firstly because several farmers decided to not cultivate tomatoes in 2005, and  
376 secondly because some farmers used different fields than those they had used in 2003. This  
377 was because most tomato producers in Mayotte are illegal immigrants who do not enjoy  
378 secure land tenure. Every year, they have to renegotiate with a land owner to obtain a piece of  
379 land to cultivate. Their situation is unstable, and their objective is thus to obtain high yields to  
380 increase their income.

381 We collected management variables during surveys of farmers, and errors may have resulted  
382 from the farmer failing to remember exactly what practices he applied in a particular field.

383 These errors were not quantified in this study, as doing so would require independent sources  
384 of management information. Errors in the model may also reflect the absence of relevant  
385 explanatory variables that were not measured in the survey (e.g. differences in pest

386 population, spatial variations in weather conditions, water consumption). We chose to  
387 perform our agronomic diagnosis using easy-to-use indicators such as the curve of critical  
388 dilution of nitrogen, and visual indicators of plant health such as sanitary status  $M_i$  and P-M3  
389 which appeared to be appropriate in our study. The critical nitrogen curve of [Tei et al. \(2002\)](#)  
390 based on the processing tomato cultivar PS1296 and tested in central Italy needs to be  
391 validated under tropical conditions using different tomato genotypes.  
392 The sanitary status of the crop was evaluated independently of the date of deleafing.  
393 Depending on whether the observation was made before or after deleafing, the  $M_i$  value could  
394 differ, which could partly explain the variability of  $M_i$ , independently of the number of  
395 pesticide applications. Our difficulty in identifying significant relationships between these two  
396 variables may also be due to strong interactions between variables and/or omission of major  
397 variables affecting yields that we were not able capture in our survey.

398

#### 399 **4. Conclusion**

400 Yield varied considerably among farmers, ranging from 0.7 to 45.3 t ha<sup>-1</sup> in 2003 (mean 19.9 t  
401 ha<sup>-1</sup>), and from 8.1 to 89.1 t ha<sup>-1</sup> in 2005 (mean 34.2 t ha<sup>-1</sup>). By using a stepwise regression  
402 procedure, we were able to explain around 80% of yield variability in the two years with a  
403 few variables, and roughly 65% of the variability of the yield component number of fruits per  
404 m<sup>2</sup>. The health status of the crop expressed by the P-M3 indicator drove the majority of  
405 variability of the number of fruits per m<sup>2</sup> in the network of fields. The period between  
406 flowering and the beginning of harvesting appears to be decisive for the elaboration of the  
407 yield component number of fruits per m<sup>2</sup>. To our knowledge, to date, there has been no  
408 diagnosis of yield-limiting factors of field-grown tomatoes in smallholder farms under  
409 tropical conditions using this method.

410 From a practical point of view, our results showed that it should be possible to increase the  
411 tomato yield in two ways: (i) increasing the number of stems per m<sup>2</sup>, either by limiting the  
412 number of disbudding operations to one at pruning, or by increasing planting density; (ii)  
413 improving farmers' knowledge of safe and efficient plant protection practices. Increasing  
414 plant density under severe pruning rather than stem density favours the use of soil resources  
415 (fertilizers, water), but has higher planting costs (seeds, labour) and mean fruit weight.  
416 Increasing stem density by keeping all stems or removing only two or three fruit stems at the  
417 flowering stage will favor the number of fruits per m<sup>2</sup> and increase humidity within the  
418 canopy, but will reduce mean fruit weight and favour the development of pathogens under  
419 tropical conditions. Nevertheless, tomato yield variability was not attributable solely to pest  
420 abundance or pesticide use. Further studies are needed to interpret the effects of interactions  
421 between planting density and health status on tomato productivity under various conditions,  
422 and to identify other management practices to improve regional production and reduce the  
423 environmental impacts of pesticide use.

424

#### 425 **Acknowledgments**

426 This study was made possible through funding from the Departmental Collectivity of  
427 Mayotte, the French Agricultural Research Centre for International Development (CIRAD)  
428 and the French Ministry of Agriculture, Food, and Fisheries. We also thank the farmers we  
429 interviewed, without whom the study would not have been possible.

430

#### 431 **References**

432 Acta, 2005. Index phytosanitaire. Acta 41<sup>ème</sup> éd., Paris, France, 831 pp.  
433 Asgedom, S., Struik, P.C., Heuvelink, E., Araia, W., 2011. Opportunities and constraints of  
434 tomato production in Eritrea. Afr. J. Agric. Res. 6, 956-967.

435 Barman, S.C., 2007. Real adoption impact measure of tomato technologies on production at  
436 farmers' level in Bangladesh. *Bangladesh J. Sci. Ind. Res.* 42 (1), 15-28.

437 Bertin, N., Heuvelink, E., 1993. Dry matter production in a tomato crop: comparison of two  
438 simulation models. *J. Hortic. Sci.* 68, 995-1011.

439 Bordat D., 2008. Mission d'identification d'insectes ravageurs auxiliaires des cultures  
440 maraîchères, Rapport de mission à Mayotte, 6-14/09/2008, Cirad, Montpellier, France, 24 p.

441 Brevault, T., Quilici, S., 2009. Oviposition preference in the oligophagous tomato fruit fly,  
442 *Neoceratitis cyanescens*. *Entomol. Exp. Appl.* 133, 165-173.

443 Chabalier, P.F., Van de Kerchove, V., Saint-Macary, H., 2006. Guide de la fertilisation  
444 organique à la Réunion. Cirad, France, 302 pp.

445 Clark, M.S., Horwath, W.R., Shennan, C., Scow, K.M., Lantni, W.T., Ferris, H., 1999.  
446 Nitrogen, weeds and water as yield-limiting factors in conventional, low-input, and organic  
447 tomato systems. *Agr. Ecosyst. Environ.* 73, 257-270.

448 Cszizinszky, A.A., 2005. Production in open field. In: Heuvelink, E. (Ed.), *Tomatoes*. Cabi  
449 Publishing, London, UK, pp. 237-256.

450 Cszizinszky, A.A., Schuster, D.J., Jones, J.B., Van Lenteren, J.C., 2005. Crop protection. In:  
451 Heuvelink, E. (Ed.), *Tomatoes*. Cabi Publishing, London, UK, pp. 199-235.

452 De Bon, H., Parrot, L., and Moustier, P., 2010. Sustainable urban agriculture in developing  
453 countries. A review. *Agron. Sustain. Dev.* 30, 21-32.

454 Doré, T., Sebillotte, M., Meynard, J.M., 1997. A diagnostic method for assessing regional  
455 variations in crop yield. *Agr. Syst.* 54, 169-188.

456 Doré, T., Clermont-Dauphin, C., Crozat, Y., David, C., Jeuffroy, M.H., Loyce, C., Makowski,  
457 D., Malézieux, E., Meynard, J.M., Valantin-Morison, M., 2008. Methodological progress in  
458 on-farm regional agronomic diagnosis. A review. *Agron. Sustain. Dev.* 28, 151-161.

459 Dumas, Y., Bussieres, P., Battilani, A., Cornillon, P., Prieto Losada, M.H., Branthome, X., Di  
460 Lucca, G., Bues, R., Dadomo, M., Machado, R., Christou, M., San Martin, C., Lyannaz, J.P.,  
461 Koutsos, T., Ho, L.C., 1998. QUALITOM, a research program to build and test a technical  
462 itineraries model in processing tomato cropping. *Acta Hort.* 487, 151-158.

463 Ece, A., Darakci, N., 2007. Determination of relationships between number of stem and yield  
464 of tomato (*Lycopersicon lycopersicum* L.). *Asian J. Plant Sci.* 6, 802-808.

465 FAO, 2011. FAO Statistics Agriculture. <http://faostat.fao.org/site/567>.

466 Heuvelink, E., 2005. Developmental processes. In: Heuvelink, E. (Ed.), *Tomatoes*. Cabi  
467 Publishing, London, UK, pp. 53-83.

468 Heuvelink, E., Dorais, M., 2005. Crop growth and yield. In: Heuvelink, E. (Ed.), *Tomatoes*.  
469 Cabi Publishing, London, UK, pp. 85-144.

470 Huat, J., 2006. Facteurs limitatifs du rendement de la tomate industrielle en périmètres  
471 irrigués au nord Sénégal. *Cah. Agric.* 15, 293-300.

472 Huat, J., 2008. Diagnostic sur la variabilité des modes de conduite d'une culture et de leurs  
473 conséquences agronomiques dans une agriculture fortement soumise aux incertitudes : cas de  
474 la tomate de plein champ à Mayotte. Ph.D. Dissertation, AgroParisTech, Paris, France.

475 Kanda, M., Wala, K., Batawila, K., Djaneye Boundjou, G., Ahanchede, A., Akpagana, K.,  
476 2009. Le maraîchage périurbain à Lomé : pratiques culturelles, risques sanitaires et  
477 dynamiques spatiales. *Cah. Agric.* 18, 356-363.

478 Latrille, E., 1981. Inventaire des terres cultivables et de leurs aptitudes culturelles, exploitation  
479 agronomique de la carte de l'inventaire des terres cultivables, conclusion générale. Rapport  
480 Cirad, Irat, Mayotte, 21 p.

481 Lemaire, G., Gastal, F., Plenet, D., Le Bot, J., 1997. Le prélèvement d'azote par les  
482 peuplements végétaux et la production des cultures. In: Lemaire, G., Nicolardot, B. (Eds.),  
483 *Maîtrise de l'azote dans les agrosystèmes*. Colloques n° 83, Inra, Paris, France, pp. 121-139.

484 Lund, T., Saethre, M.-G., Nyborg, I., Coulibaly, O., Rahman, M.H., 2010. Farmer field  
485 school-IPM impacts on urban and peri-urban vegetable producers in Cotonou, Benin. *Int. J.*  
486 *Trop. Insect Sci.* 30, 19-31.

487 Messiaen, C.M., 1998. *Le potager tropical*. Presses Universitaires de France, 583 p.

488 Meynard, J.M., David G., 1992. Diagnostic de l'élaboration du rendement des cultures. *Cah.*  
489 *Agric.* 1, 9-19.

490 Ndienor, M., Aubry, C., Mougeot, L.J.A., 2004. Diversité et flexibilité des systèmes de  
491 production maraîchers dans l'agglomération d'Antananarivo (Madagascar): atouts et  
492 contraintes de la proximité urbaine. *Cah. Agric.* 13, 50-57.

493 Odet, J., 1989. *Mémento fertilisation des cultures légumières*. Edition Ctifl, France, 398 p.

494 Peet, M.M., Welles, G., 2005. Greenhouse tomato production. In: Heuvelink, E. (Ed.),  
495 *Tomatoes*. Cabi Publishing, London, UK, pp. 53-83.

496 Raunet, M., 1992. Les facteurs d'érosion des terres et d'envasement du lagon. Cirad, Mayotte,  
497 69 p.

498 Riahi, A., Hdider, C., Sanaa, M., Tarchoun, N., Ben Kheder, M., Guezal, I., 2008. Effect of  
499 conventional and organic production systems on the yield and quality of field tomato cultivars  
500 grown in Tunisia. *J. Sci. Food Agric.* 89, 2275-2282.

501 Ryckewaert, P., Deguine, J.P., Brévault, T., Vayssières, J.F., 2010. Fruits flies (Diptera:  
502 Tephritidae) on vegetable crops in Reunion Island (Indian Ocean): state of knowledge, control  
503 methods and prospects for management. *Fruits* 65, 113-129.

504 Scholberg, J., McNeal, B.L., Jones, J.W., Boote, K.J., Stanley, C.D., Obreza, T.A., 2000.  
505 Field-grown tomato-growth and canopy characteristics of field-grown tomato. *Agron. J.* 92,  
506 152-159.

507 Stacey, D.L., 1983. The effect of artificial defoliation on the yield of tomato plants and his  
508 relevance to pest damage. *J. Hortic. Sci.* 58, 117-120.

509 Snelder, D.J., Masipiquena, M.D., de Snoo, G.R., 2008. Risk assessment of pesticide usage by  
510 smallholder farmers in the Cagayan Valley (Philippines). *Crop Prot.* 27, 742-762.

511 Tei, F., Benincasa, P., Guiducci, M., 2002. Critical nitrogen concentration in processing  
512 tomato. *Eur. J. Agron.* 18, 45-55.

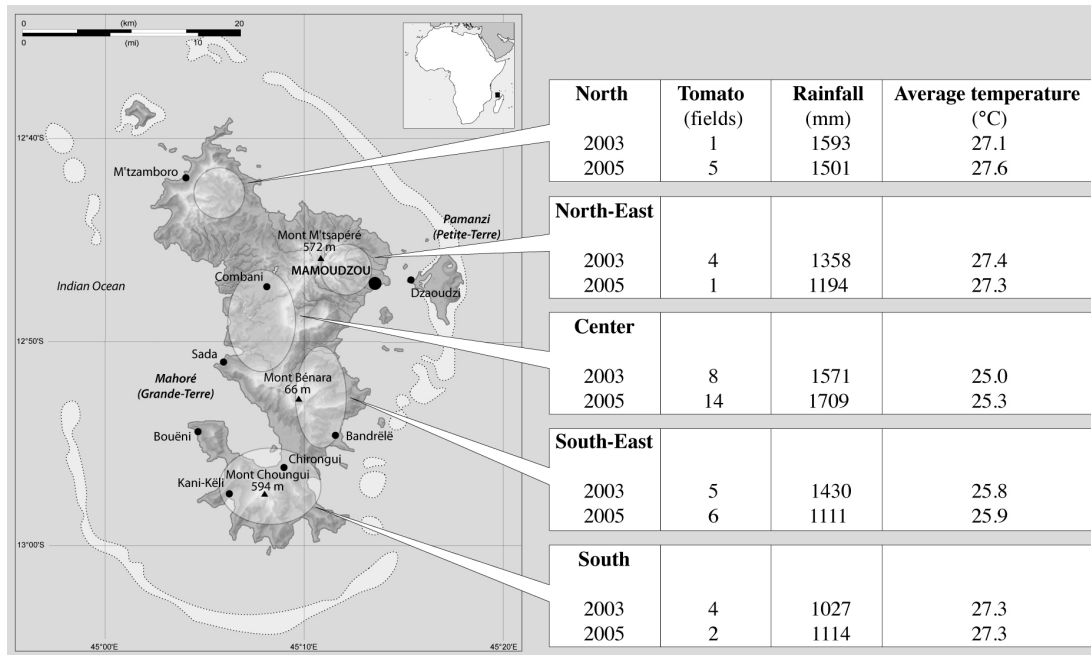
513 Temple, L., Moustier, P., 2004. Les fonctions et contraintes de l'agriculture périurbaine de  
514 quelques villes africaines (Yaoundé, Cotonou, Dakar). *Cah. Agric.* 13, 15-22.

515 Wilson, L.T., Zalom, F.G., Smith, R., Hoffmann, M.P., 1983. Monitoring for fruit damage in  
516 processing tomatoes: use of a dynamic sequential sampling plant. *Environ. Entomol.* 12, 835-  
517 839.

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**Fig. 1.** Location of the tomato fields surveyed in smallholder farms in the five major areas of Mayotte Island (Indian Ocean) in 2003 and 2005.



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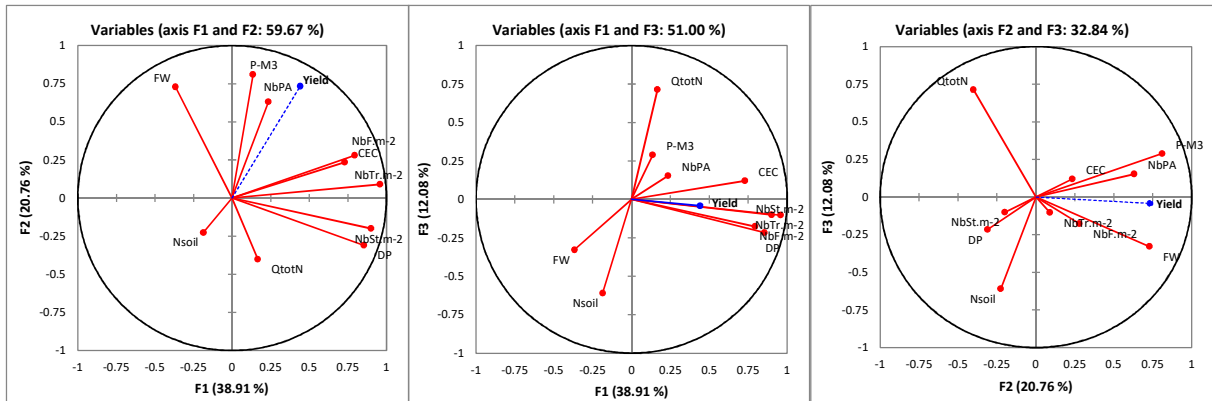


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**Fig. 2.** Principal components analysis with yield component variables, crop and soil status variables and cultivation practice variables: (A) for 2003, (B) for 2005. Yield (dashed line) was projected as a supplementary variable.

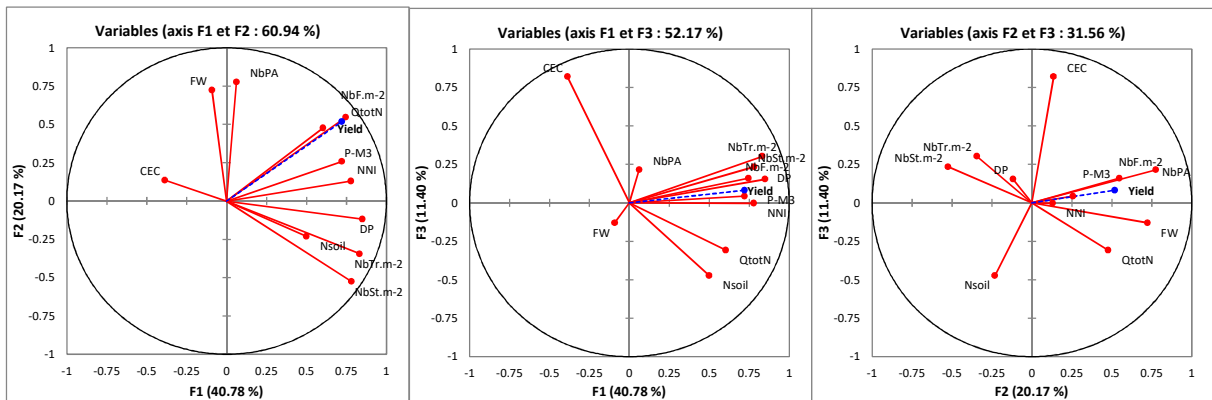
NbF m<sup>-2</sup>: number of fruits m<sup>-2</sup>; NbTr m<sup>-2</sup>: number of trusses m<sup>-2</sup>; NbSt m<sup>-2</sup>: number of stems m<sup>-2</sup>; DP: number of plants m<sup>-2</sup>; FW: fruit weight (g); QtotN: Quantity of total N applied (kg.ha<sup>-1</sup>); NbPA: number of pesticide applications; P-M3: Period in days between planting and M3 sanitary index; NNI: Nitrogen nutrition index of the crop; Nsoil: N content of soil (g.kg<sup>-1</sup>) at a depth of 0-20 cm; CEC: Cation exchange capacity of soil (meq.100g<sup>-1</sup>) at a depth of 0-20 cm.

534 **A- 2003**



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536 **B- 2005**



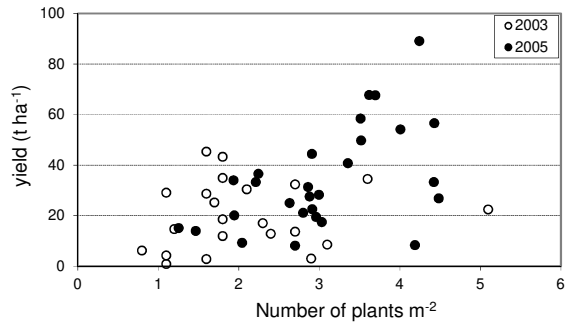
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**Fig. 3.** Relationship between yields and planting density.



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**Table 1**  
Main tomato cropping practices used.

Practices	2003		2005	
	Mean±SD	Range	Mean±SD	Range
Planting density (plants ha <sup>-1</sup> )	23918±9882	11000-54200	32180±8669	14680-48690
NPK fertilizers (kg ha <sup>-1</sup> )	196±243	0-890	858±655	0-2638
Organic manure (t ha <sup>-1</sup> )	7.2±3.6	0-14.8	7.3±6.8	0-23.3
Number of pesticide applications	9.0±4.3	4-23	9.5±3.5	0-18

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**Table 2**  
Variability of tomato yield and yield components.

Measured variables	2003		2005	
	Mean±SD	Range	Mean±SD	Range
Yield (t ha <sup>-1</sup> )	19.9±13.4	0.7-45.3	34.2±20.3	8.1-89.1
Number of plants m <sup>-2</sup>	2.1±0.9	0.8-5.1	3.0±0.9	1.3-4.5
Number of stems m <sup>-2</sup>	5.3±3.2	1.9-16.3	14.0±5.6	4.8-29.7
Number of trusses m <sup>-2</sup>	10.3±5.6	3.1-24.5	42.1±16.0	15.9-87.1
Number of fruits m <sup>-2</sup>	24.0±11.9	3.6-45.6	87.2±54.3	18.3-243.1
Mean fruit weight (g)	89.0±26.0	54.6-157.2	65.7±17.9	23.5-94.7

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559 **Table 3**  
 560 Regression statistics for yield, with variables listed in order of selection using a step forward procedure.

561  
 562 **A- 2003**  
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Significant variables*	Estimate	Standard error	t	P >  t	Cumulative r <sup>2</sup>	AIC
Constant	-24.765	4.917	-5.037	0.000	-	-
P-M3	0.227	0.067	3.387	0.004	0.550	98.645
NbF m <sup>-2</sup>	0.465	0.128	3.643	0.002	0.709	89.961
FW	0.176	0.050	3.536	0.003	0.790	83.622
CEC	0.239	0.086	2.770	0.013	0.847	77.425

564 \* P-M3: interval in days from the planting date to M3 stage; NbF m<sup>-2</sup>: number of fruits per m<sup>2</sup>;  
 565 FW: mean fruit weight; CEC: cation exchange capacity.

566  
 567 **B- 2005**  
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Significant variables*	Estimate	Standard error	t	P >  t	Cumulative r <sup>2</sup>	AIC
Constant	-9.338	6.446	-1.449	0.160	-	-
NbF m <sup>-2</sup>	0.267	0.040	6.654	< 0.0001	0.800	126.564
P-M3	0.461	0.182	2.533	0.018	0.840	122.166

569 \* NbF m<sup>-2</sup>: number of fruits per m<sup>2</sup>; P-M3: interval in days from the planting date to M3 stage.

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572 **Table 4**  
 573 Regression statistics for number of fruits per m<sup>2</sup>, with variables listed in order of selection using a step forward  
 574 procedure.

575  
 576 **A- 2003**  
 577

Significant variables*	Estimate	Standard error	t	P >  t	Cumulative r <sup>2</sup>	AIC
Constant	-9.442	5.859	-1.612	0.124	-	-
DP	8.128	1.651	4.923	< 0.0001	0.296	103.211
P-M3	0.317	0.075	4.223	0.000	0.618	90.650

\* DP: number of plants per m<sup>2</sup>; P-M3: interval in days from the planting date to M3 stage.

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 580 **B- 2005**  
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Significant variables*	Estimate	Standard error	t	P >  t	cumulative r <sup>2</sup>	AIC
Constant	-128.283	29.858	-4.296	0.000	-	-
P-M3	2.158	0.567	3.808	0.001	0.423	210.188
NbPA	5.891	1.786	3.297	0.003	0.558	203.624
DP	21.299	7.493	2.842	0.009	0.656	197.499

\* P-M3: interval in days from the planting date to M3 stage; DP: number of plants per m<sup>2</sup>; NbPA: number of pesticide applications.

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**Table 5**

Average application rates of pesticides used by farmers in 2003 and 2005 calculated as a percentage of the dose recommended by pesticide manufacturers in *Index Phytosanitaire Acta* (Acta, 2005).

Pesticide	2003		2005	
	Mean±SD	Range	Mean±SD	Range
Deltamethrin	112±62	43-267	180±95	22-360
Lambda-cyhalothrin	208±104	87-533	218±124	113-480
Tau-Fluvalinate	251±148	100-404	317±104	200-400
Dicofol	115±68	44-180	293±195	155-431
Cyromazine	141	-	82±27	42-113
Abamectin	-*	-	136±8	130-141
Mancozeb	129±64	14-267	294±212	75-805
Copper sulphate	99±102	5-288	134±89	44-314
Maneb + Thiophanate-methyl	91±79	17-200	128±79	62-226
Chlorothalonil	19±2	18-21	84±31	50-109
Difenoconazole	-	-	420	-
Cymoxanil + zinc metirame	-	-	153±5	149-156

590 \* -: no measurement

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