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Relations between Root System and Tuber Yield in the Hybrid Population of the Potato Plants*

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Detailed and numerous studies on the aerial parts of potato plants have been made to clarify their productivity. Until recently, however, there had been little information on the root system which is the main organ controlling plant growth. For several years, though, various investigations concerning the root system have been reported by several authors, such as LESCZYNSKI and TANNER[8], SWIEZYNSKI *et al.*[11], and JOYCE and GRAY[7]. But the role of the root system in growth has remained far from clear.

In 1975, therefore, we started systematic investigation of root growth and morphology, and several results have been obtained[4,5] : (i) varietal differences of the root system are related to the time of maturity, i.e. early varieties have smaller root dry weight (DW) compared with late ones; (ii) the relationship of the time of maturity with root DW appears at the earlier stage of plant growth than for those with leaf DW and stem DW; (iii) differences of the root system between locations have also been found and show some influence on the increase and maintenance of leaf area. These results suggest that procedures for increasing root DW, whether by means of breeding or cultivation, will result in higher tuber yield accompanying a longer growing period.

The purpose of this report is to clarify whether the relations of root DW with the time of maturity and tuber yield mentioned above are true in the genetically more divergent population derived from the crosses between cultivars and breeding materials, and whether we could get higher yielding clones through a selection of larger root DW.

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Materials and Methods

268 unselected clones derived from six crosses between two cultivars and three selected breeding materials were grown under field conditions in Shimamatsu (Eniwa city in Hokkaido). Each clone, represented by six plants, was planted on May 10 in 1979 at a distance of 75 cm between the rows and 39 cm within the row. A combination of fertilizer at the rate of 420 kg/ha of 12–18–12 (N, P_2O_5, K_2O) was banded just before planting.

In late July, which is almost the maximum stage of top dry weight (the top max. stage), measurements were made from one plant per individual clone. Aerial parts were cut off at the ground surface and separated into leaf and stem after a recording of their morphological characters. Dry weight was measured after ovendrying at 80°C for 48 hrs. Underground parts of the plant were excavated over an area of 75 cm × 39 cm to 30 cm in depth. After soaking in the water during one night, these were washed to remove the soil and other plant residue by means of a self-devised root washing apparatus. Thereafter, the roots and underground stems were stored at 4°C until measurement. The tubers were ovendried for their dry weight measurement. In middle August, the maximum root diameter and the number of adventitious roots at a distance of 5 cm from the underground

stem nodes were measured, as well as the number of stems. The roots and underground stems were then separated and the dry weight was recorded. After leaf yellowing, the dry tuber yield and starch value were measured from three plants per clone.

The calculations of the obtained data were made by using a SPSS and BMDP at Hokkaido University Computing Center.

Results and Discussion

1. *The relations between the characters in the pooled population*

A wide range of phenotypic differences among the clones was observed within the pooled hybrid population, as shown in Table 1. Leaf DW and root DW ranged from 1.85 g/pl. to 50.01 g/pl. and from 0.09 g/pl. to 5.68 g/pl., respectively. The coefficient of variation (C.V.) was 37.1% in leaf DW and 47.5% in root DW. Morphologically, the number of branches showed an extremely wide range of variation, from 0 to 13 per plant. The C.V.s of the number of branches, number of stems and number of roots were higher than those of stem length, stem diameter and root diameter. The growing period (days from sprouting to leaf yellowing) was 68 days in the earliest clone and 145 days in the last clone. Yield (dry tuber yield) also showed a large variation, from 106.1 g/pl. to 413.8 g/pl..

When we considered the relationships between these characters, we found that root DW correlated highly with stem DW ($r=0.80^{***}$) and leaf DW ($r=0.68^{***}$). It also showed significant correlations with root diameter ($r=0.56^{***}$), stem length ($r=0.53^{***}$), growing period ($r=0.49^{***}$) and yield ($r=0.48^{***}$). However, the coefficient between root DW and the number of roots was low ($r=0.34^{***}$) and a significant correlation between root DW and tuber DW at the top max. stage ($r=0.05$) was not found.

The relations between the characters measured are summarized in Fig. 1, using clustering of the characters with the average distance method of coefficients. These clusters indicate that root DW correlates most closely with stem DW and leaf DW. The morphological characters which relate positively with them are root diameter, stem length and number of branches. Whereas, the number of roots correlates with the number of stems and tuber DW at the top max. stage. While clones with larger root DW, stem DW and leaf DW tend to have

Table 1. Minimum, maximum and mean values, standard deviation (SD) and coefficient of variation (C.V.) in the characters measured.

Variable	Minimum	Maximum	Mean	SD	C.V.
Top max. stage[1]					
Leaf DW (g/pl.)	1.85	50.01	21.24	7.86	37.2
Stem DW (g/pl.)	2.24	54.77	21.22	10.31	48.6
Root DW (g/pl.)	0.09	5.68	1.83	0.87	47.5
Tuber DW (g/pl.)	16.28	257.44	96.48	37.22	38.6
Stem length (cm)	21.0	74.0	52.1	9.5	18.2
Stem diameter (mm)	8.0	20.0	12.6	2.2	17.5
Number of stems (/pl.)	1.0	14.0	3.9	1.8	46.2
Number of branches (/pl.)	0	13.0	1.8	2.4	133.3
Root diameter (mm)	0.4	2.4	1.2	0.3	25.0
Number of roots (/pl.)	16.0	169.0	78.2	30.7	39.3
Harvesting stage					
Growing period (days)[2]	68.0	145.0	97.7	17.2	17.6
Starch value (%)	10.4	25.0	20.0	2.0	10.0
Dry tuber yield (g/pl.)	106.1	413.8	229.1	53.2	23.2

Note. 1) The maximum stage of top dry weight.
2) Days from sprouting to leaf yellowing.

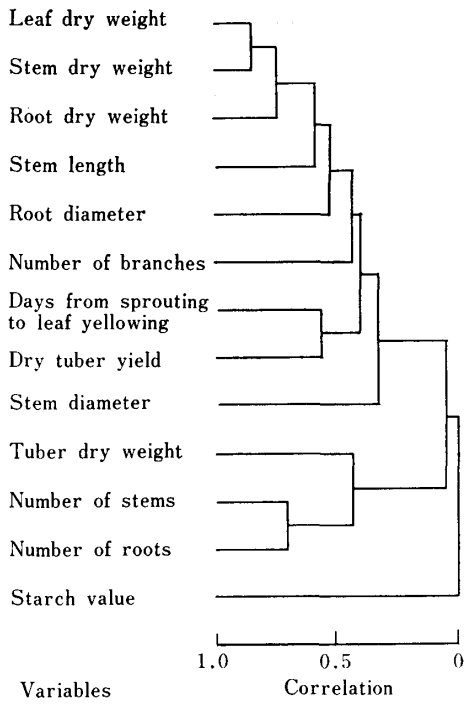

Fig. 1. Classification of characters measured in late July, when top dry weight attained almost maximum value, and at harvesting stage.

higher yields and a longer growing period.

2. *Comparisons of the character of the different maturity groups*

Since there could be no replication of the clones, random variation might be considered in those characters measured. In order to see the relations between the characters more strictly, the clones were grouped at 10 day intervals into the six maturity groups, i. e. EE (min.–80 days), E (81–90 days), ME (91–100 days), ML (101–110 days), L (111–120 days) and LL (121–max.). As shown in Table 2, mean root DW and mean yield in the group became larger in the later maturity group than in the earlier maturity group. Simple correlation coefficients between mean root DW and mean growing period, and between mean yield and mean growing period were very high, 0.99*** and 0.97**, respectively (Table 3). Although mean leaf DW also became larger in the later group, the differences of mean leaf DW among the maturity groups were smaller than those of root DW. Hence, the mean ratio of root DW to leaf DW was higher in the later group. On the other hand, mean tuber DW at the top max. stage was the largest in the E group and the smallest in the LL group. Correlations of mean tuber DW at the top max. stage to mean root DW, mean growing period and mean yield were significantly negative, −0.91*, −0.92** and

Table 2. Mean and SD of some characters in each maturity group.

Range of growing period		Min.-80	81-90	91-100	101-110	111-120	121-Max.
Maturity group		EE	E	ME	ML	L	LL
Number of clones		24	99	41	45	31	28
Growing period	Mean	76.5	84.9	94.8	105.8	114.6	133.7
(days)	SD	3.5	2.7	2.6	3.1	2.8	7.7
Dry tuber yield	Mean	175.2	209.5	226.4	248.0	262.9	280.7
(g/pl.)	SD	27.9	37.2	44.0	52.0	49.4	60.1
Root DW	Mean	1.30	1.57	1.77	1.93	2.15	2.77
(g/pl.)	SD	0.70	0.69	0.74	0.71	0.78	1.18
Leaf DW	Mean	17.23	21.18	20.78	21.84	22.91	22.76
(g/pl.)	SD	8.43	7.77	7.25	7.09	8.99	7.79
Root DW/Leaf DW	Mean	7.8	7.5	9.9	9.1	9.9	12.5
(×100)	SD	2.9	2.6	9.2	2.8	3.7	4.5
Tuber DW at the top	Mean	103.5	108.5	102.6	95.2	73.4	66.9
max. stage (g/pl.)	SD	34.1	38.1	32.3	39.8	21.1	25.9
Tuber growth rate[1)]	Mean	3.06	3.15	2.97	2.85	3.02	2.63
(g/pl./day)	SD	1.72	1.34	1.09	0.88	0.98	0.70

Note. 1) Tuber growth rate during the period from the top max. stage to leaf yellowing.

Table 3. Simple correlation coefficients between the characters in different maturity groups.

variable	Yield[1)]	Root DW	Leaf DW	Root/Leaf	Tuber DW	Tuber GR[2)]
Growing period	0.97**	0.99***	0.82*	0.92**	-0.92**	-0.83*
Yield[1)]		0.95**	0.92**	0.84*	-0.85*	-0.73
Root DW			0.80	0.94**	-0.91*	-0.85*
Leaf DW				0.62	-0.66	-0.47
Root/Leaf					-0.84*	-0.88*
Tuber DW						0.70

Note. 1) Dry tuber yield.
2) Tuber growth rate during the period from the top max. stage to leaf yellowing.
*, ** and *** are significant at 5, 1 and 0.1% level, respectively.

Table 4. Simple correlation coefficients between the characters within each maturity group.

Variables	Maturity group					
	EE	E	ME	ML	L	LL
Root DW vs Leaf DW	0.84***	0.78***	0.66***	0.71***	0.68***	0.64***
Root DW vs Tuber DW	0.60**	0.31**	0.21	0.32*	0.18	0.09
Leaf DW vs Tuber DW	0.56**	0.51***	0.40**	0.62***	0.40*	0.52**
Root DW vs Yield	0.49*	0.37***	0.39*	0.35*	-0.08	0.45*
Leaf DW vs Yield	0.50*	0.41***	0.41**	0.43**	-0.03	0.29
Tuber DW vs Yield	0.44*	0.34***	0.27	0.42**	-0.11	0.20

−0.85*, respectively. Mean tuber growth rate during the period from the top max. stage to leaf yellowing differed slightly among the maturity groups, showing negative correlations with root DW and leaf DW.

We conclude from these results that the clones in the later maturity group tend to have larger root DW and a higher ratio of root DW to leaf DW than the clones in the earlier maturity group. The positive relation of root DW to yield among the different maturity clones would result from the connection of root DW to growing period. It will therefore be possible to say that the positive correlations between root DW, growing period and yield reported in our previous paper[4)] will be found also in the genetically divergent hybrid population.

Although there have been few reports of these aspects in the potato plants, Swiezynski et al.[11)] reported the positive correlation between the root/shoot ratio and the length of growing period (r=0.21) in 25 clones. In other crops, Monyo and Whittington[9)] indicated that early flowering varieties of wheat had a lower root weight and root/shoot ratio than late flowering ones. Blum et al.[1)] showed the difference of root volume between two sorghum maturity isogenic lines.

3. *Relations between characters within the maturity group*

A large variation within the maturity group was found in the characters, as shown in Table 2. The C.V. in each maturity group was near or more than 40% in root DW, more than 30% in leaf DW and near 20% in yield.

Some significant correlations between their characters were observed in Table 4. In the EE group, correlations between root DW, leaf DW, tuber DW at the top max. stage and yield were positively significant. Almost similar relations were observed in the E, ME and ML groups, although coefficients of root DW to leaf DW and to tuber DW at the top max. stage decreased. In the L and LL groups, however, the relations between the characters were different from those mentioned above. A significant correlation was found only in the relation between tuber DW and leaf DW in both groups and in the relation between root DW and yield in the LL group.

These results indicate that in the earlier

maturity groups the differences of yield between clones of the same maturity seem to be related to those of root DW and leaf DW. The clones with larger root DW and leaf DW tend to have higher yield. Whereas in the later maturity groups, although larger tuber DW at the top max. stage is correlated with larger leaf DW, the differences of yield between the clones seem to be rather independent on those of leaf DW and root DW.

There have been several reports indicating the varietal differences in the nutrient uptake efficiency of the root system (CACCO *et al.*[2], FRICK and BAUMAN[3], and SCHENK and BARBER[10]). We also found varietal differences in ER (dry matter production per unit root DW per day) among the late varieties in a previous experiment[6]. Therefore, the differences of yield between clones of the same maturity might be dependent on the differences of dry matter production per unit root DW and also per unit leaf DW in the later maturity groups.

We conclude, from Fig. 2, that selecting the clones with larger root DW should promise a higher tuber yield. In addition, the ratios of tuber yield to root DW and to leaf DW seem to be important in the later maturity clones.

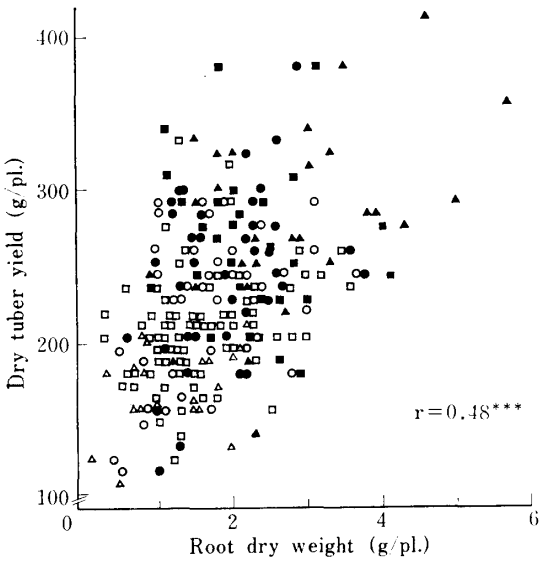

Fig. 2. Relationship between root dry weight and dry tuber yield.
Note. △ : EE, □ : E, ○ : ME, ● : ML, ■ : L, ▲ : LL.
Maturity groups were the same as those shown in Table 2.

Summary

268 unselected clones derived from crosses between cultivars and breeding materials were grown under field conditions and the relationship between the root system and tuber yield was investigated. The results obtained are summarized as follows:

1. In the pooled hybrid population, root dry weight (DW) and dry tuber yield (yield) ranged from 0.09 g/pl. to 5.68 g/pl. and from 106.1 g/pl. to 413.8 g/pl., respectively. Root DW had the highest correlation with stem DW (r=0.80***) and leaf DW (r=0.68***). The morphological characters which related positively with these DW were root diameter, stem length and number of branches, whereas the number of roots correlated with the number of stems and tuber DW at the maximum stage of top DW. Clones with larger root DW, stem DW and leaf DW tended to have longer growing period and higher yields.

2. When the clones were classified into the six maturity groups, simple correlation coefficients of mean growing period to root DW and to yield were very high, 0.99*** and 0.97**, respectively. The positive relation of root DW to yield among the different maturity clones appeared to result from the connection of root DW to growing period.

3. The differences of yield among the clones of the same maturity seemed to be related to those of root DW and leaf DW in the earlier maturity groups. However, in the later maturity groups the ratios of tuber yield to root DW and to leaf DW might be important.

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* In Japanese with English summary.

〔和 文 摘 要〕

バレイショ交配分離集団における根系と塊茎収量との関係

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バレイショ交配分離集団（268 系統）における根系と塊茎収量との関係を明らかにするため，地上部最大期（7月下旬）に部位別乾物重（葉，茎＋ストロン，根および塊茎）ならびに形態的形質を，また収穫期には塊茎乾物収量とでんぷん価を調査した．

1．各調査形質において分離集団内に大きな表現型変異が認められた（第 1 表）．形質間の関係をみると（第1図），根乾物重（根重）は葉重および茎重と，$r=0.68^{***}$ および $r=0.80^{***}$ の高い正の相関関係を示し，根，葉および茎の大きさは相互に密接な関係を示すことが明らかとなった．形態的形質のうち，根茎，茎長，分枝数はこれら部位別乾物重と正の相関関係を示し，一方根数は茎数および地上部最大期塊茎乾物重と密接に関係していた．また，葉，茎および根重の大きな系統では塊茎収量が高く，生育日数の長いことが認められた．

2．分離集団を6つの熟性群に分類し，形質間の相関関係を検討した（第2表）．平均根重と平均生育日数および平均塊茎収量との間に，それぞれ $r=0.99^{***}$ および $r=0.95^{**}$ の非常に高い正の相関関係が認められた（第3表）．晩生群の系統は早生群の系統に比較し，根重が大きく，葉重に対する根重の割合が高く，そして塊茎収量が大となることが明らかとなった．

3．同一熟性群内における形質間の関係をみると（第4表），熟期の等しい系統間に認められる塊茎収量の差異は，早生群では根重および葉重の差異と関係していた．しかし，晩生群では塊茎収量と根重および葉重との間に有意な相関関係が認められず，塊茎収量の差異は単位根重ならびに単位葉重当たりの乾物生産量の差異に起因するものと推察された．