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Difference in Root Growth of Potato Plants among Years and Cropping Seasons*

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Abstract : To clarify the role of the roots on the dry matter production and the tuber yield of the potato plants (*Solanum tuberosum*), the dry weight and respiration rate of the roots up to 30 cm in depth were investigated at 4—6 times during the growing season with 1—2 main variety(s) at autumn cropping for 3 years and at spring cropping for 1 year.

1. The difference in root DW among years and cropping seasons became apparent at a relatively early stage before initial flowering, being much larger than the difference in LAI.

2. The difference in root activity among years and cropping seasons was much smaller than the difference in root DW.

3. During one month after initial flowering, the difference in photosynthetically active radiation intercepted by the canopy could not fully explain the difference in CGR. On the other hand, the root DW showed a highly positive correlation with CGR ($r=0.971^{**}$) and tuber bulking rate ($r=0.993^{**}$).

It was concluded that the difference in root growth among years and cropping seasons would be one of the major factors affecting dry matter production during the tuber bulking period and tuber yield.

Key words : Annual difference, Dry matter production, Root dry weight, Root respiration rate, Seasonal difference, *Solanum tuberosum*.

バレイショにおける根の生長の年次間および作期間の差異：岩間和人（三重大学教育学部）

要 旨：バレイショの乾物生産および収量に対する根の役割を明らかにするため、春作と秋作ならびに秋作年次間において、土壌表層 30 cm に含まれる根の乾物重と呼吸速度の生育に伴う推移を比較した。

1. 年次・作期間における葉面積指数の差異は開花始め（萌芽後 30 日頃）以降に明らかとなり、その最大値における差異が比較的小さかった（2.8—4.0）。これに対し、根重の差異は開花始め以前に明らかとなり、またその最大値における差異が大きかった（5.6—18.1 g/m²）。

2. 年次・作期間における根活力（単位根重当りの根呼吸速度）の差異は、根重の差異に比べ小さかった。また、根活力はいずれの年次および作期でも生育に伴い低下したため、根重と根活力とから推定した全根活力（単位土地面積当りの根呼吸速度）は、開花始め頃に最大となり、その後は低下した。従って、塊茎の肥大期間中に十分な養水分供給を維持するためには、大きな根重を確保することが必要であると推察した。

3. 開花始めから 1 ヶ月間において、年次・作期間に認められた個体群生長速度の差異は、作物体の吸収した有効日射量の差異では十分に説明できなかった。しかし、同期間の個体群生長速度と根重、ならびに塊茎の肥大速度および収量と根重最大値との間には、いずれも極めて高い正の相関関係が認められた。

以上のことから、年次・作期間における根重の差異は、塊茎肥大期間中の乾物生産ならびに収量の差異をもたらした主要な要因の一つであると推察した。

キーワード：乾物生産、根重、作期間差異、根呼吸速度、年次間差異、バレイショ。

The role of the roots in the plant growth has been less known in potato plants^{2,10,15,22}. Our previous studies^{6,7} clarified the genetic difference in root dry weight (DW) and its relation with shoot and tuber growth. The objectives of the present study were to investigate the difference in root growth among years

and cropping seasons, and to clarify its relation with dry matter production and tuber yield under the field conditions. The root growth was observed on a dry weight basis. The root respiration rate was also measured to identify the difference in root activity.

Materials and Methods

Experimental sites

The experiments were carried out in the field of the Institute for Experimental Farming, Faculty of Agriculture, Mie University

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(Takanoo-tyo, Tsu city ; 35°N, 136°E) in 1984—1986, where potatoes were being cultivated twice a year, in spring and autumn. The data were obtained at autumn cropping (AC) for 3 years and at spring cropping (SC) for 1 year. The soils were clay loam with hard pan below 30 cm at AC in 1984 and at SC, and sandy loam with hard pan below 60 cm at AC in 1985 and 1986.

Methods for cultivation

The outline of the methods was shown in Table 1. Dejima and Norin 1 are main varieties in the double cropping areas in Japan. Dejima was bred from the progenies of Norin 1. The characteristics of these two varieties are relatively similar, e.g. late maturity and short dormancy. Although both varieties were planted for all experiments, only one variety was used at AC for the study because of incomplete sprouting due to heat damaged in the other variety. Certified seed tubers (about 100 g per piece) from Nagasaki for Dejima and from Hiroshima for Norin 1 were used. They were bisected with the exception of AC in 1986. Fertilizers were applied as basal dressing before planting at different levels for each experiment due to the difference in the soil fertility. Mulching of polyvinyl chloride (PVC) sheet was done when planting at AC in 1986 and at SC. The date of sprouting was recorded when half of the plants sprouted. The date of harvesting was decided depending on the climatic conditions, i.e. the start of rainy season at SC and the first severe frost at AC.

Methods for sampling

Dry weight and leaf area were measured 5–6 times during the growing season with 2–3

replications of 4–5 hills. Aerial parts cut off at the ground surface were separated into leaves and stems. Leaf area was measured with an automatic leaf area meter. The underground parts, excavated over the planting area up to 30 cm in depth, were soaked in water for one night, washed with a root washing apparatus devised by the author to remove soil and other plant residues, and separated into roots, underground stems and tubers. Dry weight was measured after oven-drying at 80°C for 48 hrs. At harvesting, the tuber yield was recorded with 10–20 hills per replication.

The root respiration rate was measured 4–6 times during the growing season on the different date of dry weight measurements. The procedures used, modifications of the Inden⁵⁾ method were as follows; At 9–10 o'clock, one plant per replication was dug up at a 30 cm depth, and immediately washed with running water to remove soil and other plant residues from roots as carefully as possible. After cutting off the roots at the portion of 2 cm from the underground stem nodes, 6–8 samples with 2–3 adventitious roots per each (about 1 g for FW) were stored in air saturated distilled water for one hour. Then, each sample was disinfected by Methoxyethyl Mercury Chloride (42 ppm) for 30 seconds in order to minimize the effect of soil microorganisms, and re-stored at 25°C within 130 cc plastic bottle filled with air saturated distilled water. After 3 hours, consumption of O₂ was measured with a dissolved oxygen meter (YSI 54A Model) by comparing O₂ concentrations of the water with and without root samples. After measuring the root DW, the root respiration rate per unit root DW was calculated.

Table 1. Methods for cultivation.

Year	Season	Variety	Planting density ¹⁾ (hills/m ²)	Levels of fertilizer			Date of		
				N	P ₂ O ₅ (g/m ²)	K ₂ O	Planting	Sprouting	Harvesting
1984	Autumn	Dejima	6.25	12	20	14	Aug. 31	Sep. 15	Nov. 28
1985	Autumn	Norin 1	6.25	20	60	30	Sep. 2	Sep. 19	Dec. 7
1986	Autumn	Dejima	6.06	16	20	16	Sep. 1	Sep. 18	Nov. 30
1985	Spring	Norin 1	6.06	18	22	18	Mar. 7	Apr. 3	June 15
1985	Spring	Dejima	6.06	18	22	18	Mar. 7	Apr. 7	June 15

Note. 1) 6.25 ; 80 cm×20 cm, 6.06 ; 55 cm×30 cm.

The plot size was 25–58 m² per replicaion.

Data analysis

The growth parameters of crop growth rate (CGR) and leaf area index (LAI) were calculated using the equations indicated by Watson²⁵⁾. Photosynthetically active radiation intercepted by the canopy (Δ PAR) during the period from 30 days to 60 days after sprouting was calculated using the equation¹⁶⁾;

$$\Delta\text{PAR} = 0.444 \times S \times (1 - e^{-K \times F})$$

where 0.444 was the proportion of the wave within 400 - 700 nm relative to full spectrum radiation; S and F were the means of solar radiation and LAI respectively during these period; K, the light-interception coefficient, was fitted to 0.7.

Meteorological data recorded at the Institute for Experimental Farming, Faculty of Agriculture, Mie University, were used for the analysis.

Results and Discussion

1. Comparison of the climates

Day length during the growing season was strikingly different between cropping seasons. At SC, it increased from 12 h 33 min at sprouting to 14 h 26 min at harvesting. While, at AC it decreased from 12 h 20 min at sprouting to 10 h 6 min at harvesting. As shown in Fig. 1, solar radiation and mean daily air temperature during the growing season were also different between cropping seasons. Solar radiation after 30 days from sprouting (30 Days), which was approximately the time of initial flowering, was about 330 - 390 cal/cm²/day at SC, while it was about 140 - 270 cal/cm²/day at AC. As the growing sea-

son progressed, mean daily air temperature increased at SC, in contrast to a decline at AC. Before 30 Days, it was higher at AC, above 17°C. Thereafter, it was lower at AC, below 17°C. On the other hand, the difference in accumulated precipitation during the growing season did not seem to depend on cropping seasons (Fig. 1). AC in 1985 and SC had much larger precipitation than AC in 1984 and 1986.

2. The difference in root DW

The time trends in root DW and LAI are shown in Fig. 2. Until 30 Days, the root DW increased linearly in all plants. The rate of increase, however, showed a large difference among the plants. SC plants showed larger increase than AC plants with the exception of 1986. Thereafter, all AC plants stopped increasing, while SC plants showed an additional increase. Consequently, the maximum root DW during the growing season showed large differences among the plants. The smallest was only 30% of the largest. Since the varieties used in AC differed from year to year, the annual difference in root weight may be attributable to the varietal difference. However, in the case of SC, where the two varieties were investigated simultaneously, the difference in root weight was small between the two varieties. It indicated that the difference in root growth among the plants in the present study was mainly attributable to the difference among years and cropping seasons.

On the other hand, LAI showed a similar increase among the plants until 30 Days. Thereafter, the difference in the increase of

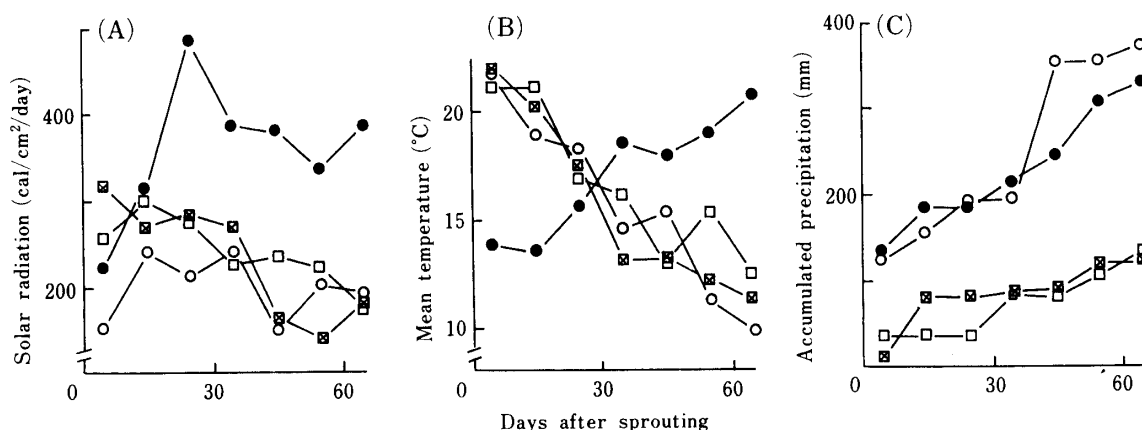


Fig. 1. Changes in solar radiation (A), mean daily air temperature (B) and accumulated precipitation (C) during the growing season.

Note. □: AC in 1984, ○: AC in 1985, ⊠: AC in 1986, ●: SC (Norin 1).

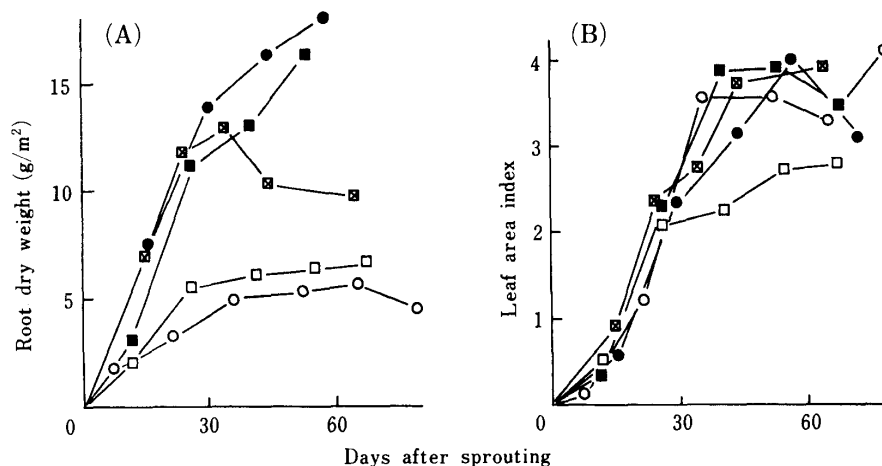


Fig. 2. Changes in root dry weight (A) and leaf area index (B) during the growing season.
Note. $\square$: AC in 1984, $\circ$: AC in 1985, $\boxtimes$: AC in 1986, $\bullet$: SC (Norin 1), $\blacksquare$: SC (Dejima).

LAI became apparent among the plants. However, all the plants with the exception of AC plant in 1984 attained more than 3 in maximum LAI. The difference in maximum LAI among the plants was relatively small. The smallest was 70% of the largest.

It has been reported that there were annual and seasonal differences in shoot and tuber growth in potato plants^{13,17,18}. However, there were no literature reporting those in root growth. In the present study, it was found that there was a large difference in root growth among years and cropping seasons. In addition, the results indicated that the difference in root growth became apparent at the relatively early stage before initial flowering and was much larger than the difference in LAI.

3. The relationship between root growth and meteorological factors

Since the cultivation methods used in the experiments were not necessarily consistent among years and cropping seasons, it would be better to consider that not only meteorological factors but also other factors caused the difference in root growth mentioned above. However, since meteorological factors showed a typical difference among years and cropping seasons, the effect of meteorological factors on root growth was considered.

During one month after sprouting, although the root growth tended to be enhanced when the total plant growth was enriched ($r=0.747$), the difference in root DW was more closely related to the difference in dry matter distribution ratio (DR) in the roots ($r=0.916^*$). Sugi et al.^{20,21} indicated that shorter

day length in AC than in SC caused the earlier restriction of shoot growth because of the earlier tuber initiation. Similar to their results, SC plants showed larger value in leaf DR and stem DR, while smaller values in tuber DR during these periods, as shown in Table 2. In AC plants, root DR tended to be smaller, when compared with SC plants. These results suggested that the root growth also tended to be restricted in AC plants as compared with SC plants due to the effect of shorter day length on tuber growth.

However, AC plant in 1986 showed similar root DR to that of SC plants. It indicates that the factors other than the day length may also influence root DR. On this account, the effect of solar radiation on root growth was reported in wheat²⁴, oat³ and rice²³. Similar to their results, Fig. 3 shows that the increase of root DW during one month after sprouting tended to be larger at the higher solar radiation as a result of a larger increase in the total DW and a higher root DR. These results suggested that solar radiation was one of the factors affecting root growth.

The marked difference in root growth after 30 Days between cropping seasons may well confirm the above explanations. The difference in day length and solar radiation between cropping seasons became more apparent after 30 Days compared with before 30 Days. Day length was longer and solar radiation was more intense at SC than at AC, while root DW continued to increase in SC plants but not in AC plants.

From these results, the author hypothesizes

Table 2. Increase in total dry weight and dry matter distribution ratio for each organ during one month after sprouting.

Year	Season	Variety	Increase in total DW (g/m ²)	Distribution ratio (%)			
				Leaf	Stem ¹⁾	Tuber	Root
1984	Autumn	Dejima	197.5	31.2	28.4	37.6	2.9
1985	Autumn	Norin 1	186.0	33.5	29.1	35.2	2.3
1986	Autumn	Dejima	290.7	25.3	24.5	46.0	4.3
1985	Spring	Norin 1	224.1	42.4	36.7	14.7	6.2
1985	Spring	Dejima	284.1	38.0	36.4	21.4	4.1

Note. 1) Stem + Stolon.

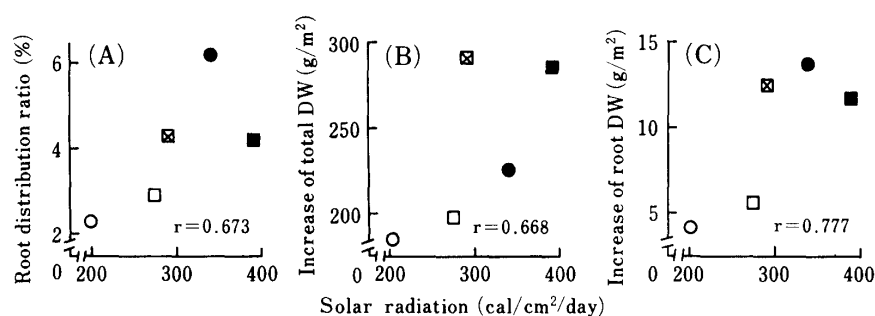


Fig. 3. Relationships of solar radiation with dry matter distribution ratio for roots (A), increase of total dry weight (B) and increase of root dry weight (C) during one month after sprouting.

Note. Symbols are the same as those shown in Fig. 2.

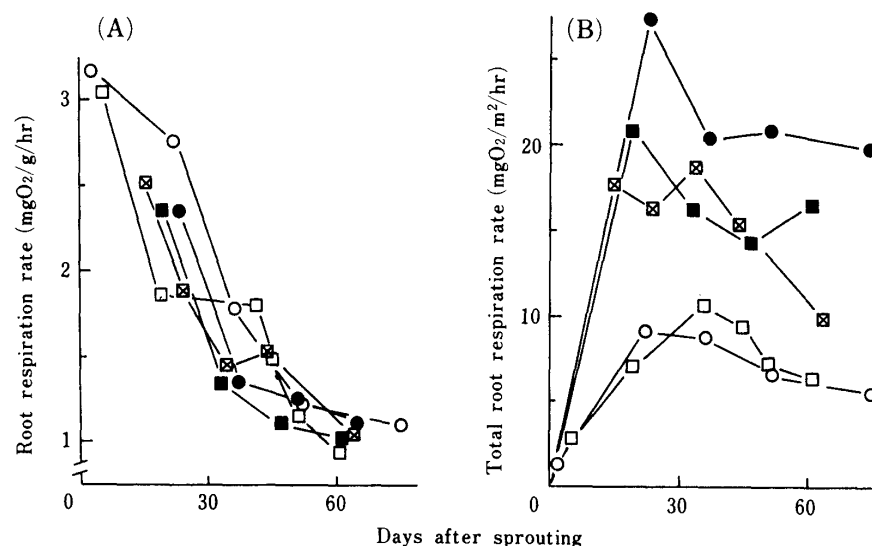


Fig. 4. Changes in root respiration rate per unit root dry weight (A) and total root respiration rate per unit soil area (B) during the growing season.

Note. Symbols are the same as those shown in Fig. 2.

that root growth may be affected by both day length and solar radiation, resulting in more restricted root growth in AC plants than in SC plants. Although there were also large

differences in air temperature and precipitation among years and cropping seasons, the author could not identify the effects of these factors on root growth in the present study.

4. The difference in root respiration rate

Since it was reported in rice^{14,19)} that plant growth related significantly not only with the amount of roots but also with root activity, root respiration rate per unit root DW (URR) was investigated in the present study. As shown in Fig. 4, URR decreased exponentially with time in each plant. The difference in URR among the plants was relatively small compared with those in root DW. As a result, the total root respiration rate per unit soil area (TRR) estimated by multiplying URR by root DW showed large differences among the plants depending on the differences in root DW among the plants. In addition, Fig. 4 also shows that the TRR in each plant attained its maximum value during the growing season at about 30 Days, declining with time.

These results indicated that the difference in root activity among years and cropping seasons would be much smaller than the difference in the amount of roots, at least in the varieties used in the study. In addition, it was indicated that during tuber bulking period the amount of roots would be very important to maintain sufficient nutrient and water absorption for tuber growth due to the progressive decline of root activity.

5. The relation of root DW with dry matter production

Fig. 5 shows the time trend in CGR during the growing season. Although all plants showed similar increase in CGR until 30 Days, thereafter large differences in CGR were seen among the plants. Since it has been reported that one of the main factors affecting CGR was the amount of solar radiation intercepted by the canopy^{1,12,17)}, the mean values of LAI, solar radiation, Δ PAR and CGR during one month after 30 Days were calculated (Table

3). Among AC plants, there was no practical difference in Δ PAR value because of the compensation of smaller LAI in 1984 by a higher level of solar radiation. However, there was a large difference in CGR among AC plants. Therefore, it would be reasonable to consider that the factors other than Δ PAR caused the difference in CGR among AC plants. In addition, Δ PAR was extremely larger in SC plants because of solar radiation of higher level. AC plant in 1986, however, gave similar CGR value to those of SC plants. Therefore, the difference in Δ PAR could not sufficiently explain the difference in CGR between AC plants and SC plants.

On this account, Fig. 6 shows the relation of CGR with root DW during one month after 30 Days. The plants with a larger root DW showed a larger CGR. The result indicated that the difference in root DW was one of the

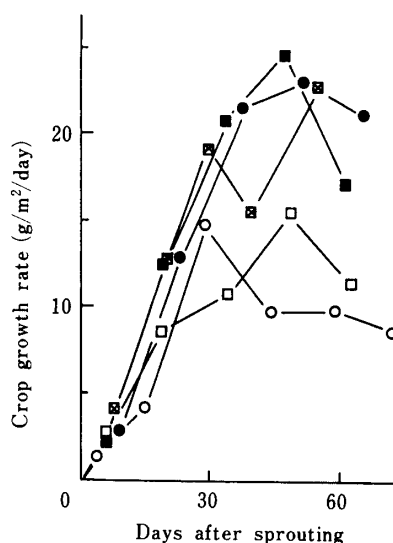


Fig. 5. Changes in crop growth rate during the growing season.

Note. Symbols are the same as those shown in Fig. 2.

Table 3. Mean of LAI, solar radiation, Δ PAR¹⁾ and CGR during one month after 30 Days.

Year	Season	Variety	LAI	Solar radiation (cal/cm ² /day)	Δ PAR (cal/cm ² /day)	CGR (g/m ² /day)
1984	Autumn	Dejima	2.41	223	80.7	13.0
1985	Autumn	Norin 1	3.42	190	76.7	10.8
1986	Autumn	Dejima	3.47	184	74.5	19.8
1985	Spring	Norin 1	3.22	358	142.3	22.2
1985	Spring	Dejima	3.70	357	146.6	21.6

Note. 1) Photosynthetically active radiation intercepted by the canopy.

main factors affecting the difference in CGR after flower initiation among years and cropping seasons. The author hypothesizes that in the field, where shortages in nutrient and water frequently occur, dry matter production would be affected not only by the amount of solar radiation intercepted but also by the amount of nutrient and water absorbed. In the present study, the amount of roots would have been the main factors affecting water and nutrient absorption.

6. *The relation of root DW with tuber growth and tuber yield*

The characteristics involved in tuber growth and tuber yield on the dry weight basis are listed in Table 4. The tuber bulking started at 25 – 31 days. It was several days earlier in AC

plants compared with SC plants. However, the contribution of its difference for the difference in tuber yield among the plants was relatively small, because the difference in tuber bulking rate among the plants was very large. It ranged 9.0 – 19.1 g/m²/day. The tuber yield was affected mainly by the tuber bulking rate ($r=0.976^{**}$).

Since the tuber bulking rate showed a linear relation to CGR during one month after 30 Days ($r=0.973^{**}$), it was supposed that the factors affecting CGR also influenced the tuber bulking rate. Fig. 7 demonstrates the relation of root DW with tuber bulking rate; the tuber bulking rate increased proportionally with the increase of the maximum root DW during the growing season. A similar

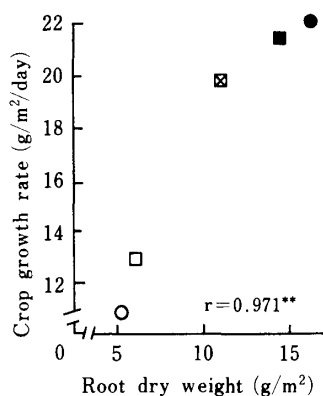


Fig. 6. Relationship between root dry weight and crop growth rate during one month after 30 Days.

Note. Symbols are the same as those shown in Fig. 2.

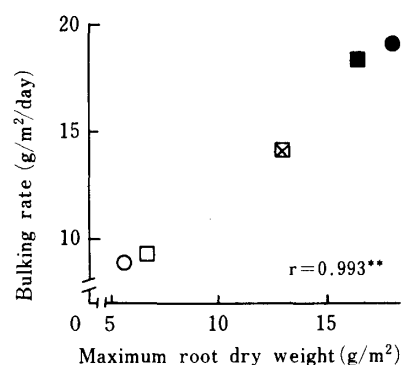


Fig. 7. Relationship between mean tuber bulking rate during tuber bulking period and maximum root dry weight during the growing season.

Note. Symbols are the same as those shown in Fig. 2.

Table 4. Days from sprouting to harvesting, days from sprouting to the initiation of tuber bulking, tuber bulking period, mean tuber bulking rate and tuber dry yield.

Year	Season	Variety	Days to harvesting	Days to tuber bulking ¹⁾	Bulking period ²⁾ (days)	Bulking rate ³⁾ (g/m ² /day)	Yield (g/m ²)
1984	Autumn	Dejima	74	28	46	9.2	477.8
1985	Autumn	Norin 1	79	28	51	9.0	505.8
1986	Autumn	Dejima	73	25	48	14.1	729.5
1985	Spring	Norin 1	73	31	42	19.1	850.2
1985	Spring	Dejima	69	29	40	18.5	788.1

Note . 1) Days from sprouting to the date when tuber dry weight attained 50 g/m².

2) Days from the date when tuber dry weight attained 50 g/m² to the date of harvesting.

3) (Tuber dry yield – 50) / Bulking period.

linear relation was also observed between the maximum root DW and the tuber yield ($r=0.987^{**}$).

Although the present tuber yield was not necessarily high in comparison with that in single cropping areas, it was due to the shorter growing period in double cropping areas. Since the mean bulking rate during the tuber bulking period of Norin 1 was 12 g/m²/day in Hokkaido (main area for single cropping), and 11 g/m²/day in Nagasaki (main area for double cropping)[†], the bulking rate obtained in the present study was relatively high. Its highest value, 19 g/m²/day was comparable to the value of 18 g/m²/day (estimated % of dry matter as 20) in England, where tuber fresh yield of 94 t/ha was achieved⁴⁾. Therefore, the present results indicated that potato plants would show a linear positive relation of root DW to the tuber yield until a rather high yield level, at least in double cropping areas.

In potato plants about 90% of the total root length in the soil concentrated within the surface soil to a depth of 30 cm⁸⁾. Therefore, it was considered that root DW values obtained in the present study are almost consistent with those in the soil. However, the roots penetrating into the soil below 30 cm in depth were also found at the sampling times. Kawata et al.¹¹⁾ clarified that rice grain yield until 6 t/ha increased linearly with the increase of root DW within the soil of 0–5 cm in depth. At the higher yield levels, however, the relation became unclear. They suggested that the roots penetrating into deeper soil might become important for the higher yield. Asfary et al.²⁾ also suggested in reference to potato plants that the few roots below 30 cm were very active in absorbing water and nitrate. In addition, in a root pruning experiment⁹⁾ the reduction of root DW up to 40% within the soil of 0–30 cm in depth resulted in a tuber yield reduction of 40% in early variety, while 16% in late variety. Therefore, the effect of the roots penetrating into deeper soil may become apparent in the plants with longer growing

period.

From the present study, it was concluded that the difference in root growth among years and cropping seasons would be one of the main factors affecting dry matter production during the tuber bulking period and the tuber yield. More attention must be focused on the development of methods for manipulating root growth especially in AC by means of breeding or cultivation techniques.

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* In Japanese with English summary.

** In Japanese without English summary.