J. Amer. Soc. Hort. Sci. 130(6):799–805. 2005.

Analysis of *Solanaceae* Species Harvest-organ Growth by Linear Increase in Harvest Index and Harvest-organ Growth Rate

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Additional index words. crop growth model, biomass partitioning, potato, tomato, eggplant

Abstract. **Crop growth simulation models have been mainly developed to simulate final yield reliably. Thus, a main challenge in these models is the definition of a stable method for expressing the growth of harvested organs (e.g., fruit, seed, tuber, etc.). Generally, two approaches have been used: growth rate analysis of harvested organs [yield growth rate (YGR)] and analysis of harvest index (HI) increase over time (dHI/dt). This work aims to: 1) examine whether YGR and dHI/dt increase linearly over much of growing period, and 2) compare the two growth indices in terms of stability across a number of treatments, in order to identify which is the best indicator of harvest-organ growth. This analysis has already been performed for a large number of field crops, including wheat (*Triticum aestivum* L.), sunflower (*Helianthus annuus* L.), soybean [*Glycine max* L. (Merr.)], and pea (*Pisum sativum* L.), but it has never been attempted in crops where final yield is not simply seeds. In this study, YGR and dHI/dt performances for tomato (*Lycopersicum esculentum* Mill.), potato (*Solanum tuberosum* L.), and eggplant (*Solanum melongena* L.) were compared using 21, 18, and 4 datasets, respectively. Results indicated that both descriptors of harvest-organ growth increased linearly for most of the growth period, whilst the comparison among the two variables in terms of stability showed that, although a direct statistical test failed, dHI/dt was more suitable to describe harvest-organ growth (smaller coefficient of variability) under a large range of crop management conditions (e.g., irrigation, sowing date, planting density, and water salt concentration).**

Crop models are useful tools to simulate crop growth and development. Since one of the aims of these models is usually the accurate prediction of final yield, the ability to simulate mass partitioning to reproductive organs is essential to meet this objective. Two common approaches to calculating reproductive growth have been based on: 1) the determination of a linear harvest-organ growth rate during much of the reproductive period [yield growth rate (YGR)] and 2) the quantification of the increase in harvest index (HI) (the ratio of yield components to total aboveground biomass) during reproductive growth. A third approach has been infrequently used based on an estimation of a partitioning coefficient. However, the partitioning coefficient is difficult to determine experimentally and it is calculated only by invoking some rather dubious assumptions (Duncan et al., 1978). These assumptions include a constant overall crop growth rate for the entire period from leaf canopy closure through much of reproductive development, and a constant fruit growth rate (i.e., YGR). Further, there is no physiological basis for expecting a partitioning coefficient to remain constant throughout the reproductive period. Therefore, in this analysis we will focus only on the YGR component of the partitioning-coefficient approach and not attempt the questionable extension to estimate a partitioning coefficient.

The estimation of YGR in itself is problematic because of the assumed stability in reproductive organ growth rate over much of the reproductive period. The methodology to estimate YGR is also difficult to implement experimentally because it requires estimation of harvest-organ numbers (Jamieson et al., 1991) and the estimation of an individual YGR that is representative of the whole plant (Spaeth and Sinclair, 1984). Commonly, YGR is determined by harvesting grains from a fixed number of plants or land area and the average grain weight is measured (Bindi et al., 1999).

Using the second approach involving the calculation of HI increase, Spaeth and Sinclair (1984) showed that normalisation of final seed yield can decrease problems due to large uncertainty in measurements of field-grown plants. Spaeth and Sinclair (1985) found that seed growth in soybean may be better defined by determining the change of harvest index with time during the seed-growth period. They found that HI increased linearly over much of the seed-development period and that the rate of increase of HI (dHI/dt) was almost constant for most soybean cultivars. This was consistent with results subsequently obtained by Muchow (1988) on maize (*Zea mays* L.) and sorghum [*Sorgum bicolor* L. (Moench)] across fertility treatments and by Moot et al. (1996) who found low variability of dHI/dt in wheat among cultivars, fertility and drought treatments. The same behaviour was confirmed by Bindi et al. (1999) comparing different species subjected to different treatments. The linear change of HI with time and its stability for a cultivar across a number of treatments for a single crop make this descriptor of reproductive growth particularly useful, especially for modelling purposes. The use of dHI/dt avoids the necessity of calculating detailed aspects of seed growth such as seed number and size (Chapman et al., 1993).

In most cases, dHI/dt has generally proven more stable in describing reproductive growth than YGR for species producing

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Received for publication 21 Jan. 2005. Accepted for publication 5 Apr. 2005.

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grains such as sunflower, wheat, soybean, and maize (Bindi et al., 1999). On the other hand, there is no information comparing these two approaches in describing reproductive growth in vegetable crops producing fruits or tubers such as tomato, potato and eggplant. Therefore, the objectives of this work were first: to identify the period during harvest-organ growth when it is appropriate to consider that dHI/dt and YGR increase linearly. No analysis is available for tomato, potato and eggplant to define over what range of data dHI/dt and YGR can be assumed as constant. Second: to compare relative statistical stability of dHI/dt and YGR in this linear phase, for tomato, potato, and eggplant across a number of treatments in different years. The results of these analyses were expected to give an indication of which approach is better for simulating organ growth in these species.

Material and Methods

The data used in this work were collected from different studies reported in the literature (Table 1). In particular, 43 data sets (21 for tomato, 4 for eggplant, and 18 for potato), which included from 6 to 14 sampling points of harvest-organ mass and total above ground biomass, were processed and analysed. These studies reported data on tomato, potato, and eggplant growth in response to various treatments. Thus, the linearity and stability of YGR and dHI/dt were tested for a large range of crop habits, including temperature, irrigation, fertility, plant density, sowing date and water salinity.

Definition of ranges of linearity. An analysis was first performed to identify if YGR and dHI/dt increased linearly during the whole harvest-organ growth period. This was done by fitting linear, quadratic, cubic and logistic regression models on these variables (YGR and dHI/dt) against time. The performances of each regression model were evaluated by computing the R^2 and root mean square error (RMSE). Moreover, significant differences between linear and nonlinear models were tested by F tests based on residual errors of each regression model.

A second analysis was done to define over what range during harvest-organ growth was it appropriate to consider that YGR and dHI/dt changed linearly. In previous studies (Bindi et al., 1999; Soltani et al., 2004), the ranges of linearity were determined by: 1) removing data points from the regression at the beginning and the end of harvest-organ growth periods until there was no statistical difference in the residuals between cubic and linear regression models ($P > 0.05$) (Bindi et al., 1999); and 2) using a three-phase segmental regression model that defined the range of linearity of these variables as the difference between times at which the rate of the segmental regressions changed (Soltani et al., 2004). Since data from most studies were only available from early and middle stages of the harvest-organ growth period and only a few or no points were available for the maturation period, the more complex approach to the data analysis was simplified. In particular, linear regressions were fitted and the ranges of linearity for YGR and dHI/dt were determined by removing data at the beginning and the end of harvest-organ growth periods until the highest R^2 and the lowest RMSE were obtained.

For convenience, the endpoints defining the range of linearity for YGR and dHI/dt were expressed as fractional values (%) of maximum harvest-organ weight or HI, respectively. Therefore, independent estimates of maximum HI or harvest-organ weight were used as references. The maximum values were obtained by regressing HI and harvest-organ weight versus time using a logistic curve; and the range of linearity was defined as a fraction of the maximum value of harvest-organ weight or HI as obtained in the regression analysis using the logistic model.

Stability of YGR and dHI/dt across treatments. The stability of YGR and dHI/dt across treatments was determined only in those experiments in which different treatments were imposed on a common cultivar. Thus, 37 datasets (15 for tomato cultivar Counter, 4 for eggplant cultivar Mirabelle, and 18 for potato cultivar Russet Burbank) were selected and YGR and dHI/dt calculated for the linear range as described in the previous section were included in this comparison.

Preliminary evidence concerning the stability of YGR and dHI/dt was obtained by comparing coefficients of variation (CV). To test the statistical significance of the variability, however, a Levene's test was performed to compare the stability of YGR and dHI/dt among the experimental treatments. Levene's test compares the variances of treatments and is more powerful and robust to non-normality than the familiar Barlett and Fmax tests (Conover et al., 1981).

Results and Discussion

Definition of range of linearity. The analysis of the best regression model fitting the increase of harvest-organ mass and HI over time indicated, as also observed by Bindi et al. (1999), that more complex models tended to be statistically superior to the linear model when all experimental data were used (data not shown). This is due to presence of asymptotic regions at the beginning and end of the harvest-organ growth curves (Fig. 1) that deviated from a constant value of YGR and dHI/dt observed in the central period of harvest-organ growth. In particular, the quadratic model showed the least improvement over the linear model with only a few cases being significantly better than linear model; whilst the cubic model was superior to the linear model in describing the YGR and dHI/dt in almost all the cases (data not shown).

However, when data from either early or late stages of harvest-organ growth were removed, YGR and dHI/dt were found to be constant over much of the harvest-organ growth period (Table 2). Apart from a few cases where the range of linearity needed to be restricted between more than 20% and less than 70% of maximum value of harvest-organ weight and HI, it was not necessary to be so restrictive in defining the range of linearity (Table 2). In about the 70% of the data sets for both the variables, the range of linearity extended between 20% to 80% of the maximum value. On the basis of the average values from the 43 data sets, the mean acceptable range for linearity was ≈10% to 90% for YGR and 11% to 88% for dHI/dt. Thus, with such a wide range in the data to achieve a linear approximation, it is possible to affirm that both YGR and dHI/dt are constant during most of the harvest-organ growth period as already observed for other species (e.g., Bindi et al., 1999).

Stability of YGR and dHI/dt across treatments. Since the analysis of YGR and dHI/dt demonstrated that these variables were constant over almost the same range of harvest-organ growth (10% to 90%), their capacity for characterising crop harvest-organ growth has been evaluated on the basis of the stability of each variable across treatments. The relative stability of YGR and dHI/dt across treatments can be a useful indicator for selecting one variable over another, especially when these are applied in modelling crop growth and yield. Thus, the stability of dHI/dt and YGR was tested using those data sets where different treatments were applied to the same cultivar: 15 data sets were

Table 1. Description of 43 data sets used in this study for analysing harvest-organ growth (YGR) and increase in harvest index (dHI/dt) of tomato, eggplant, and potato grown under different conditions. The cultivar, treatments, and number of harvest dates (harvest-organ and shoot mass) of each dataset are indicated.

Crop	Cultivar	Treatment		Harvest dates (no.)	Source
Tomato	Carmen	Temperature[z]	T1	6	Andriolo et al., 1998
	Diva		T2	6	
	Carmen		T3	6	
	Diva		T4	6	
	Counter	Plant density[y]	PD1	10	Heuvelink, 1995a
	Counter		PD2	10	
	Counter		PD3	10	
	Counter	Sowing date[x]	SD1	13	Heuvelink, 1995b
	Counter		SD2	11	
	Counter		SD3	10	
	Counter		SD4	12	
	Counter		SD5	12	
	Counter		SD6	10	
	Counter		SD7	14	
	Counter		SD8	9	
	Counter		SD9	8	
	Counter		SD10	14	
	Counter		SD11	10	
	Counter		SD12	8	
	Counter	Fertility[w]	F1	10	Heuvelink and Bertin, 1994
	Counter		F2	10	
Eggplant	Mirabelle	Saline solution irrigation[v]	SI1	9	Ruggiero et al., 1994
	Mirabelle		SI2	9	
	Mirabelle		SI3	8	
	Mirabelle		SI4	8	
Potato	Russet Burbank	Irrigation1[u]	I1	7	Johnson et al., 1988
	Russet Burbank		I2	6	
	Russet Burbank		I3	6	
	Russet Burbank		I4	6	
	Russet Burbank		I5	7	
	Russet Burbank		I6	7	
	Russet Burbank	Irrigation2[t]	I_R1	8	Belanger et al., 2001
	Russet Burbank		I_R2	8	
	Russet Burbank		I_R3	8	
	Russet Burbank		I_R4	8	
	Russet Burbank		I_R5	8	
	Russet Burbank		I_R6	8	
	Russet Burbank		I_R7	8	
	Russet Burbank		I_R8	8	
	Russet Burbank		I_R9	9	
	Russet Burbank		I_R10	9	
	Russet Burbank		I_R11	8	
	Russet Burbank		I_R12	8	

[z] T1 and T2 = greenhouse without ventilation, T3 and T4 = ventilated greenhouse.

[y] PD1 = 3.1 plants/m^2, PD2 = 2.1 plants/m^2, PD3 = 1.6 plants/m^2

[x] SD1 = 1987 Day 321; SD2 = 1992 Day 6; SD3 = 1989 Day 2; SD4 = 1988 Day 87; SD5 = 1988 Day 98; SD6 = 1991 Day 119; SD7 = 1988 Day 136; SD8 = 1990 Day 142; SD9 = 1989 Day 155; SD10 = 1988 Day 164; SD11 = 1990 Day 232; SD12 = 1988 Day 249.

[w] F1 = control, F2 = fruit removed.

[v] SI1 = 0% salt concentration, SI2 = 0.125% salt concentration, SI3 = 0.5% salt concentration, SI4 = 1% salt concentration.

[u] I1 = site 1 irrigated 1985, I2 = site 1 irrigated 1986, I3 = site 2 not irrigated 1985, I4 = site 3 not irrigated 1985, I5 = site 3 not irrigated 1986, I6 = site 3 not irrigated 1985 (site 1 = Hancock, Wis.; site 2 = Grand Forks, N.Dak.; site 3 = Rosemount, Minn.).

[t] I_R1 = site 1 irrigated 1995, I_R2 = site 1 not irrigated 1995, I_R3 = site 2 irrigated 1995, I_R4 = site 2 not irrigated 1995, I_R5 = site 3 irrigated 1996, I_R6 = site 3 not irrigated 1996, I_R7 = site 4 irrigated 1996, I_R8 = site 4 not irrigated 1996, I_R9 = site 4 irrigated 1997, I_R10 = site 4 not irrigated 1997, I_R11 = site 4 irrigated 1997, I_R12 = site 4 not irrigated 1997 (sites located in the upper St. John River Valley, N.B., Canada).

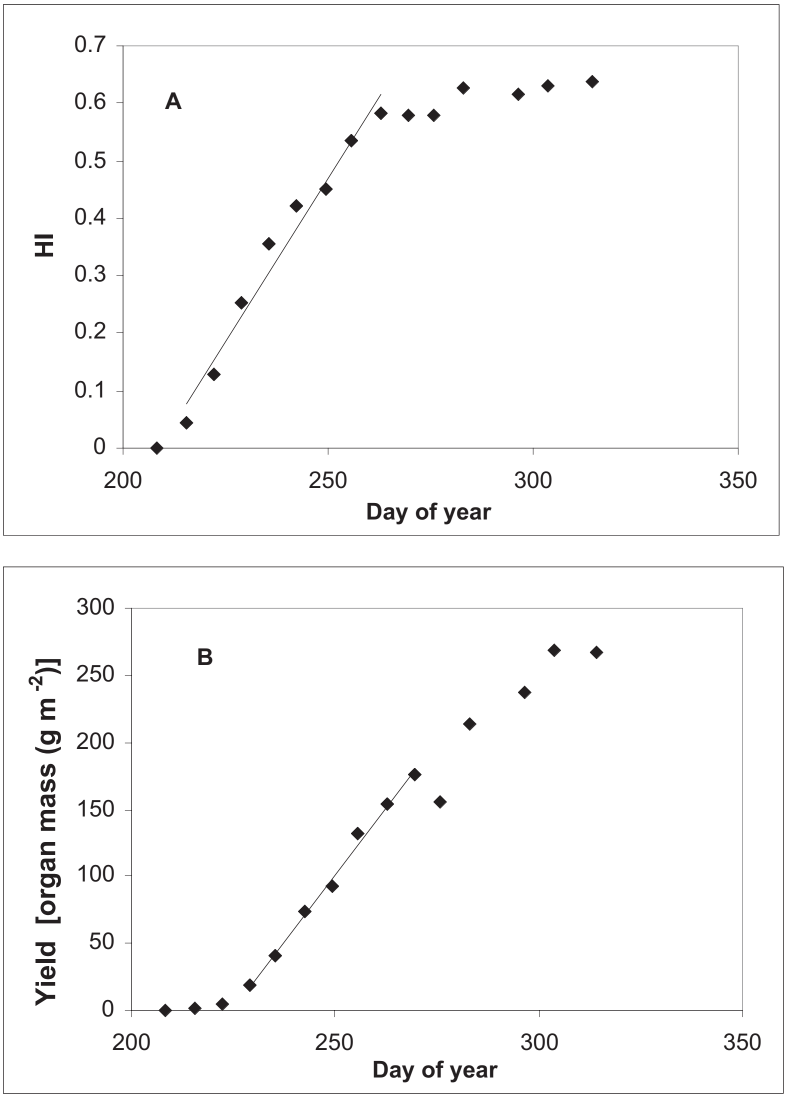

Fig. 1. Harvest index (HI) (**A**) and total harvest-organ mass (**B**) plotted against day of the year for tomato sown on day of year 142 (Heuvelink**,** 1995b). The datum for each sampling date is presented, as well as the linear regression line for the period that was confirmed as linear for each variable.

used for the tomato cultivar Counter, four data sets for eggplant cultivar Mirabelle, and 18 data sets for potato cultivar Russet Burbank (Table 3).

In the tomato experiments, the variation in dHI/dt was smaller than in YGR across treatments of planting density (Heuvelink, 1995a) and sowing date (Heuvelink, 1995b), as illustrated by lower CVS (Table 3). More specifically, in the planting-density experiment (Heuvelink, 1995a) CVS of YGR and dHI/dt were small and similar (11.2% and 9.4%, respectively), whereas in the sowing-date experiment (Heuvelink, 1995b) CVS were rather large (53.5% for YGR and 23.9% for dHI/dt) (Table 3). The large variability in CV was particularly evident in YGR where YGR decreased markedly for plants after early January (SD4). While the sowing date caused variability in dHI/dt, the variation resulted mainly from the results of the final sowing dates (SD11, SD12) (Figs. 2 and 3). Overall, these results are consistent with the conclusions of Bange et al. (1998) and Bindi et al. (1999), which found a strong impact of temperature on yield growth. The analysis of temperature and radiation regimes recorded during this study showed a good relationship between climate conditions and YGR and dHI/dt ($r = 0.44$ for temperature vs. YGR, $r = 0.57$ for temperature vs. dHI/dt; $r = 0.81$ for radiation vs. YGR, $r = 0.83$ for radiation vs. dHI/dt). However, in both cases Levene's test did not demonstrate that the stability of the slopes of dHI/dt were significantly greater ($P < 0.05$) than that of YGR.

In the eggplant experiment, plants treated with irrigation water of differing salt concentrations showed variability in dHI/dt that was slightly smaller than that of YGR (Table 3). Also in this case, however, Levene's test indicated that difference in CV between dHI/dt and YGR were not significant.

In the potato experiment with variation in sites and irrigation treatments, the variability in YGR and dHI/dt had the same behaviour as found for tomato. The variation of YGR was large among treatments as illustrated by the high CVS (Table 3). Levene's test failed to show that the stability of the slopes of dHI/dt were significant different than that of YGR, even though in one case this was close to the $P < 0.1$ level of significance. Also in this experiment the different environmental conditions (i.e., sites and irrigation treatments) reduced the stability in both variables (29% for YGR and 20% for dHI/dt).

Conclusions

This analysis of the 43 data sets in which harvest-organ mass and total above ground mass of tomato, eggplant, and potato were measured during harvest-organ growth demonstrated that both YGR and dHI/dt may be well approximated by linear regression models. However, when all experimental data were used, more complex regression models, such as the cubic equation, were found to give superior representations of the data. By removing the data from either the early and late stages of harvest-organ growth, the growth of the organs may be expressed, over much of the period of growth, by a constant YGR or dHI/dt. The range of data for the linear expression was essentially equivalent for both growth variables, showing an average acceptable linear range between 11% and 88% of the maximum harvest-organ mass or maximum HI.

Even if the statistical analysis did not demonstrate a higher stability in dHI/dt than YGR, the constantly lower CVS for dHI/dt in all the five experiments examined demonstrated a clear advantage in describing the harvest-organ growth of these crops based on the HI increase. However, there was evidence that the stability of dHI/dt was less when the comparison has been done among plants grown under different temperature and radiation regimes (e.g., different sowing dates), confirming the hypothesis, proposed by Bange et al. (1998) and Bindi et al. (1999), about the strong impact of temperature on harvest-organ growth.

Overall, this study indicated that the assumption that dHI/dt is constant over much of the period of harvest-organ growth is valid. Moreover, in agreement with previous studies on crops from which seeds are harvested, the results showed that dHI/dt remains stable over a range of growth conditions (e.g., sowing dates, irrigation, and plant density). Thus, the stability and the relative ease with which dHI/dt may be incorporated into crop growth simulation models, indicates the desirability of characterizing the growth of harvested organs in vegetable crops producing fruits or tubers, such as tomato, potato, and eggplant with this index.

Table 2. Determination over what range of harvest-organ mass and harvest index (HI) growth of tomato eggplant and potato grown under different conditions, it is appropriate to consider that yield growth rate (YGR) and HI (dHI/dt) change linearly. The endpoints defining this range were obtained by removing data at the beginning and the end of harvest-organ and HI growth periods until the highest R^2 and the lowest root mean square error of fitted regression lines was obtained. These endpoints were expressed as fractional values (%) of maximum harvest-organ weight and HI, respectively. Number of harvest dates included in the linear regression and its R^2 are also shown.

				YGR				HI			
				Range of linearity		Harvest dates (no.)	R^2	Range of linearity		Harvest dates (no.)	R^2
Crop	Cultivar	Treatment		Low	High			Low	High		
Tomato	Carmen	Temperature[z]	T1	4.8	100.0	5	0.99	11.6	100.0	5	0.97
	Diva		T2	12.9	100.0	5	0.99	24.7	100.0	5	0.98
	Carmen		T3	15.9	100.0	4	0.97	9.4	100.0	5	0.97
	Diva		T4	9.4	100.0	4	0.98	18.9	100.0	4	0.98
	Counter	Plant density[y]	PD1	16.4	100.0	7	0.96	2.8	84.2	5	0.98
	Counter		PD2	11.8	76.3	6	0.99	14.3	89.3	5	0.98
	Counter		PD3	9.7	84.3	6	0.99	16.4	94.5	5	0.97
	Counter	Sowing date[x]	SD1	15.5	76.1	7	0.98	7.9	79.4	5	0.99
	Counter		SD2	7.9	71.4	5	0.99	13.1	86.9	5	0.97
	Counter		SD3	29.3	100.0	6	0.97	8.2	88.5	4	0.93
	Counter		SD4	17.5	90.0	7	0.99	6.6	90.2	9	0.97
	Counter		SD5	26.2	92.9	6	0.98	23.3	91.7	6	0.98
	Counter		SD6	18.3	100.0	7	0.95	3.3	83.3	5	0.97
	Counter		SD7	6.4	76.6	8	0.98	21.0	96.8	9	0.98
	Counter		SD8	2.8	80.6	6	0.99	3.6	83.9	5	0.98
	Counter		SD9	7.9	78.9	5	0.96	1.6	89.1	5	0.97
	Counter		SD10	7.4	66.7	7	0.99	6.3	90.6	8	0.99
	Counter		SD11	7.7	100.0	6	0.96	11.1	88.9	4	0.99
	Counter		SD12	18.2	63.6	4	0.92	8.2	75.5	7	0.96
	Counter	Fertility[w]	F1	7.4	78.7	7	0.97	16.1	87.1	6	0.98
	Counter		F2	7.3	94.4	7	0.99	2.2	86.7	5	0.99
Eggplant	Mirabelle	Saline solution irrigation[v]	SI1	5.1	92.4	4	0.97	0.5	85.0	5	0.98
	Mirabelle		SI2	2.6	88.5	4	0.96	17.0	93.7	4	0.95
	Mirabelle		SI3	2.5	80.1	4	0.95	7.1	77.4	4	0.95
	Mirabelle		SI4	1.2	89.5	4	0.94	8.5	96.8	4	0.96
Potato	Russet Burbank	Irrigation1[u]	I1	7.6	100.0	6	0.98	13.6	79.5	5	0.96
	Russet Burbank		I2	15.5	100.0	5	0.96	13.1	100.0	6	0.98
	Russet Burbank		I3	6.4	100.0	6	0.97	1.3	100.0	6	0.99
	Russet Burbank		I4	8.8	95.3	4	0.95	1.4	100.0	5	0.96
	Russet Burbank		I5	9.4	95.3	5	0.97	1.3	93.3	5	0.99
	Russet Burbank		I6	11.4	100.0	5	0.97	16.7	100.0	6	0.99
	Russet Burbank	Irrigation2[t]	I_R1	9.7	100.0	6	0.97	15.8	90.8	7	0.99
	Russet Burbank		I_R2	8.4	95.0	6	0.97	9.5	90.5	7	0.97
	Russet Burbank		I_R3	11.3	100.0	6	0.99	25.7	75.7	4	0.95
	Russet Burbank		I_R4	3.2	62.6	5	0.98	20.9	86.6	6	0.98
	Russet Burbank		I_R5	19.8	91.6	4	0.94	10.8	82.4	4	0.97
	Russet Burbank		I_R6	7.7	96.7	5	0.97	10.7	85.3	5	0.97
	Russet Burbank		I_R 7	11.5	100.0	5	0.99	10.4	90.9	5	0.99
	Russet Burbank		I_R8	13.4	83.0	4	0.99	10.4	64.9	4	0.99
	Russet Burbank		I_R9	6.9	100.0	7	0.98	16.7	75.0	4	0.96
	Russet Burbank		I_R10	8.4	100.0	6	0.99	14.8	84.0	5	0.94
	Russet Burbank		I_R11	4.7	100.0	7	0.99	16.3	70.0	5	0.96
	Russet Burbank		I_R12	4.4	100.0	7	0.98	7.6	86.1	5	0.97
Mean				*10.2*	*90.7*			*11.2*	*88.2*		
SD				*6.1*	*11.4*			*6.7*	*8.7*		

[z] T1 and T2 = greenhouse without ventilation, T3 and T4 = ventilated greenhouse.

[y] PD1 = 3.1 plants/m^2, PD2 = 2.1 plants/m^2, PD3 = 1.6 plants/m^2

[x] SD1 = 1987 Day 321; SD2 = 1992 Day 6; SD3 = 1989 Day 2; SD4 = 1988 Day 87; SD5 = 1988 Day 98; SD6 = 1991 Day 119; SD7 = 1988 Day 136; SD8 = 1990 Day 142; SD9 = 1989 Day 155; SD10 = 1988 Day 164; SD11 = 1990 Day 232; SD12 = 1988 Day 249.

[w] F1 = control, F2 = fruit removed.

[v] SI1 = 0% salt concentration, SI2 = 0.125% salt concentration, SI3 = 0.5% salt concentration, SI4 = 1% salt concentration.

[u] I1 = site 1 irrigated 1985, I2 = site 1 irrigated 1986, I3 = site 2 not irrigated 1985, I4 = site 3 not irrigated 1985, I5 = site 3 not irrigated 1986, I6 = site 3 not irrigated 1985 (site 1 = Hancock, Wis.; site 2 = Grand Forks, N.D.; site 3 = Rosemount, Minn.).

[t] I_R1 = site 1 irrigated 1995, I_R2 = site 1 not irrigated 1995, I_R3 = site 2 irrigated 1995, I_R4 = site 2 not irrigated 1995, I_R5 = site 3 irrigated 1996, I_R6 = site 3 not irrigated 1996, I_R7 = site 4 irrigated 1996, I_R8 = site 4 not irrigated 1996, I_R9 = site 4 irrigated 1997, I_R10 = site 4 not irrigated 1997, I_R11 = site 4 irrigated 1997, I_R12 = site 4 not irrigated 1997 (sites located in the upper St. John River Valley, N.B., Canada).

Table 3. Analysis of the variability of yield growth rate (YGR) and harvest index (dHI/dt) in those experiments where a single cultivar of tomato, eggplant and potato was subjected to different treatment levels. Coefficient of variation [CV (standard deviation/mean value)] and its level of significance according the Levene's test, are shown (NS = nonsignificant for $P < 0.05$).

Crop	Cultivar	Treatment		YGR (g·m^{-2}·d^{-1})	dHI/dt (g·g^{-1}·d^{-1})	CV (%)		Significance of difference in CV between YGR and dHI/dt
						YGR	dHI/dt	
Tomato	Counter	Plant density[z]	PD1	9.06	0.012			
	Counter		PD2	7.36	0.0104			
	Counter		PD3	7.71	0.0101	11.2	9.4	0.81^{NS}
	Counter	Sowing date[y]	SD1	8.9	0.0127			
	Counter		SD2	10.3	0.0116			
	Counter		SD3	14.1	0.0121			
	Counter		SD4	7.2	0.0098			
	Counter		SD5	8.2	0.0105			
	Counter		SD6	7.6	0.0126			
	Counter		SD7	7.1	0.0085			
	Counter		SD8	5.8	0.0116			
	Counter		SD9	6.1	0.0097			
	Counter		SD10	4.2	0.0114			
	Counter		SD11	0.99	0.0091			
	Counter		SD12	1.4	0.0037	53.5	23.9	0.24^{NS}
Eggplant	Mirabelle	Saline solution irrigation[x]	SI1	21.08	0.0217			
	Mirabelle		SI2	23.14	0.0189			
	Mirabelle		SI3	18.72	0.0184			
	Mirabelle		SI4	17.81	0.0223	11.9	9.6	0.54^{NS}
Potato	Russet Burbank	Irrigation1[w]	I1	16.70	0.0110			
	Russet Burbank		I2	19.70	0.0109			
	Russet Burbank		I3	9.07	0.0115			
	Russet Burbank		I4	12.36	0.0101			
	Russet Burbank		I5	12.99	0.0098			
	Russet Burbank		I6	12.71	0.0085	26.8	10.5	0.13^{NS}
	Russet Burbank	Irrigation2[v]	I_R1	17.10	0.0129			
	Russet Burbank		I_R2	12.26	0.0144			
	Russet Burbank		I_R3	14.76	0.0145			
	Russet Burbank		I_R4	8.27	0.0122			
	Russet Burbank		I_R5	16.29	0.0186			
	Russet Burbank		I_R6	14.19	0.0195			
	Russet Burbank		I_R7	23.92	0.0204			
	Russet Burbank		I_R8	21.54	0.0202			
	Russet Burbank		I_R9	16.353	0.0201			
	Russet Burbank		I_R10	13.978	0.0201			
	Russet Burbank		I_R11	15.2	0.0153			
	Russet Burbank		I_R12	9.4	0.023	29.0	20.1	0.88^{NS}

[z] PD1 = 3.1 plants/m^2, PD2 = 2.1 plants/m^2, PD3 = 1.6 plants/m^2.

[y] SD1 = 1987 Day 321; SD2 = 1992 Day 6; SD3 = 1989 Day 2; SD4 = 1988 Day 87; SD5 = 1988 Day 98; SD6 = 1991 Day 119; SD7 = 1988 Day 136; SD8 = 1990 Day 142; SD9 = 1989 Day 155; SD10 = 1988 Day 164; SD11 = 1990 Day 232; SD12 = 1988 Day 249.

[x] SI1 = 0% salt concentration, SI2 = 0.125% salt concentration, SI3 = 0.5% salt concentration, SI4 = 1% salt concentration.

[w] I1 = site 1 irrigated 1985, I2 = site 1 irrigated 1986, I3 = site 2 not irrigated 1985, I4 = site 3 not irrigated 1985, I5 = site 3 not irrigated 1986, I6 = site 3 not irrigated 1985 (site 1 = Hancock, Wis.; site 2 = Grand Forks, N.Dak.; site 3 = Rosemount, Minn.).

[v] I_R1 = site 1 irrigated 1995, I_R2 = site 1 not irrigated 1995, I_R3 = site 2 irrigated 1995, I_R4 = site 2 not irrigated 1995, I_R5 = site 3 irrigated 1996, I_R6 = site 3 not irrigated 1996, I_R7 = site 4 irrigated 1996, I_R8 = site 4 not irrigated 1996, I_R9 = site 4 irrigated 1997, I_R10 = site 4 not irrigated 1997, I_R11 = site 4 irrigated 1997, I_R12 = site 4 not irrigated 1997 (sites located in the upper St. John River Valley, N.B., Canada).

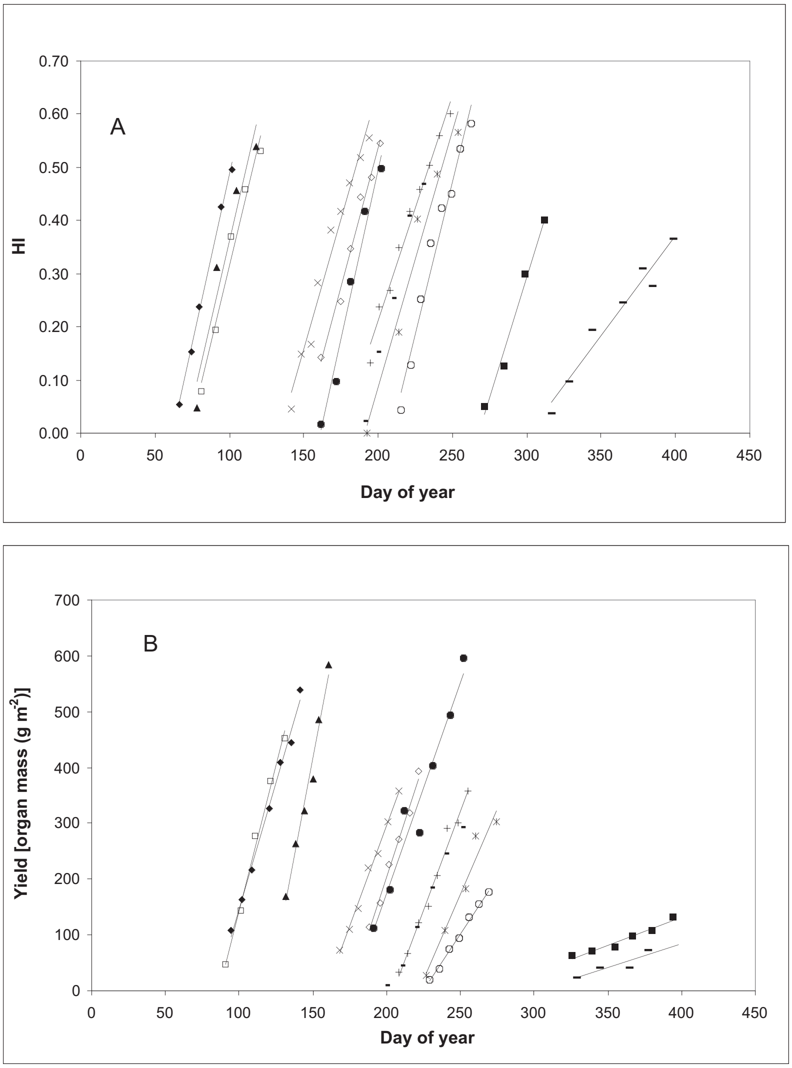

Fig. 2. Regression lines for the periods that were confirmed as linear for harvest index (HI) (**A**) and harvest-organ mass (**B**) for tomato sown on different dates (Heuvelink**,** 1995b). Legend: for each sowing date treatment, the corresponding year and day of year of sowing time are specified: ◆ = 1987 day 321; □ =1992 day 6; ▲ = 1989 day 2; × = 1988 day 87; ◇ = 1988 day 98; • = 1991 day 119; + = 1988 day 136; ▪ = 1990 day 142; ✳ = 1989 day 155; ○ = 1988 day 164; ■ = 1990 day 232; ▬ = 1988 day 249.

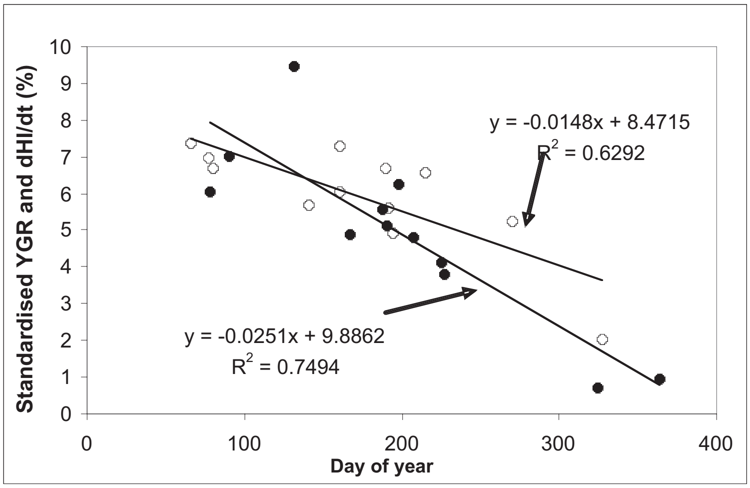

Fig. 3. Standardized values of the rate of increase (%) of harvest index (dHI/dt) and yield growth rate (YGR) for tomato sown on different dates (Heuvelink**,** 1995b). The dHI/dt and YGR for each sowing date is presented, as well as the linear regression lines. Closed circles represent YGR, open circles represent dHI/dt.

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