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Comparison of Root Characters among Cultivated Potatoes (*Solanum tuberosum*) and Their Wild Relatives

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Abstract : In order to obtain basic information regarding improvement of potato root characters through breeding using its wild relatives, morphology, respiration activity, dry weight (DW), length and surface area of the roots of 12 potato cultivars and lines and 8 wild relatives (Table 1) were investigated during the flowering stage under field conditions.

The roots of the wild potato species were thinner but their dry matter percentages were higher than those of the cultivars and lines (Table 2). From observation of root monoliths (Fig. 1), it appeared that the number, diameter and length of the lateral roots differed among the materials (species) used. The cultivars exhibited relatively high root respiration rate compared to the wild species on the basis of either root DW or root length (Table 2). Some wild species had a considerably larger root DW, root length and root surface area, and higher ratio of root DW to leaf DW than the cultivars and lines (Table 2 and 3).

From the results it can be seen that some wild species have good potential to be used as parents in the breeding for the improvement of root characters in potato.
Key words : Potato, Root DW, Root length, Root morphology, Root respiration rate, Root surface area, *Solanum tuberosum*, Wild relatives.

バレイショ栽培種と野生種の根の諸形質の比較：岩間和人・西部幸男*（三重大学教育学部・*北海道農業試験場）

要　旨：バレイショの野生種を利用して，栽培種の根の特性を育種的に改良するために，基本的情報として栽培品種および系統 12 種と野生種 8 種における根の形態，呼吸活性，乾物重，長さおよび表面積を開花期に圃場条件下で比較した．

野生種は栽培品種および系統に比べ，根の平均直径が細く，また根の乾物率が高い特性を示した．また，根のモノリスの観察から，分枝根の数と太さと長さに供試材料間で顕著な差異を認めた．根重当りおよび根長当りのいずれにおいても根の呼吸活性は，栽培品種のほうが野生種よりも高い値を示した．幾つかの野生種は，栽培品種および系統に比べ，根重，根長，根表面積および葉重に対する根重の割合において顕著に大きな値を示した．

本実験の結果から，野生種と栽培種との交配により，根の特性に関して大きな遺伝的変異を示す後代が得られるものと予想され，野生種は栽培種の根の特性の育種的改良に寄与することが示唆された．
キーワード：根重，根長，栽培種，根形態，根呼吸活性，根表面積，バレイショ，野生種．

The cultivated species of potato (*Solanum tuberosum*) originated from a small gene source in South America, therefore, its genetic variation is relatively narrow[3]. However, increasing the genetic diversity by crossing between wild species and cultivated species is being frequently performed especially in the improvement of disease resistance. Although the wild species may possess many superior morphological and physiological characters relating to their leaves and roots, information about these are rarely reported[4,5,12].

Based on observation of the annual and seasonal differences in the growth of potato cultivars[8], it has been found that differences in the root dry weight (DW) was closely related with the tuber bulking rate and tuber yield. The results also indicated that during the autumn cropping the short day length and the small amount of solar radiation tended to restrict root growth of potato. Therefore, it is in this situation that breeding to improve root DW could be proposed.

The purpose of this study is to compare the roots between the cultivated species and the wild species of potato to get basic information for the improvement of root characters by breeding. The morphology, respiration activity, DW, length and surface area of the roots of 12 potato cultivars and lines and 8 wild

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relatives were investigated during the flowering stage.

Materials and Methods

The experiment was done in the Hokkaido National Agricultural Experiment Station in 1986. The soil was volcanic ash sandy loam. The materials (species) used are listed in Table 1 and these were divided into three groups, namely ; the T group, which is commonly cultivated species in Japan ; the TW group, which is product of crosses between the cultivated and wild species and includes the new cultivars and lines ; the W group, which is composed of wild potato species. Although *S. phureja* and *S. ajanhuiri* are cultivated species in South America, these are included in the W group in this report.

The materials other than the W group were planted on May 1 to 6 at distance between plants of 75 cm × 36 cm (3.704 pls/m^2). There were at least 6 rows of 4.3 m length in each plot. The W group was planted on May 13 and 14 using 60 cm × 30 cm (5.556 pls/m^2) distance between plants within a plot of 2 m × 2 m. All materials were fertilized bandly in a row before planting with 120, 200, 140 kg/ha for N, P_2O_5, K_2O, respectively. The date of the initial flowering was recorded on July 10 for the T and TW groups, and on July 10 to 20 for the W group.

One hill per material was sampled at two different locations during the period from July 30 to August 8. After cutting off the shoots, each hill was dug to a depth of 30 cm to obtain root samples. Immediately after digging, the roots were washed with running water to remove soils and other plant residues. Then, the roots were cut off at the portion of 2 cm from the underground stem nodes. Four samples with 2—3 adventitious roots having lateral roots (about 1 g, fresh weight) were taken per hill for root respiration measurement. The root respiration rate per sample was measured following the method described in earlier report[8]. Each sample was sandwiched two times between paper towel softly by hand to determine fresh weight. After storing in a 5 : 5 : 90 mixture of formalin, acetic acid and alchohol to prevent degradation, the root length was measured using the method described by Tennant[13]. The DW was recorded after oven-drying for 48 hrs at 80°C. The roots other than the above measurements were

Table 1. Materials used in the experiment.

Materials	Maturity[1]	Related species
T group		
Danskakuimo[2]	E	*S. tuberosum*
Norin No. 1	L	*S. tuberosum*
Benimaru	L	*S. tuberosum*
TW group		
Hatsufubuki	E	*S. tuberosum*, *S. chacoense*, *S. phureja*, *S. demissum*
Konafubuki	L	*S. tuberosum*, *S. chacoense*, *S. phureja*, *S. demissum*
Hokkai No. 69	L	*S. tuberosum*, *S. chacoense*, *S. demissum*
Shimakei No. 539	L	*S. tuberosum*, *S. chacoense*, *S. demissum*, *S. andigena*
R 392-25	E	*S. tuberosum*, *S. demissum*, *S. andigena*
R 392-50	E	*S. tuberosum*, *S. demissum*, *S. andigena*
WB 65051-16	L	*S. tuberosum*, *S. chacoense*, *S. phureja*
WB 66201-10	L	*S. tuberosum*, *S. chacoense*, *S. phureja*, *S. demissum*
S 822229-1	L	Diploid of *S. tuberosum*, *S. phureja*
W group		
S. phureja	L	
S. microdontum	L	
S. vernei	L	
S. commersonii	L	
S. stoloniferum	L	
S. ajanhuiri	L	
S. chacoense	L	
S. spegazinii	L	

1) E : Early maturity, L : Late maturity.
2) English name ; Irish Cobbler.

soaked in water for one night, washed with a root washing apparatus, oven-dried and weighed. The leaf DW, the stem (plus stolon) DW and the tuber DW were also recorded.

For data analysis, mean root diameter was estimated from the equation[6];

$$D = 20/\sqrt{\pi \times p \times d \times sRL},$$

where D is mean root diamether (cm); d is root dry matter percentage; sRL is root length per unit root DW (cm/g); and p is root gravity (g/cm^3) having a constant value of 1.03[6]. The root length and root respiration rate per unit soil area were calculated by multiplying root DW per unit soil area with sRL and root respiration rate per unit root DW, respectively. The root surface area per unit soil area was calculated from the mean root diameter and root length per unit soil area.

On August 15 and 16, the soil monoliths (5 cm in thickness, 30 cm in length, and 30 cm in depth) for the materials were excavated, washed to remove soil and plant residues by water as carefully as possible so as not to disturb the root profile, and photographed.

Results

The root characteristics of the materials are shown in Table 2. The W group showed significantly higher root dry matter percentage

Table 2. Comparisons of mean root diameter (D), root dry matter percentage (DW%), root respiration rate per unit root DW (URR), root respiration rate per unit root length (ULRR), and root DW (RDW), root length (RL), root surface area (RA) and root respiration rate (TRR) per unit soil area.

Materials	D (mm)	DW%	URR (mgO_2/g)	ULRR (μgO_2/m)	RDW (g/m^2)	RL (m/m^2)	RA (m^2/m^2)	TRR (mgO_2/m^2)
T group								
Danshakuimo	0.392	7.0	0.96	8.35	9.79	1,118	1.38	9.35
Norin No.1	0.387	7.7	0.90	8.44	16.10	1,690	2.06	14.32
Benimaru	0.371	6.7	1.12	8.32	12.37	1,673	1.94	13.86
Mean	0.383	7.1	0.99	8.37	12.75	1,494	1.79	12.51
TW group								
Hatsufubuki	0.376	6.6	0.97	7.37	7.85	1,017	1.21	7.56
Konafubuki	0.385	7.2	0.84	7.29	7.91	915	1.10	6.62
Hokkai No.61	0.397	6.1	0.94	7.32	11.21	1,400	1.75	10.33
Shimakei No.539	0.403	7.1	0.99	9.00	10.73	1,209	1.49	10.62
R 392-25	0.412	6.4	0.74	6.40	8.11	925	1.19	5.90
R 392-50	0.365	7.3	0.57	4.55	9.17	1,186	1.35	5.24
WB 65051-16	0.374	7.2	0.89	7.25	5.07	627	0.73	4.53
WB 66201-10	0.370	9.4	0.76	7.92	6.84	655	0.76	5.19
W 822229-1	0.384	9.1	0.66	7.08	14.55	1,347	1.63	9.54
Mean	0.385	7.4	0.82	7.13	9.05	1,031	1.25	7.28
W group								
S. phureja	0.296	11.8	0.72	6.06	40.88	4,855	4.52	29.29
S. microdontum	0.246	10.8	1.06	5.57	21.03	3,949	3.05	22.26
S. vernei	0.254	10.6	0.71	3.99	15.60	2,898	2.27	11.08
S. commersonii	0.329	8.6	0.92	6.88	15.08	2,030	2.10	13.87
S. stoloniferum	0.282	12.8	0.58	4.80	12.88	1,564	1.38	7.50
S. ajanhuiri	0.332	10.0	0.89	7.90	8.37	941	0.98	7.50
S. chacoense	0.296	9.6	0.86	5.84	4.79	711	0.66	4.11
S. spegazinii	0.387	7.4	1.12	9.89	3.37	383	0.46	3.84
Mean	0.303	10.2	0.86	6.37	15.25	2,166	1.93	12.43
Difference of group mean T : TW	NS	NS	**	*	**	**	**	*
T : W	**	**	*	**	NS	**	NS	NS
TW : W	**	**	NS	NS	**	**	**	**
Total mean	0.352	8.5	0.86	7.01	12.08	1,555	1.60	10.12
LSD (0.01)	0.087	1.8	0.30	2.85	6.92	818	0.69	6.40
CV (%)	20.4	32.5	26.6	30.9	94.6	103.1	82.2	88.8

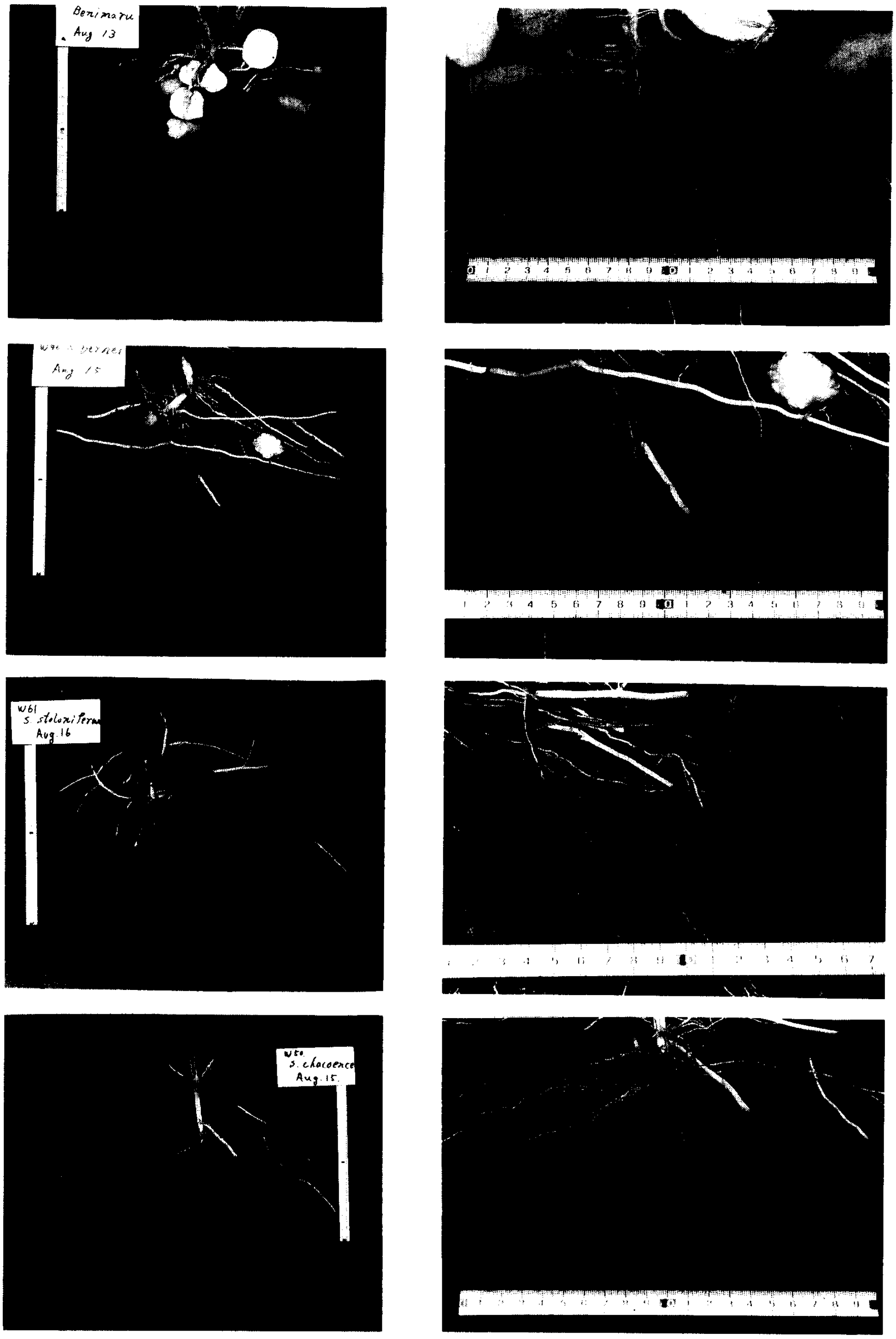

Fig. 1. The root profiles excavated by the monolith in some materials used in the present study. The figures from the top to the bottom are *S. tuberosum* (cv. Benimaru), *S. vernei*, *S. stoloniferum* and *S. chacoense*, respectively. The left figures are the total root profiles and the right figures are the parts of the left materials. A measure length within each figure is 20 cm.

Table 3. Comparisons of leaf DW, stem DW and tuber DW per unit soil area, and the ratios of stem DW to leaf DW and of root DW to leaf DW.

Materials	Leaf DW (g/m^2)	Stem DW (g/m^2)	Tuber DW (g/m^2)	Stem : Leaf (g/g)	Root : Leaf (g/g)
T group					
Danshakuimo	124.2	78.2	671.5	0.63	0.079
Norin No. 1	143.6	169.7	498.3	1.18	0.112
Benimaru	120.9	152.2	460.5	1.26	0.102
Mean	129.6	133.4	543.4	1.02	0.098
TW group					
Hatsufubuki	111.0	86.5	397.3	0.78	0.071
Konafubuki	82.6	95.4	475.1	1.17	0.104
Hokkai No. 61	99.0	92.7	513.8	0.94	0.112
Shimakei No. 539	91.3	91.8	304.1	1.01	0.118
R 392-25	66.2	35.1	351.0	0.53	0.122
R 392-50	91.3	56.7	498.7	0.62	0.100
WB 65051-16	65.6	62.2	225.7	0.95	0.077
WB 66201-10	67.5	78.1	186.4	1.16	0.101
W 822229-1	110.6	184.1	540.5	1.67	0.132
Mean	87.2	87.0	388.1	0.98	0.104
W group					
S. phureja	120.1	214.2	0	1.78	0.340
S. microdontum	113.2	205.7	0	1.88	0.207
S. vernei	147.7	187.5	0	1.27	0.106
S. commersonii	116.5	197.9	1.0	1.75	0.145
S. stoloniferum	65.4	148.2	6.5	2.27	0.198
S. ajanhuiri	73.9	75.8	11.5	1.03	0.113
S. chacoense	117.3	102.9	0	0.88	0.041
S. spegazinii	55.8	62.1	4.5	1.11	0.075
Mean	101.2	149.3	2.9	1.50	0.153
Difference of group mean T : TW	**	**	**	NS	NS
T : W	*	NS	**	**	*
TW : W	*	**	**	*	**
Total mean	99.2	118.9	257.3	1.19	0.123
LSD (0.01)	60.5	69.3	189.5	0.32	0.110
CV (%)	39.0	68.0	130.8	54.9	74.0

and smaller mean root diameter than the T and TW groups. This indicates that the roots of the wild species tended to be thin and fiberlike compared with those of the cultivars and the lines. From the root monolith observations (Fig. 1), it appeared that the lateral roots differed among the materials. *S. vernei* and *S. stoloniferum* had a lot of thin laterals, while *S. chacoense* had less laterals. The cultivars had relatively thicker laterals. Comparing the root activity among the materials, the T group showed a significantly larger root respiration rate per unit root DW than the TW and W groups. The difference was more apparently shown in the root respiration rate per unit root length because of the thinner roots in the W group compared with the T group.

Comparing the root DW among the materials, the variation in root DW within the W group was very large. Two wild species, *S. phureja* and *S. microdontum*, showed significantly larger root DW than the cultivars and lines in the T and TW groups. On the other hand, *S. chacoense* and *S. spegazinii* showed extremely smaller root DW than the cultivars and lines. Since the roots were thinner and the root length per unit root DW was longer in the wild species compared with the cultivars and lines, the differences in the root length between the wild species and the cultivars and lines were larger than those in the root DW. Four wild species, *S. phureja, S. microdontum, S. vernei* and *S. commersonil* showed significantly longer root length than the cultivars and lines. A similar tendency in the difference among the materials was also found in the root surface area and the root respiration rate per unit soil area. The root surface area was related very closely with the root DW (r=0.973**). In addition, it may be noted that, comparing the CV value of each character, variation among the materials was much larger in the characters relating to the root mass than those of the root morphology and the root respiration activity per unit root mass.

The DWs of the leaf, stem and tuber are shown in Table 3. The leaf DW was significantly greater for T group than for the TW and W groups, indicating that the cultivars of the T group possessed larger leaf DW compared with the cultivars and lines of the TW group and the wild species. This is in line with the results reported by others[4,5,12]. On the other hand, the stem DW of the W group did not show significant difference with that of the T group. As a result, the ratio of the stem DW to leaf DW (stem : leaf ratio) was significantly greater in the W group than in the T group. Meanwhile, the stem DW of the TW group tended to be smaller than those of the T and W groups. This resulted in an almost similar stem : leaf ratio between the TW and T groups. The tuber DW was apparently larger in the cultivars and lines of the T and TW groups than in the species of the W group.

Considering the relationship between the root DW and the leaf DW and stem DW among the materials, the root DW showed a relatively close relationship with the stem DW (r=0.761**), but not with the leaf DW (r=0.477*). As a result, as shown in Table 3, the ratio of the root DW to the leaf DW (root : leaf ratio) showed a large variation among the materials. Since the root DW varied more among the materials than the leaf DW, the root : leaf ratio was affected mainly by the root DW. The wild species with a larger root DW showed a higher root : leaf ratio. The root : leaf ratio of *S. phureja* and *S. microdontum* were more than two times compared with those of the cultivars and lines.

Discussion

Upon comparing leaf photosynthetic rate per unit leaf area (P) in wheat, Khan and Tsunoda[10] reported that P was higher in the wild species than in the cultivated species. Our primary experiment[7] observing the root respiration rate per unit root DW (URR) indicated that the progenies of *S. vernei* × *S. tuberosum* expressed higher URR than those of *S. tuberosum* × *S. tuberosum*. From these results, we expected in the present study to find some wild species with higher root activities per unit root mass than the cultivars. The present results, however, indicated that the variation of the root respiration rate both on root DW basis and on root length basis were relatively small among the examined materials. The cultivars of the T group exhibited relatively higher values than the wild species for these characters. Therefore, the improvement of root activity per unit root mass may be hopeless, at least using the present materials.

The wild species examined, however, had relatively high root dry matter percentages and also tended to possess thinner and numerous laterals than the cultivars and lines. In addition, some of the wild species showed considerably larger root DW, longer root length and higher root : leaf ratio than the cultivars and lines. These characteristics may be beneficial when the roots extend at unsuitable soils for water and nutrients. Khan and Tsunoda[11] have suggested that the higher ratio of root DW to leaf DW in the wild wheat compared with the cultivated wheat may be a result of adaptation to a restricted moisture supply in the soil where these wild plants are growing. We consider that the introduction of the above mentioned root character of the wild species to the cultivars may improve the ability of the cultivars to tolerate shortage conditions of water and nutrients. In addition, although a plant ideotype in view of the nutrient and water absorption is not exactly identified presently, the progenies from the crosses between these typical wild species for the root characters and the cultivars may produce good materials for consideration because the progenies will show a large variation in root characters.

Ekanayake et al.[1] reported that, in rice, the narrow sense heritability for root DW was high, 0.92. Gavelman et al.[2] succeeded in the transfer of a larger root DW characteristic in a bean breeding line to an adapted cultivar. In comparing the root DW among hybrid populations derived from different crosses in potato[9], we also found that a hybrid population from a cross with a larger root DW parent had a wider range of variation and a significantly larger value in the root DW than those from crosses with smaller root DW parents. Therefore, we hypothesize that some of the present wild species (e.g. *S. phureja* and *S. microdontum*) are very promising as crossing materials used to introduce larger root DW and higher root : leaf ratio to the cultivars.

It is very interesting that both the largest wild species, *S. phureja*, and the smallest wild species, *S. chacoense*, for the root DW, root length and root : leaf ratio among the present materials are being frequently used as breeding materials at the present station. *S. chacoense* has a relatively small stem DW and the lowest stem : leaf ratio among the wild species. Its characteristics are in line with those of the cultivars and lines recently bred in the TW group. With a view to introduce large root character to the cultivars, however, use of *S. chacoense* as parent material may not be beneficial because of its considerably small root DW.

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References

1. Ekanayake, I.J., J.C.O Toole, D.P. Garrity and T. M. Masajo 1985. Inheritance of root characters and their relations to drought resistance in rice. Crop Sci. 25 : 927—933.
2. Gabelman, W.H., G.C. Gerloff, T. Schettini and R. Coltman 1986. Genetic variability in root systems associated with nutrient acquistion and use. Hortic. Sci. 21 : 971—973.
3. Hawkes, J.G. 1979. Genetic poverty of the potato in Europe. Proc. Conf. Broadening Genetic Base of Crops. Wageningen, 1978. Pudoc, Wageningen. 19—27.
4. Inoue, H. and A. Tanaka 1978. Comparison of source and sink potentials between wild and cultivated potatoes. Japan. J. Soil Sci. Plant Nutr. 49 : 321—327.*
5. Isoda, A., K. Nakaseko and K. Gotoh 1982. Dry matter production and some morphological characters of *S. demissum* backcrossed with *S. tuberosum*. Mem. Fac. Agric. Hokkaido Univ. 13 : 330—335.*
6. Iwama, K. 1985. Method for estimating root surface area and root diameter. Rep. Tokai Br. Crop Sci. Soc. Japan 99 : 79—81.**
7. ——— 1985. Genetical variation of root respiration rate among cross seedlings in potato plants. Rep. Tokai Br. Crop Sci. Soc. Japan 100 : 15—19.**
8. ——— 1988. Difference in root growth of potato plants among years and cropping seasons. Japan. J. Crop Sci. 57 : 346—354.
9. ———, K. Nakaseko, A. Isoda, K. Gotoh and S. Nishibe 1981. Comparison of root systems among hybrid populations derived from different crosses in potato (*Solanum tuberosum*). Japan. J. Crop Sci. 50 : 365—372.
10. Khan, M.A. and S. Tsunoda 1970. Evolutionary trends in leaf photosynthesis and related leaf characters among cultivated wheat species and its wild relatives. Japan. J. Breed. 20 : 133—140.
11. ——— and ——— 1970. Growth analysis of cultivated wheat species and their wild relatives with special reference to dry matter distribution among different plant organs and to leaf area expansion. Tohoku J. Agric. Res. 21 : 47—59.
12. Ogata, S. and Y. Ishizuka 1967. Variation of nutrio-physiological characters of crops in the process of their crossing. I. Response of cultivated, wild and their hybrid potatoes to nitrogen nutritional condition. J. Soil Sci. Plant Nutr. Japan 38 : 79—84.*
13. Tennant, D. 1975. A test of a modified line intersect method of estimating root length. J. Ecol. 63 : 995—1001.

* In Japanese with English summary.
** In Japanese without English summary.