Jpn. J. Crop Sci. 64(1) : 86—92 (1995)

Effects of Scion and Stock on Root Growth of Grafting Plants between Two Potato Varieties with Different Root Mass*

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Received April 30, 1994

Abstract : The relationships of root growth with shoot and tuber growths have still not been clear in potato plants. The aim of this report is to clarify whether a varietal difference in root growth of potato plants is determined by some inherent characteristics in the root organ per se, or affected by the growth of other organs. Four combinations of grafting plants between two late varieties, Norin 1 and Konafubuki, with different root mass were produced and cultured in large pots (25 cm in diameter, 50 cm in depth) with plentiful water supply. Dry weight (DW) of each organ and leaf area were measured at three stages, just after the transplanting, approximately after the initial flowering and after the last flowering, for three years. Analyses of variance for the characters were performed using the years as replications. The stock genotypes significantly influenced root DW of the grafting plants at the three stages examined. The effects of scion genotypes on root DW were not significant. The negative relationship was found between root DW and tuber DW in the grafting plants. Shoot DW and leaf area were not significantly different among the grafting plants. We concluded that the difference in root DW between the two varieties was mainly due to the inherent characteristic in the dry matter partition to roots and tubers just after the tuber initiation.
Key words : Dry matter partition, *Solanum tuberosum* L.

根量の異なるバレイショ品種間の接木個体における根の生長に及ぼす穂木と台木の影響：岩間和人・高田治・大波正寿・中世古公男（北海道大学農学部）

要　旨：バレイショにおける根の生長の品種間差異が，根のみの遺伝的要因に起因するものか，また他の器官の生長に影響されて発現するものかを明らかにするため，同一熟性で根量の異なる2品種（コナフブキと農林1号）の地上部（穂木）と地下部（台木）を用いて，萌芽後約10-15日目に4種類の接木個体（同一品種間の接木個体と異品種間の接木個体）を作り，接木の活着後，根系調査用の特性ポット（直径25 cm，深さ50 cm）に移植し，充分な灌水条件下で栽培した．移植期，第一花房終花期，最終花房終花期の3時期に茎葉部（葉，茎およびストロン），塊茎および根の乾物重と葉面積を測定し，各器官の生長に及ぼす穂木と台木の影響を検討した．実験は3年間行ない，測定形質について年次を反復とした分散分析を行ない，接木個体間の差異を解析した．根重では，いずれの調査期でも接木個体間に有意な差異が認められ，農林1号を台木とした個体はコナフブキを台木にした個体に比べ著しく大きな値を示した．台木に比べ穂木の影響は小さかった．塊茎重においても接木個体間に大きな差異が認められたが，根重と塊茎重とはいずれの調査期でも負の相関関係を示した．一方，茎葉重と葉面積では接木個体間の差異が小さかった．以上のことから，供試した2品種間における根の生長の差異は，塊茎の肥大開始直後における，根と塊茎との間での乾物分配特性の品種間差異に主として起因するものと結論した．
キーワード：乾物分配特性，*Solanum tuberosum* L.

It has already been shown that there are significant differences in the amount of roots among potato varieties with different maturity classes ; i.e. late varieties have a larger root dry weight (DW) than early ones[1,5]. Positive correlations have also been found among root DW, shoot DW and tuber yield[5,10]. However, since most of the characteristics in potato plants positively relate to plant maturity[6], it is quite difficult to identify the definite contribution of roots to plant growth. The physiological relationship of root growth with shoot and tuber growth is yet to be solved.

In the previous study under the field condi-

* Supported by Grant-in-Aids for Scientific Research (No. 02304017, 04660011) from the Ministry of Education, Science and Culture, Japan. Part of this work was presented at the 191st meeting of the Crop Science Society of Japan held in April, 1991.

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tions, we found consistently over three planting densities a significant varietal difference in the root length of potato to a depth of 1 m[7]. Since the two varieties examined were the same maturity class, they were convenient for studying the contribution of roots to plant growth and tuber yield, independently of maturity classes. The result indicated the importance of longer root length to maintain larger leaf area and tuber growth rate at the late growing stage.

The aim of the present study is to clarify whether the difference in root growth between the two varieties is determined by an inherent characteristic of roots per se or affected by the growth of other organs. For that purpose, we made the grafting plants of four combinations between the two varieties (self-grafting of each variety, reciprocal graftings between varieties), cultured in large pots with a plentiful water supply, and investigated the effects of the scion and stock genotypes on the growth of shoot, tuber and root.

Materials and Methods

The experiment was conducted in a greenhouse at the Faculty of Agriculture, Hokkaido University (Sapporo, 42 °N latitude) in 1990, 1991 and 1992, with two late varieties of potato (*Solanum tuberosum* L.), Norin 1 and Konafubuki. Seed tubers were planted on 26 April in 1990 and 1991, and on 11 May in 1992, in small pots (20 cm in diameter, 20 cm in depth) filled with a brown lowland soil in 1990 and a volcanic ash sandy loam soil in 1991 and 1992. Compound fertilizers (7.2 g/pot, N ; 7.0%, P_2O_5 ; 11.5%, K_2O ; 9.0%, MgO ; 3.0%) and calcium superphosphate (only in 1992, 4.1 g/pot, P_2O_5 ; 17.5%) were incorporated into the soils.

At 10 to 15 days after sprouting, the scion was cut at the height of about 5 cm, shaped to a wedge, fixed into a slit of the stock, and bound with cellophane tape. The grafts were kept in a moist atmosphere for one week, then thinned to one stem per pot and moved to the greenhouse. The leaves of the stock were cut off and any axillary buds on the stock that grew were removed. In late June, successful grafts were transplanted into large pots (25 cm in diameter, 50 cm in depth). The top 30 cm of soils were the same as those used in the small pots and the bottom 20 cm of soils were normal sand. After transplanting, plentiful water to adjust the water table to the depth of 10 cm from the pot bottom was supplied from the bottom of each pot every evening.

Samplings of several plants per each graft combination were done at three stages ; just after the transplanting (stage 1 ; 4 plants in 1990, and 3 plants in 1991 and 1992), approximately after the initial flowering (stage 2 ; 3 plants in each year), and after the last flowering (stage 3 ; 3 plants in 1990 and 1991, and 2 plants in 1992). The date of the samplings was June 22, July 24 and August 20 in 1990, June 24, July 22 and August 16 in 1991, and June 25, July 15 and August 11 in 1992. At each stage, after measuring the leaf area with the automatic leaf area meter, the DWs of leaves, stems (including stolons) and tubers were recorded after oven drying for three days at 70°C. The root sampling was divided into two processes. After pulling up the plants the roots attached to underground stems and the easily collectable roots in the pot were first sampled and washed by running water on nylon cloth (about 0.2 mm of mesh size). The residual fine roots in the pots were estimated by sampling part of the well stirred soils (about 2% to total soils in weight), washing and collecting the roots. The roots were stored in a glass bottle filled with FAA solution (50% ethanol, acetic acid, formalin ; 18 : 1 : 1 parts by volume) at 5°C. After measuring the root length (only in 1991 and 1992, not shown in the present paper), root DW was recorded. The root DW collected from part of the soils was about 20% to the total root DW.

At the data analysis, we calculated the mean values among two to four plants of each grafting treatment in the characters at each stage or during each period. On the basis of these values we conducted the analysis of variance with randomized complete block design using the years as blocks.

Results

1. DWs of root, tuber and shoot

Table 1 shows the root DW, tuber DW and shoot DW at three stages. Plant growth was different among the three years, especially for the roots. It may have been due to the difference in the soil types, fertilizers and/or meteorological conditions among the three years. However, we don't discuss about the causes in

Table 1. The root DW, tuber DW and shoot DW of the self- and reciprocal-grafting plants of two varieties, Konafubuki (K) and Norin 1 (N), at three stages.

Character	Root DW (g pl.$^{-1}$)			Tuber DW (g pl.$^{-1}$)			Shoot DW (g pl.$^{-1}$)		
Stage[1)]	1	2	3	1	2	3	1	2	3
Year[2)]									
1990	0.41	4.94	4.41	1.5	19.0	48.3	1.4	23.8	25.1
1991	0.72	2.37	2.76	2.4	11.2	59.2	1.8	19.2	36.9
1992	0.84	2.12	2.26	1.4	13.1	63.1	2.3	22.7	31.6
p[4)]	**	**	**	NS	NS	*	*	NS	**
Grafting plants[3)]									
Scion Stock									
N N	0.74	4.42	4.36	0.2	7.1	37.0	2.0	24.9	30.6
K N	0.76	3.54	3.66	0.5	7.9	57.4	2.0	23.4	31.8
N K	0.52	2.39	2.32	3.3	19.3	61.3	1.7	18.4	28.2
K K	0.60	2.21	2.23	3.1	23.3	71.7	1.5	20.8	34.2
P	*	*	*	*	*	**	NS	NS	NS

1) Stage 1 ; after the transplanting, Stage 2 ; after the initial flowering, Stage 3 ; after the last flowering.

2) The mean values of four grafting plants. 3) The mean values of three years.

4) Probability of the differences : ** ; Significant at 1% level, * : Significant at 5% level, NS ; Nonsignificant.

this paper. We will consider the differences in the characteristics among the grafting plants based on the mean values of three years in the following results and discussion.

The plants with Norin 1 stock had significantly larger root DW than those with Konafubuki stock at stage 1. The effects of the stock genotypes on root DW became more apparent at stage 2. The effects of the scion genotypes on root DW were not significant at both stages. However, the plants with Norin 1 scion tended to have a larger root DW than those with Konafubuki scion in the plants of Norin 1 stock at stage 2. After that, the increase of root DW almost stopped in all grafting plants. The differences in root DW among the plants were seen continuously at stage 3.

The effects of both stock and scion on tuber DW were contrary to those on root DW. At stage 1, the plants with Konafubuki stock showed significantly larger tuber DW than those with Norin 1 stock. The effects of stock genotypes similar to those at the early stage were also seen at the two later stages. In addition, the effects of scion genotypes on tuber DW became apparent at stage 2 and stage 3. The tuber DW tended to be larger in the plants with Konafubuki scion than in those with Norin 1 scion, when compared with the same stock plants. Consequently a negative relationship between tuber DW and root DW was found among the plants at each stage.

The shoot DW was larger in the plants with Norin 1 stock at stage 1 and stage 2. These differences in shoot DW between the plants were, however, not significant and much smaller than those in root DW and tuber DW.

2. Leaf area, net assimilation rate and growth rate of total DW

Fig. 1 shows the mean leaf area (LA), net assimilation rate (NAR) and growth rate of total DW (Total GR) in the grafting plants during a different growing period. From sprouting to stage 1, LA tended to be larger in the plants with Norin 1 scion. The differences among the plants were, however, statistically not significant because of large interactions between years and grafting plants. The differences also disappeared during the period from stage 1 to stage 2, when the leaf area largely increased in all grafting plants. During the later two periods, all grafting plants showed similar LA. The results indicated that the two varieties had inherently similar characteristics of the stock and the scion for the leaf area production.

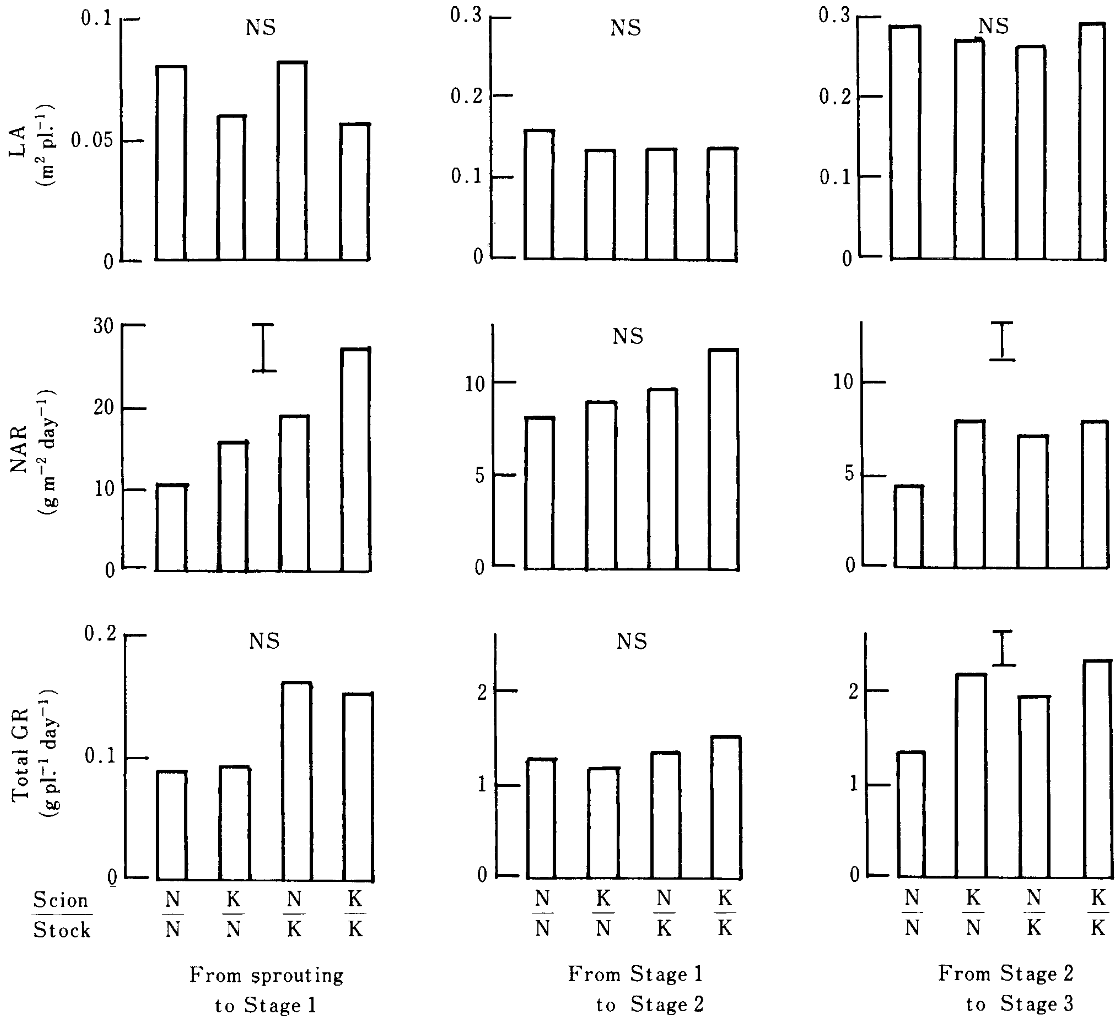

Fig. 1. The mean leaf area (LA), net assimilation rate (NAR) and growth rate of total DW (Total GR) of the self- and reciprocal-grafting plants of two varieties, Konafubuki (K) and Norin 1 (N), during each sampling period.

Note. The mean values of three years are shown.

The vertical bar in the figure shows the LSD at 5% level.

The NS indicates that the differences are not significant.

Stage 1 ; after the transplanting, Stage 2 ; after the initial flowering, Stage 3 ; after the last flowering.

On the other hand, there were large differences in NAR between the grafting plants. Before stage 1, NAR was higher in the plants with the scion or the stock of Konafubuki than in those of Norin 1. The similar trend in NAR was also shown from stage 1 to stage 2, though the differences in NAR became smaller and not significant. From stage 2 to stage 3, in the grafting plants with Norin 1 stock, the plant of Konafubuki scion showed a significantly higher NAR than that of Norin 1. In the grafting plants with Norin 1 scion, the plant of Konafubuki stock had also a significantly higher NAR than that of Norin 1 stock. Consequently, the self-grafting plant of Norin 1 showed much smaller NAR than the other plants.

Because of the differences in NAR among the plants, Total GR tended to be higher in the plants with Konafubuki stock than in those with Norin 1 stock before stage 1. Although the differences among the plants were small from stage 1 to stage 2, after that Total GR showed the significant differences among the plants in the same manner as NAR. These results suggested that the scion and the stock of Konafubuki had genetically higher potential for dry matter production than those of Norin 1.

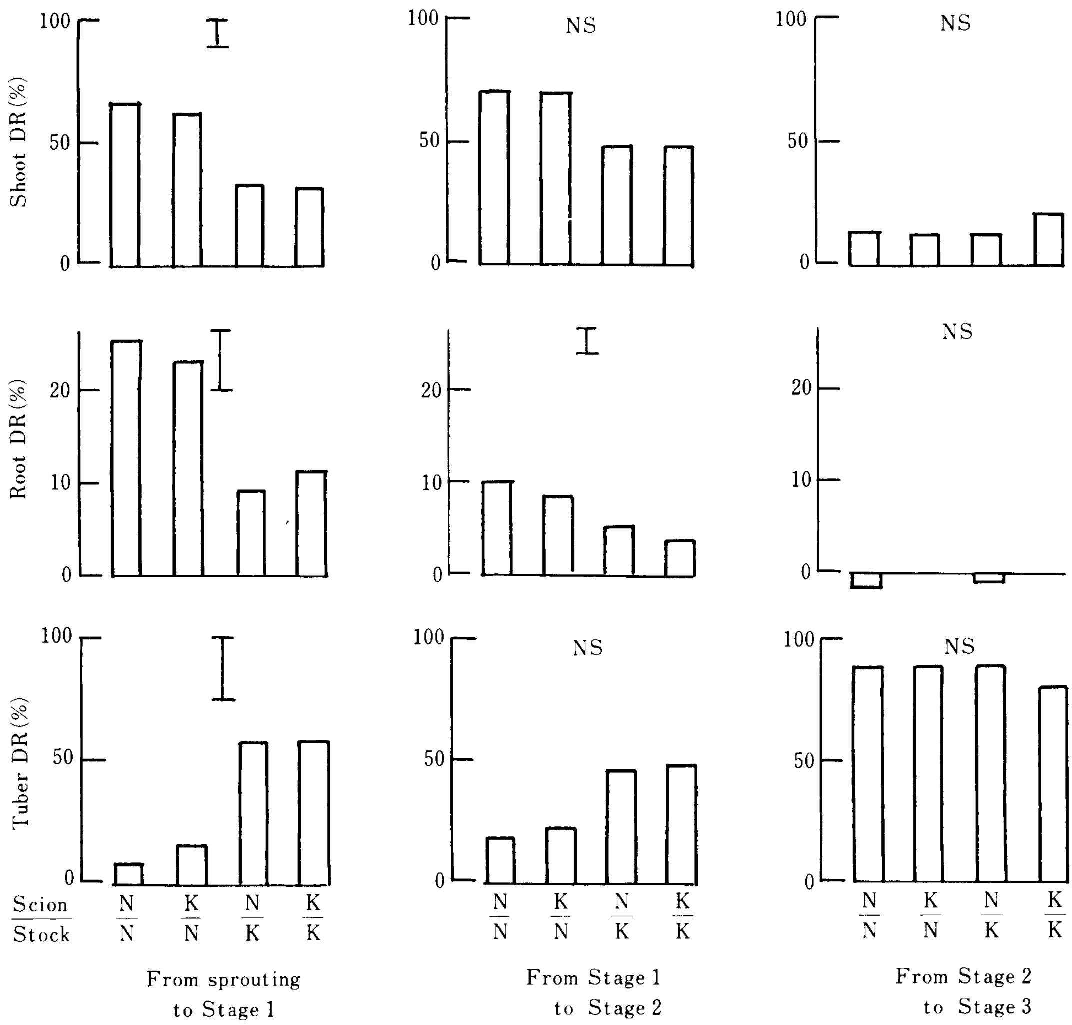

Fig. 2. The distribution ratios of the dry matter (DR) to the shoot, root and tuber of the self- and reciprocal-grafting plants of two varieties, Konafubuki (K) and Norin 1 (N), during each sampling period.
Note. The same as those shown in Fig. 1.

3. Dry matter partition

From sprouting to stage 1, the distribution ratio of the dry matter (DR) to each organ was significantly different between the grafting plants with different stock (Fig. 2). The plants with Konafubuki stock were much higher in tuber DR, while much lower in root DR than those with Norin 1 stock. The shoot DR was also significantly lower in the plants with Konafubuki stock, but the differences in shoot DR were relatively smaller than those in root DR and tuber DR. The effects of scion genotypes were not found in all DRs.

During the next period, the effects of stock genotypes on the DRs became much smaller. The differences between the plants were significant only in root DR. However, the effects of scion genotypes became apparent in root DR and tuber DR. The grafting plants with Konafubuki scion tended to have a higher tuber DR, while lower root DR than those with Norin 1 scion.

From stage 2 to stage 3, most of the dry matter was distributed to the tubers in all grafting plants. The root DR was almost zero. The differences in tuber DR and shoot DR between the plants were small.

Discussion

In the present study for three years, irrespective of the scion genotypes, the grafting plants with Norin 1 stock showed consistently larger root DW than those with Konafubuki stock at all stages examined. The larger root DW in the grafting plants with Norin 1 stock resulted from the higher root DR at the early stages of tuber bulking. In addition, both root DR and root DW had a negative relationship to tuber DR and tuber DW, respectively. These results indicated that the present two varieties had genetically different characteristics of the stock. In the stock of Norin 1, the transported photosynthetic products from the shoots tended to distribute more for root growth and less for tuber growth than in the stock of Konafubuki.

The negative relationship in growth between the underground organs was also reported in the grafting studies of other crops. In sweet potato[2,3] and beet[12], the grafting plants with the stock of larger storage roots had smaller fibrous roots. In addition, Siddique et al.[11] recently reported that new varieties of wheat had a smaller root DW, which contributed to the increase of grain yield. Therefore, it may be generalized that a genotypical difference in root DW results from an inherent characteristic of dry matter partition between roots and strage organs.

Trudgill and Thompson[13] reported that in the grafting plants between the early and the late varieties of potato the scion genotypes mainly influenced the growth of each organ, while the influence of stock genotypes was less. Their result does not agree not only with the present results but also with those in other grafting experiments of potato[4], beet[12] and sweet potato[3,4,9]. In these underground crops, the effects of stock genotypes on the growth of each organ were generally larger than those of scion genotypes.

It may, however, be noted that some influences of scion genotypes on the root growth were also shown in the present study. These differences in root DW also related to those in root DR, tuber DR and tuber DW. Although we are unable strictly to propose a reason for these relationships, Koda et al.[8] recently reported that some chemical substances, which were produced in the leaves, influenced the tuber growth of potato. These substances may relate to the effects of scion genotypes on dry matter partition to the roots and the tubers.

The present study showed that the scion and the stock of Konafubuki tended to be higher in NAR and Total GR than those of Norin 1. The results suggested that in the efficiency of leaves for the dry matter production Konafubuki was superior to Norin 1, which was due to inherent characteristics of both stock and scion. It was reported in the grafting experiments of potato[4], sweet potato[3] and beet[12] that a sink potential of stock for dry matter accumulation influenced NAR and Total GR. Since sink potential is undoubtedly larger in tubers than in roots, we consider that Konafubuki stock has a higher sink potential than Norin 1 stock at least at the early stage of tuber bulking, which results in higher NAR and Total GR of Konafubuki stock plants.

In respect to the relationship of root DW with NAR and Total GR, the differences in NAR and Total GR among the grafting plants had no relationship or rather negative relationship to those in root DW. The result was not consistent to the previous finding[7] under the field conditions with the present two varieties. It may, however, be noted that in the present study plentiful water was supplied daily and soil volume was also limited because of the pot experiment. We suppose that in these conditions a larger root mass may be unable to show its superiority in respect to water and nutrient absorption. Further studies with the present varieties should be conducted to evaluate whether a larger root mass is beneficial or not for dry matter production under a shortage of water.

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