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Effects of Planting Date on the Growth and Yield of Two Potato Cultivars Grown from Microtubers and Conventional Seed Tubers

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Abstract : This study clarified the effect of planting date on the growth and yield of potato (*Solanum tuberosum* L.) plants grown from conventional seed tubers (CT) and microtubers (MT). CT of about 50 g and MT of 1 to 3 g of early (Kitaakari) and late (Norin 1) maturity cultivars were planted at Hokkaido University, Sapporo, Japan, on May 13, June 4 and June 25, and their growth and yields were investigated. The linear increase in leaf area index started later, but thereafter was higher in MT plants than in CT plants, irrespective of cultivar and planting date. Tuber formation was later in MT plants than in CT plants of both cultivars, but this difference was smaller on the last planting date. The linear increase in tuber dry weight started later in MT plants than in CT plants, but the rate of increase was similar in MT and CT plants of both cultivars and on all planting dates. Delaying the date of planting reduced the tuber yield, mainly because of the shortening growing period in MT and CT plants. The reduction in tuber yield and growing period was greater for the late cultivar Norin 1 compared with the early cultivar Kitaakari of CT and MT plants. Despite the climatic variations among the planting dates, MT plants yielded 71 to 90% of tuber fresh weight relative to CT plants, suggesting that MT are a good alternative as propagules for potato cultivation in countries where seed production is difficult.

Key words : Field cultivation, LAI, *Solanum tuberosum* L., Tuber bulking, Tuber formation.

Potato microtubers (MT) are small potatoes of around 1 cm diameter and are usually produced *in vitro* in a closed container under controlled photoperiod, light intensity and temperature conditions. At present, some private companies are producing MT for sale to potato growers in countries such as China, India, Israel, and Japan. Because MT are produced *in vitro* and are small, they have advantages compared with conventional seed tubers (CT), such as a shorter production period, easier handling, reduced transportation costs. MT can be produced in any country independent of its climatic conditions that are difficult to control in the field.

Studies on the growth and yield of field-grown potato plants from MT, however, are few. Wattimena et al. (1983), using plants grown from MT and transplanted to a field, reported similar tuber yields between MT and CT plants. However, Lommen and Struik (1994) reported that MT plants had a much lower yield than CT plants, from only 16% to a maximum 55% of tuber fresh yield of CT plants. Leclerc and Donnelly (1990) had a smaller tuber yield in MT than in CT plants and suggested that this difference in tuber yield was due to the higher susceptibility of MT plants to early soil water stress and high temperature. In our previous studies MT plants had a 20% smaller tuber yield than CT plants; the year-to-year variation in tuber yield was greater in MT than in CT plants (Kawakami et al., 2003), but the growth and yield of plants grown from MT and CT were similarly affected by soil water stress (Kawakami et al., 2005).

This study was carried out in order to observe the effect of climatic factors other than soil water stress (i.e., temperature, day length, solar radiation) on the growth and yield of plants grown from MT and CT of early and late maturity cultivars in fields.

Materials and Method

The experiment was conducted on the Experimental Farm of the Field Science Center for Northern Biosphere, Hokkaido University, Sapporo, Japan (43° 04' N, a brown lowland soil, Typic Udifluvent) in 2001. CT weighing about 50 g and MT weighing 1 to 3 g of an early maturing cultivar, Kitaakari (KA), and of a late maturing cultivar, Norin 1 (N1), were used as propagules. The MT were produced by Kirin Brewery Co., Ltd., Japan and were harvested on November 2000 and the CT were produced by the National Center for Seeds and Seedlings (Hokkaido, Japan) and were harvested on October 2000. Both CT and MT were hardened under natural light and the sprout length reached approximately 10 mm and 5 mm, respectively, at planting. The seed tubers were planted by hand three times: May 13 (first planting, P1), June 4 (second

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Abbreviations : CT, conventional seed tuber; DAE, days after emergence; KA, Kitaakari; LAI, leaf area index; MT, microtuber; N1, Norin 1; P1, first planting (May 13); P2, second planting (June 4); P3, third planting (June 25).

Table 1. Climatic factors at 30-day intervals of three planting dates.

Parameter	Planting date [1]	Days after emergence 0 - 29	30 - 59	60 - 89	90 - Maturity KA [2]	N1
Average minimum air temperature (°C)	P1	10.9	16.7	16.3	14.9	10.6
	P2	14.4	16.4	15.9	12.0	8.5
	P3	16.9	16.0	11.0	8.1	6.4
Average maximum air temperature (°C)	P1	21.2	25.1	25.1	21.8	19.2
	P2	23.9	24.5	24.0	20.7	17.8
	P3	24.6	25.0	19.9	17.0	15.6
Solar radiation ($MJ\ m^{-2}$)	P1	542	416	512	193	551
	P2	472	467	395	97	371
	P3	402	498	297	60	201
Precipitation (mm)	P1	38	99	65	221	305
	P2	61	66	267	22	84
	P3	75	97	214	34	50
Average soil temperature (°C)	P1	17.5	20.6	19.9	18.3	14.8
	P2	19.8	19.6	19.6	16.4	13.0
	P3	20.0	19.9	15.4	12.4	10.8
Day length (h:min)	P1	15:16	15:05	14:06	13:03	12:08
	P2	15:16	14:34	13:19	12:25	11:38
	P3	14:51	13:43	12:20	11:24	10:59

1) P1: May 13, P2: June 4, P3: June 25, 2001.
2) KA: Kitaakari, N1: Norin 1.

planting, P2), and June 25 (third planting, P3) in a split-plot design with planting dates assigned as main plot and tuber type and cultivar as subplot, with three replications. On all planting dates the planting depth was about 7 cm for CT and 3 cm for MT, the planting distance was 75 cm between rows and 25 cm between hills, and each plot consisted of six rows of 15 plants each (16.88 m^2) for both CT and MT. Fertilizers were applied just before planting at 70, 48, 75 and 18 kg ha^{-1} of N, P, K and Mg, respectively, and the plots were covered with an un-woven fabric polyester soil cover (Passlight, Unitika Co., Ltd., Japan) after planting for two weeks to make uniform the initial plant stand. Insects and diseases were controlled according to the standard practice of the Experimental Farm of the Field Science Center for Northern Biosphere, Hokkaido University. The plots were weeded by hand during the early growth stage and were rainfed for the entire growing period.

The emergence and physiological maturity were the dates when 70% of plants emerged and 70% of the leaves of plants turned yellow, respectively, from observations at 2- to 3-days intervals. To examine tuber formation, four plants in each replication two or three times a week from about two weeks after emergence were dug up and were analyzed as in Kawakami et al. (2003).

For each planting date, four plants of each cultivar and tuber type in each replication were taken to analyze plant growth at three growth stages: tuber formation at 21, 27, 26 days after emergence (DAE) for P1, P2, P3, respectively; flowering at 36, 40, 40 DAE for P1, P2, P3, respectively; maximum shoot growth (around the end of flowering) at 69, 68, 53 DAE by KA and 77, 80, 72 DAE by N1, for P1, P2, P3, respectively. All leaves of each plant were stripped and the leaf area of the randomly taken sub-sample of around 1000 cm^2 for each plant was measured by using an automatic area meter (AMM-9, Hayashi Denko Co., Ltd., Japan). The dry weights (DW) of tuber and leaf were measured after oven drying at 70 °C for more than 72 hrs, and the leaf area index (LAI) was calculated as the product of the measured leaf area/ leaf DW ratio and the total leaf DW. The marketable (heavier than 20 g) tuber fresh and dry weights were recorded after physiological maturity for 12 plants of each cultivar and tuber type in each replication.

Meteorological data were recorded at the agro-meteorological station of Hokkaido University, and the soil temperature was recorded by using a data logger (SK-L 200 T, Sato Keiryoki MFG. Co., Ltd., Japan) in one plot in each replication at approximately 7 cm depths from the soil surface. The tuber DW and LAI were compared between CT and MT plants of cultivar KA and N1 during the approximately linear increase phase by regressing them on DAE using data from all replicates for all planting dates, with CT and MT treated as a dummy variable (Draper and Smith, 1966). The increase of LAI stopped approximately at around 70 DAE in KA and 80 DAE in N1. The linear increase of tuber DW was observed from when the tuber DW was approximately 10 g m^{-2} until physiological maturity in both cultivars. Data outside of these ranges were not used for regression line comparisons. Analysis of variance was made to test the significance among planting date, seed tuber type, cultivar and their interaction by using SPSS Base 7.5.1 J for Windows (SPSS Inc., USA).

Results

1. Climatic patterns

The average minimum air temperature was higher in the later than in the earlier planting date from 0 to 29 DAE, was similar between 30 to 59 DAE and was higher in the earlier than in the later planting date from 60 DAE until physiological maturity. The air temperature after 90 DAE was especially low for P2 in N1 and for P3 in both cultivars (Table 1). Similar trends were observed in average maximum air temperature, with the exception that no especially high average maximum air temperature was observed during the growing period from each planting date. The solar radiation was higher in the earlier planting date throughout the growing season in both cultivars, with the exception between 30 to 59 DAE when the later planting date had higher accumulated radiation than the earlier planting date. The precipitation varied among the planting dates and was especially high between 60 to 89 DAE for P2 and P3 and from 90 DAE for P1. At emergence, the day length on P1 was about 15 hr, increased until about 15 hr 25 min at 30 DAE and then started to decrease. For P2, the day length was longest at emergence, remained long until about

Table 2. Effect of planting date on percentage of emergence, and days from emergence to tuber formation in MT and CT plants of cultivars N1 and KA [1].

Planting date (P) [2]	Cultivar (C) [3]	Tuber type (T) [4]	Percentage of emergence (%)	Days to tuber formation (days)
P1	N1	CT	100 [5]	19
		MT	100	29
	KA	CT	100	19
		MT	100	24
P2	N1	CT	96	24
		MT	99	34
	KA	CT	100	23
		MT	98	34
P3	N1	CT	97	23
		MT	97	24
	KA	CT	98	22
		MT	96	26
P			ns [6]	**
C			ns	ns
T			ns	**
CxT			*	ns
PxC			ns	ns
PxT			ns	**
PxCxT			ns	ns

[1] The tuber formation stage was the date when the percentage of plants having at least one tuber for each replicate reached 70%.
[2] P1: May 13, P2: June 4, P3: June 25, 2001.
[3] N1: Norin 1, KA: Kitaakari.
[4] CT: Conventional seed tubers, MT: Microtubers.
[5] Data analyzed with angular transformation of percentage to degrees.
[6] ns: not significant ($P \geq 0.05$), *, **: significant at $P<0.05$ and 0.01, respectively.

14 DAE and then gradually decreased. For P3, the day length was about 15 hr 15 min at emergence and decreased sharply until about 14 hr 15 min at 30 DAE. The average soil temperature was about 17 °C on P1 from emergence until about 25 DAE, but was higher at around 21 °C from emergence until about 25 DAE, for P2 and P3. Between 25 and 30 DAE, the average soil temperature was higher for P1 and P2 compared with P3.

2. Emergence and tuber formation

The planting date did not affect the percentage of emergence of either tuber type or cultivar (Table 2). Although the interaction between cultivar and tuber type was significant, it was not large, and MT and CT had a high percentage of emergence in both cultivars.

However, the tuber formation between planting dates and between tuber types was significantly different. Tuber formation was significantly later for P2 (i.e., at 29 days) than for P1 and P3 (i.e., at 23-24 days), and was more than one week later in MT than CT plants. The interaction between planting date and tuber type was significant: the difference between MT and CT plants was large for P2 and small for P3. Similar patterns were observed for the effect of tuber type and planting date on days to tuber bulking (data not shown).

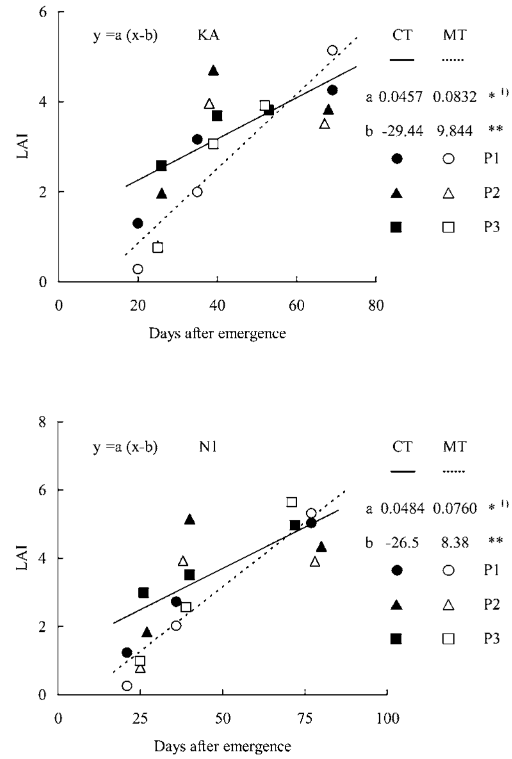

Fig. 1. Time trends in leaf area index (LAI) of MT and CT plants until 69 days after emergence (Kitaakari, KA), and 80 days after emergence (Norin 1, N1).
[1]Data of the average of the three replicates are shown. Regression lines were fitted to all the data with tuber type treated as a dummy variable, and the slopes (a) and intercepts (b) were compared between CT and MT plants. The overall R^2 of the regression was 0.664 for KA ($P<0.001$) and 0.693 for N1 ($P<0.001$). * and **, significant at $P<0.05$ and 0.01, respectively.

3. LAI increase

The start of the linear increase in LAI was later in MT than in CT plants of both cultivars and on all planting dates (Fig. 1). Thereafter, however, the LAI increase rate (regression slope) was higher in MT than in CT plants of both cultivars irrespective of planting date, resulting in a higher or similar LAI in MT plants of cultivar KA at about 60 DAE, and of N1 at around 75 DAE, when LAI almost stopped the increase.

4. Tuber DW increase

The increase in tuber DW of cultivar KA was linear from about 22 DAE in CT plants and from about 33 DAE in MT plants (Fig. 2). The tuber increase rate, however, was similar between MT and CT plants, resulting in a consistently higher tuber DW in CT than in MT plants at harvest. Similar trends were observed for cultivar N1: the start of the linear increase in tuber DW was later in MT (i.e., 47 DAE) than in CT plants (i.e., 28 DAE), but the tuber increase rate was similar between tuber types during the linear growth phase, resulting in a lower tuber DW in MT than in CT plants at harvest.

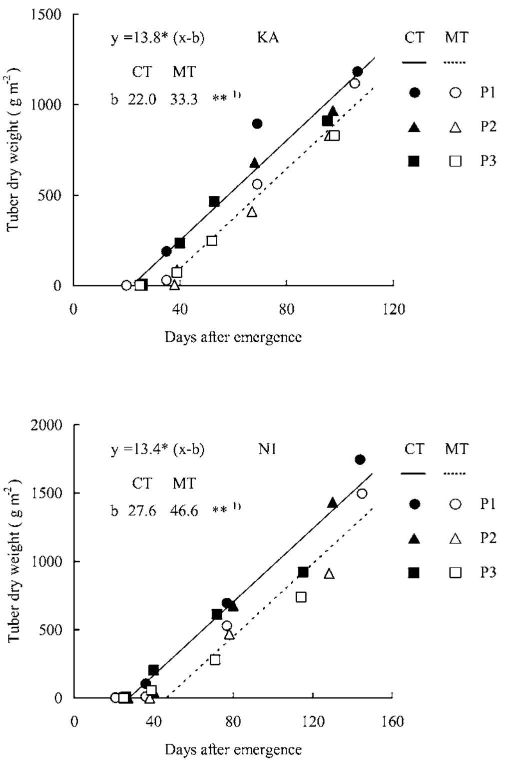

Fig. 2. Time trends in tuber dry weight (DW) of MT and CT plants until physiological maturity in cultivar Kitaakari (KA) and Norin 1 (N1).
[1)] Data of the average of the three replicates are shown. Regression lines were fitted to all the data excepting those smaller than 10 g m^{-2}, with tuber type treated as a dummy variable, and the slopes (a) and intercepts (b) were compared between CT and MT plants. Because the slopes showed no significant difference, the parallel lines model was used to test the effect of tuber type on tuber dry weights. The overall R^2 of the regression was 0.915 for KA ($P<0.001$) and 0.886 for N1 ($P<0.001$). **, significant at $P<0.01$.

Days from emergence to physiological maturity (growing period) was significantly affected by planting date (Table 3). The growing period was longest for P1 and shortest for P3. The cultivar response to planting date was also different. The reduction in growing period with later planting date was higher for cultivar N1 than KA. However, we observed no significant difference between MT and CT plants in the growing period. The tuber fresh yield was affected by planting date: the tuber fresh yield, averaged for both tuber type and cultivar was 6.85 kg m^{-2} for P1, 5.13 kg m^{-2} for P2, and 4.44 kg m^{-2} for P3. Cultivar N1 had a higher tuber fresh yield than KA, and CT plants had an average 20% larger tuber fresh yield than MT plants. The average size of the harvested tubers was 99 g for MT and 115 g for CT plants. The difference in tuber fresh yield between MT and CT plants was significantly smaller in KA than in N1 (tuber type and cultivar interaction was significant). The decrease in tuber fresh yield due to later planting was also higher for N1 than KA.

Table 3. Effect of planting date on the period from emergence to physiological maturity (growing period), and marketable tuber fresh yield in MT and CT plants of cultivars KA and N1.

Planting date	Cultivar	Tuber type	Growing period	Tuber fresh yield
(P)[1]	(C)[2]	(T)[3]	(days)	(kg m^{-2})
P1	N1	CT	144	8.55
		MT	145	7.17
	KA	CT	107	6.14
		MT	106	5.55
P2	N1	CT	130	6.74
		MT	128	4.77
	KA	CT	97	4.88
		MT	96	4.16
P3	N1	CT	115	4.89
		MT	114	4.01
	KA	CT	95	4.70
		MT	98	4.18
P			** [4)]	*
C			**	**
T			ns	**
CxT			ns	*
PxC			**	**
PxT			ns	ns
PxCxT			ns	ns

[1)] P1: May 13, P2: June 4, P3: June 25, 2001.
[2)] N1: Norin 1, KA: Kitaakari.
[3)] CT: Conventional seed tubers, MT: Microtubers.
[4)] ns: not significant ($P\geq0.05$), *, **: significant at $P<0.05$ and 0.01, respectively.

Discussion

The high percentage of emergence of both MT and CT in this study agreed with our previous study (Kawakami et al., 2003). Almost all planted tubers produced a plant and, although the interaction between percentage of emergence of tuber type and cultivar was significant, it was not large. Therefore, we conclude that MT have a high percentage of emergence and they are not affected by climatic variation such as that during this study.

The main climatic factors controlling tuber formation are night temperature and day length (Cutter, 1992; Struik and Ewing, 1995). The combination of long day length and high soil temperature for P2 compared with P1 and P3 until 30 DAE may have caused the longer days to tuber formation for P2. Because the difference in number of days to tuber formation between MT and CT plants was larger for P2 than for P1 and P3, longer day length and higher soil temperature may have caused the greater delay in tuber formation in MT than in CT plants. In this study, MT plants formed tubers more than one week later than CT plants, which agreed with our previous studies in which MT plants formed tubers later than CT plants in cultivars N1 (Kawakami et al., 2003) and KA (Kawakami et al., 2004).

The start of the linear increase in LAI was delayed in MT plants, but the increase rate was higher in MT than in CT plants of cultivars N1 (Kawakami et al.,

2003) and KA (Kawakami et al., 2004). Despite the climatic variation between planting dates in this study, the patterns of the difference in the start and rate of LAI increase between MT and CT plants were similar: in both cultivars the linear increase in LAI started later and the increase rate was higher in MT than in CT plants. Therefore, we conclude that in the climatic range of this study, MT plants produce a higher or similar LAI than CT plants at around maximum shoot growth.

The later start of the linear increase in tuber DW in MT than in CT plants and the similar increase rate between them in this study agree with our previous study of cultivar N1 (Kawakami et al., 2003), but not of KA (Kawakami et al., 2004), in which the start was not different and the increase rate was lower in MT than in CT plants. Probably, the higher initial temperature at later planting date in this study may have favored earlier tuber growth in CT plants, but not in MT plants of KA, and which may be related to a greater restriction of water and nutrients for higher tuber increase because of the initial smaller root system of MT plants compared with CT plants (Kawakami et al., 2003).

Tuber fresh yield is closely related to leaf area duration (Bremner and Radley, 1966; Kooman et al., 1996). The shortening of the growing period was the main cause of the lower tuber yield with the later planting date in this study. In the same way, the shorter growing period seems to be the main factor causing the lower tuber yield in cultivar KA than in N1. Early allocation of assimilates to the tubers stops foliage growth earlier and shortens the longevity of individual leaves (Kooman and Rabbinge, 1996). Therefore, the shorter day length at late growth stage for P2 and P3 probably promoted earlier distribution of dry matter to tubers, resulting in a shorter growing period. The low minimum temperature from 90 DAE at P2 and P3 of N1 may have shortened the leaf growth period in this cultivar.

The higher tuber yield of CT than MT plants, however, was not caused by differences in growing period, because CT and MT plants had a similar growing period for all planting dates and by both cultivars. The main factor leading to higher tuber yield in CT than in MT plants was the earlier start of the increase in tuber DW, resulting in a longer bulking period in CT than in MT plants.

MT plants of KA yielded an average 88% of tuber fresh yield compared with CT plants, and MT plants of N1 yielded 79%. This 9% higher tuber fresh yield in MT plants of KA than in MT plants of N1, however, is not consistent with our previous studies during four years (Kawakami et al., 2003 and 2004), where we observed no constant relative higher yield in MT plants of cultivar KA than N1. Therefore, we conclude that although in some years MT plants of KA may have a higher relative tuber yield than MT plants of N1, the relative tuber yield by MT plants does not differ between the two cultivars.

In this study, despite a large climatic difference between the different planting dates, MT plants had 71 to 90% of the tuber yield of CT plants of the two cultivars differing in maturity period. The results suggest that MT can be used as propagules in a wide range of climatic conditions, especially in countries where the field production of healthy potato seed tubers is difficult.

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