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Causes for low tuber yields of transplants from *in vitro* potato plantlets of early cultivars after field planting

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SUMMARY

Transplant crops derived from *in vitro* produced plantlets of cultivars differing in earliness were grown in three experiments in three years in the Netherlands, during field periods of maximally 12 weeks. Seed tuber crops were included in the first year. Fresh tuber yield was analysed as the result of the radiation intercepted by the crop's canopy (AIR; accumulated intercepted radiation), the efficiency of conversion of intercepted radiation into dry matter (RCC; radiation conversion coefficient), the proportion of dry matter allocated to tubers (HI; harvest index), and the tuber dry-matter concentration (TDMC). Transplant crops had a lower AIR and lower yields than crops from seed tubers. Variables RCC, HI and TDMC were not affected by the type of propagule used. In transplant crops, yields from early cultivars could be extremely low when compared to later cultivars, due to a low AIR. This cultivar effect did not occur in crops from seed tubers. Among transplant crops, the lower AIR was the most consistent reason for lower tuber yields of earlier cultivars. It resulted from a slower increase in soil cover after transplanting and a lower maximum soil cover, both caused by a relatively high allocation of dry matter to tubers immediately after transplanting and resulting first in reduced haulm growth rates and subsequently also in reduced total growth rates. Senescence was not different. A higher HI partly compensated the lower AIR of the earliest cultivars. RCC and TDMC were not consistently affected by cultivar's earliness in the transplant crops.

INTRODUCTION

In vitro multiplied potato (*Solanum tuberosum* L.) plantlets are commonly used in potato seed production programmes for production of *in vitro* tubers, glasshouse production of minitubers, or field planting (Jones 1988; Struik & Lommen 1990; Van der Zaag 1990). Of these methods, field planting of transplants raised from *in vitro* produced plantlets is the fastest method to obtain large progeny tubers and gives the highest multiplication rate (Struik & Lommen 1990). However, especially of early cultivars, transplants may fail to perform well after transplanting to the field (Haverkort *et al*. 1991*a*; Dixon 1993).

The poor performance of transplants of early cultivars has to result from at least one of the factors contributing to fresh tuber yield in potato crops from different propagules: the radiation interception by the haulm, the efficiency with which the intercepted radiation is converted into biomass, the harvest index and the tuber dry-matter concentration (MacKerron & Waister 1985; Jeffries & MacKerron 1987; Spitters *et al*. 1989; Marshall & Taylor 1990; Lommen & Struik 1994). The unsuccessful performance of crops from transplants of early cultivars probably results from a limited radiation interception by the haulm, because progeny tubers might be initiated at a moment when radiation interception by the haulm is still low and/or a high proportion of dry matter might be allocated to the tubers. Both may lead to less dry matter invested in haulm growth, limited haulm development or earlier senescence. Consequently progeny tuber yield could be reduced by lowering the quantity of intercepted radiation. A proper analysis of causal and non-causal factors is needed in order to develop strategies for improvement.

In this paper the results of three field experiments are summarized, which aimed at (1) describing and quantifying the poor performance of *in vitro* produced plantlets of early cultivars in the field compared to crops from seed tubers and (2) establishing the most important causes for this poor performance. Because *in vitro* plantlets are used to produce seed tubers, crops were grown as seed crops and therefore not grown to full maturity.

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MATERIALS AND METHODS

General

The field performance of transplants raised from *in vitro* produced plantlets of cultivars differing in earliness was studied in three years. In the first year, transplants were compared to seed tubers. In later years, transplant growth was studied in time. Cultivars used and their score for earliness from the Dutch List of Varieties on a scale 1–9·5 (indicating the date of haulm senescence) were Gloria (very early maturing, score 9), Ostara (early maturing, score 8), Spunta (mid-early maturing, score 7), Bintje (mid-early maturing, score 6·5) and Elkana (late maturing, score 4).

Transplant production

In vitro plantlets were routinely multiplied by single-node cuttings on medium containing M&S basal salts and vitamins (Murashige & Skoog 1962), 2 mg glycine/l, 8 g agar/l, 20 g sucrose/l and 0·0118 g daminozide/l, pH 5·7. Temperature was 23 °C, photoperiod 16 h and light supplied by Philips-84 fluorescent tubes at 6–8 W/m². Rooted *in vitro* plantlets (2–3 cm) about 3 weeks old were planted into transplanting trays with cells of 5 × 5 × 5·5 cm l × w × d (Expt 1) or 6 × 4 × 5·5 cm (Expts 2 and 3) containing potting soil, and grown for 20–21 days before field planting. In Expt 1, transplants were produced in a glasshouse at 18/12 °C (day/night), 16 h photoperiod and additional illumination during daytime by Philips SON-T lamps for 14 days and outside for 6 days. In Expt 2, transplants were raised 21 days in a climate room at 20/15, 18/12 and 16/10 °C declining each week, 16 h at 100 W/m² supplied by Philips HPI and SON-T lamps in a 1 : 1 mixture and supplemented by fluorescent Philips TL 84 light. In Expt 3, transplants were raised in a glasshouse at 20/8 °C at the same light conditions as in Expt 1 for 18 days and outside for 3 days. Plants were watered daily. In Expts 2 and 3, transplants received a low-concentrated complete nutrient solution (Lommen & Struik 1992) twice a week.

Experimental design

Experiments were laid out in split-plot or split-split-plot designs of four (Expts 1 and 2) or five (Expt 3) blocks. In Expt 1, cultivars (Ostara, Bintje, Elkana) were assigned to main plots and propagule types (transplants and seed tubers) to subplots. In Expt 2, planting dates (normal and late) were assigned to main plots, cultivars (Gloria, Ostara and Spunta) randomized within a main plot and harvest dates (0, 14, 28, 42, 56, 70, 84 days after transplanting (DAT), randomized within a cultivar. In Expt 3, cultivars (Gloria and Bintje) were assigned to main plots and harvest dates (as in Expt 2) randomized within cultivars. Plants to be harvested at 0 DAT were not transplanted to the field. Field plots comprised 56 plants (four rows × 14 plants) in Expt 1, 32 plants (four rows × eight plants) in Expt 2 and 24 plants (four rows × six plants) in Expt 3. Observations were made on the inner 20 (two rows × ten plants), eight (two rows × four plants) and six (two rows × three plants) plants in the respective experiments. Dry weights in Expt 1 were determined from four plants per plot.

Field practice

Transplants were planted by hand in 15 cm high ridges on 17 May 1990 (Expt 1), 25 May and 22 June 1993 (Expt 2) or 31 May 1995 (Expt 3) into a light sandy soil in Achterberg, near Wageningen, the Netherlands. Presprouted seed tubers grade 28/35 mm in Expt 1 were planted on 26 April 1990, and had emerged at the time of planting the transplants except for one tuber emerging within 4 days. Transplants and tubers were spaced 20 (Expts 1 and 3) or 25 cm (Expt 2) apart in ridges 75 cm wide (66 667 and 53 333 plants/ha).

Fertilizer was broadcast at 70 kg N/ha (26 April), 48 kg P_2O_5/ha and 104 kg K_2O/ha (12 April) in Expt 1, at 70 kg N/ha, 50 kg P_2O_5/ha and 100 kg K_2O/ha (before 25 May) in Expt 2 and at 120 kg N/ha, 100 kg P_2O_5/ha and 80 kg K_2O/ha (3 May) in Expt 3. Weeds were controlled chemically before emergence and later by hand. Disease control and irrigation were carried out according to common practice. Plots were earthed up by hand to a ridge height of 23 cm after individual plots achieved a soil cover of 25% in Expt 1, 15 DAT in Expt 2, and 27 DAT in Expt 3.

Plants in Expt 1 were harvested 61 DAT at the same date as the crops from seed tubers, which was 82 days after planting (DAP) for the seed tubers.

Mean air temperatures at 10 cm during the first 2 weeks after transplanting were respectively 13·0, 16·3/16·2 (respective plantings) and 12·2 °C in the three experiments, and 15·9, 16·0/14·9 and 18·4 °C during the total transplant field period.

Observations and calculations

Fresh weights of progeny tubers and dry weights of tubers and haulm were determined. Stolons were included in the haulm fraction. Total dry weight was the sum of tuber and haulm dry weights, excluding roots.

Percentage of soil cover by the haulm was assessed weekly using a grid to estimate the fraction of radiation intercepted (Haverkort *et al.* 1991*b*). Daily values were derived by linear interpolation. Measurements at 1 (Expt 3) and 2 DAT (Expt 2) were assumed to represent soil cover at transplanting. The accumulated intercepted radiation (AIR) in the field period

Table 1. *Yield analysis in crops from transplants from* in vitro *produced plantlets (61 DAT) and seed tubers (82 DAP) of cultivars differing in earliness, Expt 1. Crops were harvested at the same date*

	Accumulated intercepted radiation (AIR) (MJ/m²)	Total dry-matter production (g/m²)	Radiation conversion coefficient (RCC) (g/MJ)	Harvest index (HI) (g/g)	Tuber dry-matter production (g/m²)	Tuber dry-matter concentration (TDMC) (g/g)	Tuber fresh yield (g/m²)
Transplant crops							
Ostara (early)	76 (4·18)*	101 (4·48)*	1·53	0·90	86 (4·37)*	0·19	416 (5·80)*
Bintje (mid-early)	199 (5·16)	299 (5·59)	1·39	0·78	230 (5·33)	0·21	1109 (6·90)
Elkana (late)	173 (5·04)	301 (5·60)	1·77	0·72	208 (5·26)	0·24	838 (6·61)
Seed tuber crops							
Ostara (early)	574 (6·33)	846 (6·72)	1·47	0·83	760 (6·53)	0·19	3710 (8·20)
Bintje (mid-early)	506 (6·33)	733 (6·60)	1·50	0·79	579 (6·36)	0·23	2525 (7·83)
Elkana (late)	488 (6·17)	825 (6·70)	1·70	0·74	611 (6·39)	0·25	2497 (7·80)
Means over crop types							
Ostara (early)	325 (5·26)	473 (5·60)	1·43	0·87	393 (5·45)	0·19	2063 (7·00)
Bintje (mid-early)	353 (5·75)	516 (6·09)	1·51	0·78	405 (5·85)	0·22	1817 (7·37)
Elkana (late)	330 (5·60)	563 (6·15)	1·74	0·73	409 (5·83)	0·24	1667 (7·20)
P							
Cultivar	0·917 (0·371)	0·614 (0·138)	0·127	0·005	0·971 (0·256)	0·002	0·576 (0·539)
Crop type	< 0·001 (< 0·001)	< 0·001 (< 0·001)	0·938	0·633	< 0·001 (< 0·001)	0·189	< 0·001 (< 0·001)
Cultivar × Crop type	0·025 (0·028)	0·016 (0·005)	0·693	0·263	0·007 (0·002)	0·234	0·001 (0·010)
S.E.M.							
Cultivar	50·0 (0·232)	61·5 (0·180)	0·092	0·018	48·4 (0·170)	0·565	257 (0·221)
Crop type	17·9 (0·098)	25·2 (0·087)	0·053	0·017	19·2 (0·072)	0·411	109 (0·112)
Cultivar × Crop type†	54·5 (0·261)	68·8 (0·209)	0·113	0·028	53·8 (0·190)	0·757	290 (0·260)
	30·9 (0·169)	43·6 (0·150)	0·092	0·030	33·2 (0·124)	0·712	188 (0·195)
D.F.	8	9	8	6	9	6	9

* Between brackets: ln-transformed data.
† Second line: crop types within cultivars.

was calculated by summarizing daily values obtained by multiplying the fraction of soil cover by the haulm and the daily global radiation. Radiation Conversion Coefficient (RCC) was the total dry weight divided by AIR. Harvest index (HI) was the tuber dry weight divided by the total dry weight.

Daily growth rates were calculated from the change in dry matter per block over 14-day intervals, relative growth rates from the change in ln-transformed dry-matter data per block. The fraction dry matter allocated to tubers in the 14-day intervals was the tuber growth rate divided by the total growth rate. When haulm or total growth rates became lower than zero because of senescence, dry-matter allocation to the tuber was assumed to be one.

Statistical analysis

Data were transformed if appropriate and subjected to analyses of variance. Expts 2 and 3 were analysed either for one harvest date or over all dates for comparisons in time. Missing values were estimated using the standard routine from the statistical package Genstat 5 release 3·1 and D.F. were reduced accordingly. For Expt 2, only averaged effects over two planting dates are presented, because cultivar responses were fairly comparable. In case interaction showed a significantly different cultivar performance for the two planting dates ($P < 5\%$) a description is given below Tables. In Expt 2, only average values over blocks were available for soil cover because the original data were lost. To compare cultivars for AIR and RCC in this experiment, the planting dates were used as replications.

RESULTS

Effects of propagule type on cultivar differences and yield formation

Cultivar ranking depended on the propagule type (Table 1). The early cv. Ostara had an extremely low AIR, dry-matter production and tuber yield in crops from transplants, whereas it performed comparably or better than later cultivars in crops from tubers (Table 1). For both propagule types, earlier cultivars had a higher HI and lower TDMC than later cultivars, but did not differ in RCC (Table 1).

For all cultivars, crops from transplants had a lower AIR than crops from seed tubers, a much lower dry-matter production and lower tuber yields (Table 1). Crops from different propagules did not differ in RCC, HI or TDMC (Table 1).

Effects of cultivar earliness on yield formation in crops from transplants

In Expts 2 and 3, transplant crops from the earlier cultivars had a lower AIR and had produced less dry matter at the end of the season (Table 2). The very

Table 2. *Yield analysis in crops from transplants from* in vitro *produced plantlets of cultivars differing in earliness, Expts 2 and 3, 84 DAT*

	Accumulated intercepted radiation (AIR) (MJ/m²)	Total dry-matter production (g/m²)	Radiation conversion coefficient (RCC) (g/MJ)	Harvest index (HI) (g/g)	Tuber dry-matter production (g/m²)	Tuber dry-matter concentration (TDMC) (g/g)	Tuber fresh yield (g/m²)
Experiment 2*							
Gloria (very early)	297	826	2·79	0·88	727	0·22	3240
Ostara (early)	799	907	1·19	0·86	772	0·19	3992
Spunta (mid-early)	872	1233	1·43	0·72	890	0·18	4911
P	0·028	< 0·001	0·022	< 0·001	0·078	< 0·001	< 0·001
S.E.M. (D.F. = 11†)	53·3	55·0	0·130	0·011	46·5	0·003	200
Experiment 3							
Gloria (very early)	414	601	1·53	0·74	443	0·16	2785
Bintje (mid-early)	1021	1378	1·35	0·68	928	0·19	4827
P	< 0·001	0·006	0·612	0·089	0·005	0·005	0·010
S.E.M. (D.F. = 4)	44·3	102·3	0·238	0·020	60·4	0·005	314

* Average values for two planting dates. No significant interaction between planting date and cultivar occurred ($P \geq 0·05$).
† For AIR and RCC, D.F. = 2. AIR and RCC were calculated from average values per planting date.

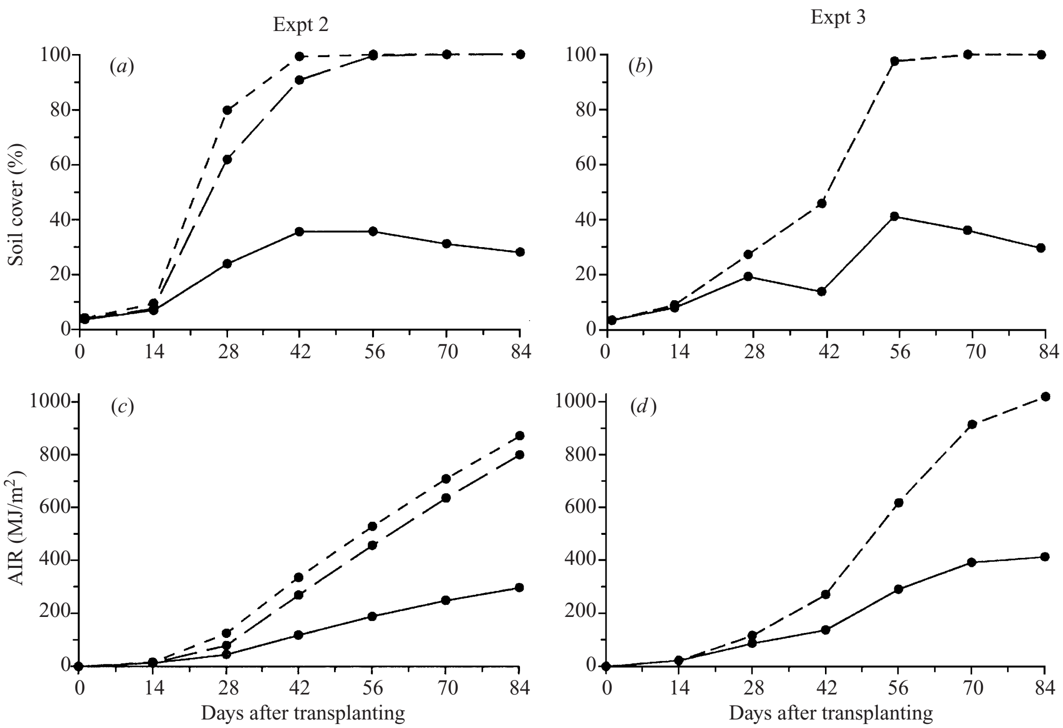

Fig. 1. Soil cover (*a*, *b*) and accumulated intercepted radiation (AIR; *c*, *d*) with time after transplanting in crops from transplants from *in vitro* derived plantlets differing in earliness. Cvs Gloria (——), Ostara (— —), Spunta (– – –) in Expt 2 (*a*, *c*), cvs Gloria (——) and Bintje (– – –) in Expt 3 (*b*, *d*). S.E.M.s were 5·99 in *a*, 4·42 over cvs and 3·57 within cvs in *b*, 51·9 in *c*, and 31·0 over cvs and 29·0 within cvs in *d*. D.F. were 20 in *a*, *c*, and 40 in *b*, *d*.

early cv. Gloria had a higher RCC than later cultivars, but not significantly in Expt 3. HI was higher for earlier cultivars, but the resulting tuber dry-matter production still was lower (Table 2). TDMC differed over cultivars and experiments (Table 2). Fresh tuber yield was lower for the earlier cultivars (Table 2).

Effects of cultivar earliness on radiation interception in crops from transplants

At transplanting, there were no differences between cultivars in ground cover ($P \geqslant 0{\cdot}05$). Thereafter, earlier cultivars showed a slower increase in soil cover and consequently had a lower AIR (Fig. 1). In addition, cv. Gloria did not reach full soil cover (Fig. 1). Soil cover did not notably decrease within the period of 84 DAP.

Effects of cultivar earliness on growth rates, tuber initiation and allocation of dry matter in crops from transplants

At transplanting, cv. Gloria had a lower haulm dry weight than other cultivars, but a higher tuber dry weight than cv. Bintje (Table 3). In all cultivars the first tubers were initiated before or immediately after transplanting (Fig. 2). For the latest cultivars, a check in tuber initiation occurred between 14 and 28 DAT in Expt 2. Tuber initiation only levelled off at the end of the season for the earliest cultivars in Expt 2 and continued over the whole field season for all cultivars in Expt 3.

Haulm RGRs did not differ between cultivars in the first two weeks after transplanting, but then became higher for later cultivars (Table 3). This situation lasted until later cultivars achieved full soil cover. Immediately after tuber initiation, tuber RGRs were higher in earlier cultivars (Expt 2, Table 3) or comparable (Expt 3). In the weeks thereafter tuber RGRs became higher in later cultivars.

Haulm GRs already were higher for later cultivars in the first weeks after transplanting in Expt 2 (Table 4). Differences persisted until the haulm started to decrease in weight, which was not obviously related to cultivar earliness. Tuber GRs initially were higher for earlier cultivars (Table 4), but differences gradually became smaller and eventually later cultivars took over. Total GRs first tended to be lower for later cultivars, but the pattern was reversed soon. Cultivar ranking then did not change until haulm senescence started.

Table 3. *Dry weights at transplanting and relative growth rates (g/g/d) of haulm and tuber fractions in three successive periods, in crops from transplants from* in vitro *produced plantlets of cultivars differing in earliness, Expts 2 and 3*

	Dry weight (g/plant)		Relative growth rate (g/g/d)					
	0 DAT		0–14 DAT		14–28 DAT		28–42 DAT	
	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber
Experiment 2*								
Gloria (very early)	0·309	0·000	0·111	nd†	0·099	0·152	0·062	0·111
Ostara (early)	0·405	0·000	0·107	nd	0·117	0·121	0·072	0·129
Spunta (mid-early)	0·379	0·000	0·118	nd	0·149	0·052	0·075	0·241
P	0·017	nd	0·482	nd	< 0·001	< 0·001	0·028	< 0·001
S.E.M. (D.F. = 12)	0·0206	nd	0·0068	nd	0·0034	0·0099	0·0032	0·0104
Experiment 3								
Gloria (very early)	0·520	0·057	0·042	0·220	0·073	0·113	0·064	0·062
Bintje (mid-early)	0·697	0·009	0·036	0·271	0·120	0·180	0·092	0·089
P	0·018	0·024	0·419	0·325	0·002	0·157	0·033	0·126
S.E.M. (D.F. = 4)	0·0325	0·0096	0·0053	0·0320	0·0046	0·0272	0·0062	0·0098

* Average values for the two planting dates. No significant interaction between planting date and cultivar occurred.
† nd: Not determined. No tubers were initiated at 0 DAT.

Earlier cultivars invested a much lower proportion of the daily increase in dry matter in haulm growth (Fig. 2). In the first two weeks after field transplanting, tubers already received 43 and 71% of all dry matter produced by cv. Gloria in Expts 2 and 3 respectively. This percentage increased or remained constant in the next two weeks (Fig. 2). In later cultivars the fraction of dry matter allocated to tubers remained stable or even dropped before starting to increase. Cultivar differences persisted until haulm senescence.

DISCUSSION

Differences between transplant crops and seed tuber crops

The poor performance of crops from transplants of *in vitro* produced plantlets of early maturing cultivars (Tables 1, 2; Haverkort *et al.* 1991*a*; Dixon 1993) proved to be a characteristic of the propagule type, because in crops from seed tubers yield was highest in the earliest cultivar (Table 1). When fresh tuber yield was analysed as being a function of AIR, RCC, HI and TDMC (MacKerron & Waister 1985; Jeffries & MacKerron 1987; Spitters *et al.* 1989) the differing cultivar response in the two crop types resulted from a lower AIR for the earliest cultivar in transplant crops, and no cultivar differences in AIR in seed tuber crops (Table 1). For RCC, HI and TDMC the cultivar response was similar for the two crop types.

The lower yields often observed in transplant crops compared to tuber crops (Table 1; Leclerc & Donelly 1990; Haverkort *et al.* 1991*a*) resulted only from lower AIR-values, whereas HI, RCC and TDMC were not different at the end of the field period (Table 1). Nevertheless, development of transplant crops did not follow the common pattern of tuber crops. Initiation of progeny tubers was more gradual and continued longer (Fig. 2) than in tuber crops where tuber numbers increase strongly within 2–3 weeks (Allen & Scott 1992), and dry-matter allocation to tubers in transplant crops (Fig. 2) did not show a consistent linear (Van Heemst 1986) or negative exponential (Kooman *et al.* 1996*b*) increase with time after tuber initiation, especially in later cultivars. The differing performance may result from the absence of a mother tuber. A larger mother tuber supplies more inputs for early growth, thus increasing soil cover and AIR (Lommen & Struik 1994). The mother tuber also affects tuber induction in potato plants (Madec & Perennec 1962) and its absence likely makes plants more dependent on and subjected to external conditions before and after field transplanting for regulation of development. In addition, there could have been a lack of possible sites for tuber initiation at the start of field growth because of the small size of transplants.

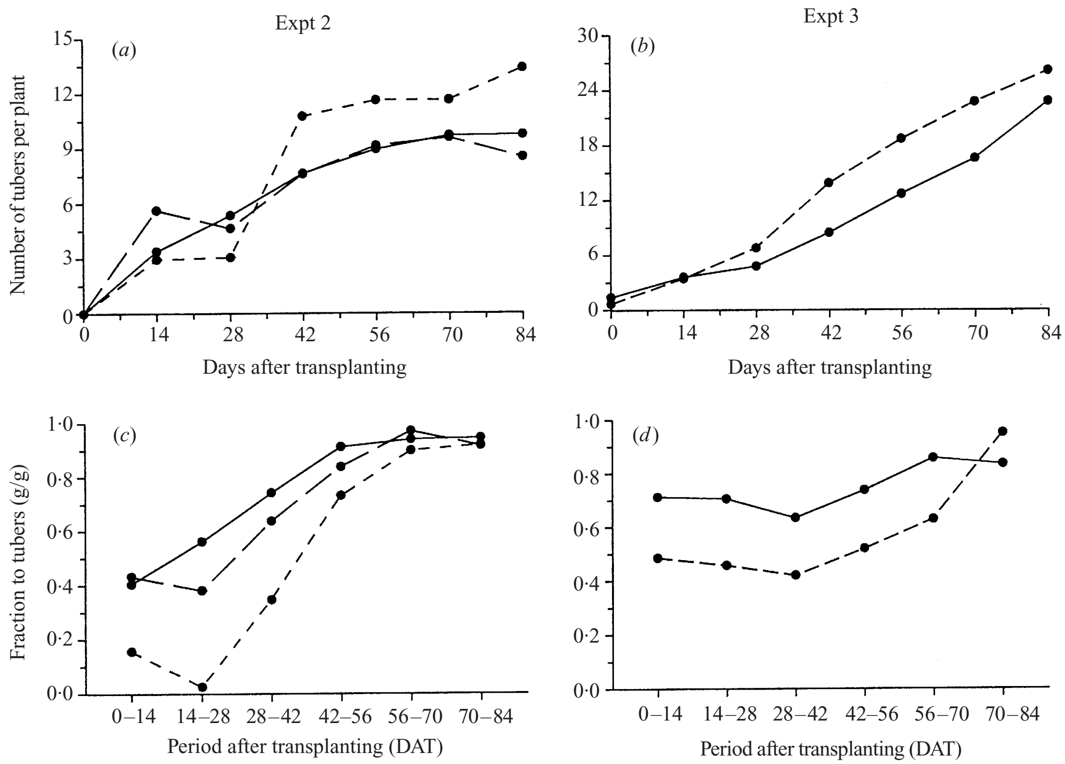

Fig. 2. Tuber number with time after transplanting (*a*, *b*) and fraction of total dry matter produced allocated to tubers in different time intervals after transplanting (*c*, *d*) in crops from transplants from *in vitro* derived plantlets differing in earliness. Cvs Gloria (——), Ostara (— —), Spunta (— — —) in Expt 2 (*a*, *c*), cvs Gloria (——) and Bintje (— — —) in Expt 3 (*b*, *d*). S.E.M.s for comparisons over and within cvs respectively were 0·483 and 0·470 (D.F. 106) in *a*, 1·65 and 1·65 (D.F. 48) in *b*, 0·0220 and 0·0233 (D.F. 88) in *c*, and 0·0625 and 0·0600 (D.F. 40) in *d*.

Causes for lower tuber yields of earlier maturing cultivars in transplant crops

Among transplant crops, the most consistent cause for lower tuber yields from earlier maturing cultivars over three field seasons was their lower AIR (Tables 1, 2). AIR for the earliest cultivar usually was more than 60% lower than that of the best performing cultivar. RCC, HI and TDMC were either not affected or in favour of earlier cultivars, thus reducing differences in tuber yield to 45%.

The lower AIR of the earliest cultivars in transplant crops resulted from a slower increase in soil cover after transplanting and for cv. Gloria to a lower maximum (Fig. 1). It was not due to an earlier decrease which is the main cause of cultivar differences in AIR in seed tuber crops grown to maturity (Kooman *et al.* 1996*a*). At the end of the field period, haulm weight also was not declining more in the very early cv. Gloria than in other cultivars (Table 4), possibly because the availability of nutrients in the less developed crop still was high.

The slower increase in soil cover in early cultivars was likely to be related to their lower haulm GRs (Table 4). In the first two weeks after transplanting, these resulted from a lower fraction of the total daily increase in dry weight invested in haulm growth (Fig. 2), not from lower total GRs (Table 4) or detectably earlier tuber initiation (Fig. 2). All cultivars had initiated tubers before or soon after transplanting (Fig. 2). Also the slightly lower haulm weight at transplanting for cv. Gloria (Table 3) may have contributed to lower haulm GRs, because haulm RGRs did not differ between cultivars in the first two weeks after transplanting (Table 3). In the next weeks, tubers remained strong sinks in the earliest cultivars and limited dry-matter allocation to the haulm (Tables 3 and 4, Fig. 2). Later, however, haulm GRs of early cultivars also became lower because of reduced total GRs resulting from limited haulm development earlier in the season.

Cv. Gloria never achieved full soil cover because the end of leaf growth – defined by Kooman & Haverkort (1995) and Kooman *et al.* (1996*b*) as the moment when 90% of the dry matter produced was allocated to the tubers – occurred in Expt 2 when soil

Table 4. *Growth rates* ($g/m^2/d$) *of tuber, haulm and total dry matter in transplant crops of cultivars differing in earliness during different time periods after transplanting, Expts 2 and 3*

	Time period																	
	0–14 DAT			14–28 DAT			28–42 DAT			42–56 DAT			56–70 DAT			70–84 DAT		
	Haulm	Tuber	Total	Haulm	Tuber	Total	Haulm	Tuber	Total	Haulm	Tuber	Total	Haulm	Tuber	Total	Haulm	Tuber	Total
Experiment 2*																		
Gloria (very early)	0·43	0·29	0·72	1·62	2·08	3·71	2·95	8·91	11·86	1·49	14·2	15·7	0·7	13·5	14·2	−0·3	13·0	12·7
Ostara (early)	0·52	0·39	0·91	2·78	1·75	4·53	6·08	10·79	16·87	3·93	20·1	24·1	−2·5	11·8	9·3	−1·2	10·4	9·2
Spunta (mid-early)	0·62	0·11	0·73	5·25	0·14	5·39	11·11	5·86	16·96	6·86	16·7	23·6	1·3	19·3	20·6	−2·5	21·5	20·6
P	0·009	< 0·001	0·013	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001†	< 0·001‡	0·001§	0·003	0·004	0·028¶	0·121	0·078	0·901	0·047	0·118
S.E.M.‖	0·034	0·020	0·041	0·212	0·105	0·223	0·347	0·370	0·566	0·766	0·94	1·57	0·91	2·47	3·16	1·31	2·85	3·63
Experiment 3																		
Gloria (very early)	0·19	0·47	0·67	0·79	1·96	2·75	1·87	3·57	5·47	2·90	6·7	9·5	2·3	8·9	11·2	3·0	10·1	13·1
Bintje (mid-early)	0·21	0·25	0·46	2·37	2·02	4·40	7·85	5·63	13·46	10·51	11·4	21·9	12·0	19·4	31·3	−1·1	27·7	26·5
P	0·565	0·019	0·017	< 0·001	0·766	< 0·001	0·005	0·122	0·006	0·002	0·124	0·010	0·035	< 0·001	0·004	0·319	0·028	0·145
S.E.M. (D.F. = 4)	0·023	0·042	0·037	0·101	0·149	0·128	1·545	0·749	0·116	0·717	1·73	1·90	2·19	0·41	2·44	2·55	3·68	5·28

* Average values for the two planting dates.
† Despite significant ($P = 0{\cdot}004$) interaction, cultivar ranking was similar at both planting dates.
‡ Significant interaction ($P = 0{\cdot}004$). Gloria had lowest growth rates at both planting dates. Ranking of Ostara and Spunta differed.
§,¶ Significant interactions ($P = 0{\cdot}004$ and 0·016 respectively). Differences over cultivars not significant ($P \geqslant 0{\cdot}05$) at the first and second planting respectively.
‖ D.F. = 12 for 0–14, 14–28, 28–42 and 42–56 DAT; D.F. = 11 for 56–70 and 70–84 DAT.

cover was less than 40% (Figs 1 and 2). In Expt 3, haulm dry weight continued to increase at a low level until the end of the season (Table 4, Fig. 2), but soil cover did not (Fig. 1), probably because no extra apical branches were produced any more and stem elongation had ceased.

Possibilities to improve the field performance

Because the most important causes for the limited haulm development in transplant crops from very early cultivars were the high proportion of dry matter allocated to tubers immediately after field transplanting and the inability to reverse this, the most prospective line to improve field performance would be to change the pattern of dry matter allocation in an early phase in the direction of haulm growth. This possibly could be achieved by high-N treatments, high-temperature treatments or long-daylength treatments (Van Heemst 1986; Wolf *et al*. 1990; Vos & Biemond 1992; Van Dam *et al*. 1996), either during transplant production or in the field.

Aiming merely at delaying tuber initiation may not be successful unless the delay is very strong or accompanied by a change in dry matter allocation, because tubers immediately became very strong sinks in the earlier cultivars (Table 3).

Still unclear are the importance of the size of the haulm at transplanting, its activity as a sink, and prospects of manipulating them. Increasing size or activity of the haulm might also increase early haulm growth, because haulm RGRs did not differ between cultivars in the first two weeks after transplanting (Table 3).

In all cases, an adequate tuber bulking period should be ensured and aggravated transplant stress be avoided.

CONCLUSIONS

(1) In field crops from transplants of *in vitro* produced plantlets grown for seed tuber production in a short growing season, fresh tuber yields of early cultivars are lower than of later cultivars because of a lower AIR; not because of a less favourable RCC, HI or TDMC.

(2) The lower AIR is mainly due to a slower increase in soil cover after transplanting and a lower maximum soil cover; not to an earlier senescence.

(3) The slower increase in soil cover after transplanting is associated with lower haulm growth rates. At first, these result from a lower proportion of the daily increase in weight that is allocated to haulm growth. Also a smaller haulm size at transplanting may contribute. Later also the total daily weight increase becomes lower as a result of limited haulm growth earlier.

(4) In crops from transplants, cultivar effects on tuber yield are different from cultivar effects in crops from seed tubers, because AIR is lower for earlier cultivars in transplant crops, but not affected by cultivar in tuber crops.

(5) Transplant crops, especially from later cultivars, do not show the linear or negative exponential increase in dry-matter allocation to tubers with time that is common in crops from seed tubers.

(6) Transplant crops do not show the pattern of tuber initiation from tuber crops. Tuber numbers increase over a longer time and a strong boost is absent.

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