The Effect of Brushing on the Growth and Quality of Field-grown Root Crops

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Abstract. Shoots of field-grown plants of European radish (*Raphanus sativus* L. 'Comet'), Japanese radish (daikon) (*R. sativus* L. 'Mino-wase'), and Asian turnip (*Brassica rapa* L. 'Hinona') were brushed twice daily, 40 cycles (back-and-forth strokes equal one cycle), for 8 (short-term) or 13, 21, or 14 days (long-term), respectively. European turnip (*B. rapa* L. 'Hikari-kabu') plants were grown in a raised bed in an uncovered plastic house and were brushed for 9 or 21 days. Short-term brushing reduced root dry weight and the root : shoot dry weight ratio (R : S) of European radish, whereas the treatment increased these measurements for Asian turnip and European turnip. Short-term brushing had no effect on growth of Japanese radish plants, but increased root dry weight gain by both turnip cultivars, thereby increasing their R : S ratios. Long-term brushing reduced root dry weight gain and the R : S ratio of European radish and root dry weight of Asian turnip but had no effect on these measurements for the other crops. Long-term brushing reduced cracking of European radish roots, thereby resulting in a higher proportion of oblong (medium quality) roots. Consequently, the percentage of marketable-quality roots of European radish was increased by brushing. Long-term brushing increased the percentage of medium-sized roots of Asian turnip at the expense of large-sized roots. Brushing had no effect on root quality of European turnip.

Summer production of cool-season root crops in western Japan is limited by high temperatures and irregular rainfall. Therefore, these crops usually are grown at higher altitudes (700 to 800 m above sea level) in the summer. Treatments enhancing root enlargement or plant tolerance to stress should improve root yield and quality. Mechanical stress, applied by rubbing stem tissue, increased drought tolerance of *Phaseolus vulgaris* (Jaffe and Biro, 1979; Suge, 1978), but brushing slightly decreased drought tolerance of lettuce, cauliflower, and celery seedlings (Biddington and Dearman, 1985). Naturally occurring mechanical stress is an important factor in plant growth under field conditions (Jaffe, 1980). Furthermore, mechanical stress applied to supplement am-

bient wind decreased growth of soybean and eggplant under outdoor conditions (Latimer et al., 1986).

Mechanical stress also affects the partitioning of assimilates within plants of several

species. Brushing increased the root : shoot dry weight ratio (R : S) in lettuce seedlings but decreased R : S in celery seedlings (Biddington and Dearman, 1985). Brushing increased the ratio of carrot storage root weight to shoot dry weight (Biddington and Dearman, 1987). However, fresh and dry weights of potato tubers were reduced by a shaking stress (Akers and Mitchell, 1985). In Japan, brushing sugar beet transplants increased the subsequent root yield (Takaki et al., 1978), provided that growth inhibition of the transplants in response to brushing is not severe (Takaki et al., 1977).

The following work tested the effect of brushing on the growth and quality of several root crop vegetables under field conditions. We examined European radish, which forms a globe-shaped storage organ; Japanese radish (daikon), which forms a long storage organ; European turnip, which has a globe-shaped storage organ; and Asian turnip, which has a long storage organ. Although the storage organs of these crops are composed of varying proportions of stem and root tissues (Ting and Wren, 1980), the term "storage root" will be used to refer to all storage organs.

The experiments were conducted during Summer 1989 at the facilities of the Faculty of Agriculture, Kagoshima Univ., Kagoshima City, Japan. The soil was a sandy loam typical of the Kagoshima area, originating from alluvial-deposit pyroclastic-flow. Raised beds, located in an unprotected field, were fertilized (per 1000 m²) with CaCO₃ (150 kg), Ca(H₂PO₄)CaSO₄ (50 kg), and a slow-release compound (15N-34P-18K) (100 kg). Beds were covered with a 0.03-mm aluminum-coated polyethylene mulch. A drip tube was installed down the center of the row under the plastic for irrigation. Ten-centimeter-diameter holes were cut in the plastic in a double, staggered-row (zig-zag) design, with 20 cm between holes in a row and 25 cm

Table 1. Seeding dates, treatment, and sampling times for four root crops subjected to short-term (ST) or long-term (LT) brushing under field conditions.

Crop	Seeding date	Treatment interval (DAS)*			Sampled for growth (DAS)
		Initiated	ST end	LT end	
European radish	6 June	16	24	29	24, 29
Japanese radish	6 June	16	24	37	24, 30, 37, 43
Asian turnip	6 June	16	24	30	24, 30, 37
European turnip	18 July	14	23	35	23, 35, 44

Table 2. Effect of brushing on the quality distribution (percentage of the total number of roots) of roots and root fresh weight within quality category of European radish.

Brushing	Medium quality*		Unmarketable*	
	Percentage of total	Fresh wt	Percentage of total	Fresh wt (g)
None	18 b*	19.8	39 a	19.9
Short-term	28 a	20.8	30 ab	20.2
Long-term	29 a	18.0	25 b	21.0
		NS		NS

*Medium quality = oblong storage roots of marketable quality.

*Unmarketable = cracked storage roots (not including culls, see text).

*Mean separation within columns by LSD, $P=0.05$. Percentage of total data analyzed by square-root transformation, original data presented.

NS Not significant at $P=0.05$.

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Fig. 1. Effect of short- and long-term brushing on shoot and root dry weights and the root : shoot dry weight ratio of radish and turnip sampled at the end of the short-term treatment (early) and at the final growth analysis (late), which corresponds to 24 and 29 days after sowing (DAS) for European radish, 24 and 37 DAS for Asian turnip, and 23 and 44 DAS for European turnip. Significant differences in data in early samples determined by *t* test: (NS) not significant at $P = 0.05$, (**) $P < 0.01$, (***) $P < 0.001$. Mean separation in late samples by LSD, $P = 0.05$.

between staggered rows. A planting hill was formed at each hole in the plastic. Each bed (0.6×11 m) was devoted to one crop. Each bed was divided into four plots (replications) of 0.6×2.8 m. The three treatments were randomly assigned to 0.9 m of row within each plot, with a guard row of plants grown between the treatments, resulting in eight hills per treatment subplot.

About 30 seeds of 'Comet' European radish were sown per 10-cm hill and thinned to six plants per hill before treatment, resulting in 48 plants/treatment subplot in each of four replications. About 15 seeds of 'Mino-wase' Japanese radish were sown per hill and thinned to four plants per hill before treatment (32 plants/treatment per replication). 'Hinona' Asian turnip seeds were sown ≈ 30 /hill and thinned to six plants per hill (48 plants/treatment per replication). The above three crops were sown in early June.

In early July, seeds of 'Hikari-kabu' European turnip were sown 0.5 cm apart in four rows 10-cm apart in an unmulched, raised bed (0.9×13 m) located in an uncovered greenhouse. The medium in this bed consisted of 7 soil : 1 sand : 2 volcanic rock (by volume) and was fertilized as described above. Plants were thinned to 4 cm apart after emergence, and all data were collected on plants grown in the center two rows. The bed was divided into four plots, as described

above, with 0.8-m sections assigned to each treatment subplot per replication, resulting in 40 plants/subplot in the center two rows. Treatments were separated by guard plants.

The mechanical stress treatment was applied by brushing the tops of the plants with a hollow steel bar that was suspended horizontally in Saran cloth from a pole resting on a wooden frame above the treatment subplots. The height of the bar was adjusted to brush the top 5 to 10 cm of the plants. Treatment was applied twice daily, 40 cycles (back-and-forth strokes equal one cycle), at 0900 and 1630 HR, for the durations listed in Table 1. Treatment intensity was selected based on previous experiments under protected (greenhouse) conditions to provide a moderate level of growth control in the absence of environmental disturbances such as wind (Biddington and Dearman, 1985; Latimer et al., 1991). Short-term brushing was considered a conditioning treatment during early plant growth in the field, usually for 1 week. Long-term treatment was continued until near the harvest time of the crop. Control subplots were untreated.

Four to six plants were randomly selected from each subplot for growth measurement at selected times during the experiments (Table 1). Shoot and storage root fresh and dry weights (after 72 h at 70°C in a forced-air oven), storage root diameter (at the widest

point), and length were determined at each sampling time. Large roots were cut in half before being dried.

All crops were subjected to a once-over harvest at the developmental stage suitable for marketing in Japan. At harvest, root fresh weight and quality (size, shape, and incidence of cracking or defects) were determined. European radish storage roots were harvested 29 days after seeding and sorted into four groups: high quality, spherical and unblemished; medium quality, oblong and unblemished; unmarketable, cracked or poor quality; and culls, plants not forming storage roots. Spherical roots are considered to be of highest quality, while oblong roots are marketable but of lower quality. Japanese radish roots were harvested before attaining a marketable size. Asian turnip roots were harvested 37 days after seeding and sorted into large (>1.5 cm in diameter), medium (0.5 to 1.5 cm in diameter), and small (<0.5 cm in diameter) size classes, which, for the purpose of a once-over harvest, correspond to quality classes of high, medium, and unmarketable, respectively. European turnip roots were harvested 52 days after seeding and sorted into marketable (>2.5 cm in diameter) or unmarketable (≤ 2.5 cm in diameter) roots. All data were subjected to analysis of variance using the general linear models procedure of SAS (Freund et al., 1986). All percent data were subjected to square-root transformation before analysis.

Effects of brushing on plant growth. At both early and late sampling times, short-term brushing reduced root growth, but not shoot growth, of European radish and the R : S ratio at the early sample time (Fig. 1). Long-term brushing maintained the reduction in root dry weight and in the R : S ratio. Short-term brushing reduced cross-sectional root diameter 7% at 24 days after sowing (DAS) ($P < 0.05$); both short- and long-term brushing reduced root diameter 7% and 9%, respectively, ($P < 0.01$) at 29 DAS (data not presented). Neither short-term nor long-term brushing affected the growth or final root or shoot dry weights of Japanese radish (data not presented).

Although brushing increased root dry weight and R : S ratio of both turnip cultivars early during treatment, this response did not persist to provide a final improvement in crop performance (Fig. 1). Short-term brushing increased root dry weight 22% and the R : S ratio 25% without affecting the shoot dry weight of Asian turnip. However, long-term brushing reduced root dry weight, but not the R : S ratio, at 37 DAS, and the beneficial effects of the short-term treatment did not persist. Root diameter increased 7% in short-term brushed plants at 24 DAS ($P < 0.05$); however, 6 days after the cessation of brushing, there was no difference in root diameter or length (data not presented). With European turnip, short-term brushing increased root dry weight 39% and R : S ratio 54% without affecting shoot dry weight at 23 DAS (Fig. 1). Long-term brushing did not affect plant growth and short-term effects did not persist. Root diameter and length were not

affected by brushing at any sampling time (data not presented).

Effects of brushing on root crop yield and quality. Brushing did not affect the proportion of high-quality European radish storage roots harvested 29 DAS. An average of 22% of the plants across treatments yielded high-quality, spherical roots. The treatments also had no effect on the number of plants not forming storage roots (mean 21%). However, both brushing treatments increased the percentage of plants forming medium-quality, or oblong, roots (Table 2). In addition, long-term brushing reduced the number of roots discarded as cracked (Table 2). Consequently, the brushing treatments effectively increased the percentage of marketable-quality roots. Mean root fresh weight was not affected by brushing in any quality class.

The storage roots of brushed Japanese radish plants, harvested in the young stage (43 DAS), were similar in quality, form, and appearance to those of the untreated plants (data not presented).

The Asian turnip showed few treatment effects. Brushing did not affect the percentage of Asian turnip roots classified as large (mean 57%) or small (13%), but long-term brushing increased the percentage of medium-sized roots (untreated 25% vs. long term brushing 37%, $P < 0.05$). There were no treatment effects on root distribution between marketable (68%) and unmarketable (32%) classes or on mean root fresh weight within the classes of European turnip roots harvested 52 DAS (data not presented).

In this study of four root crops, brushing improved the quality only of European radish under field conditions, with both brushing treatments resulting in a total of 51% of the plants producing marketable roots compared to only 39% of the untreated plants. Brushing reduced the incidence of cracking

in European radish, thereby increasing the proportion of marketable roots without affecting root weight. However, brushing reduced root growth of Asian turnip, since the increased percentage of medium-sized roots was the result of a tendency to decrease the percentage of large-sized roots. Brushing did not affect the growth or final quality of Japanese radish or European turnip storage roots. Brushing improved the R : S ratio in carrots grown under protected conditions, but brushing effects on root diameter or quality were not reported (Biddington and Dearman, 1987).

Although, in our study, shoot growth reductions were observed within days after initiating the brushing treatment for each crop tested, shoot dry weight generally was unaffected by brushing, suggesting that the treatment effects were masked by the ambient environmental conditions. We postulated that we could still affect dry-weight partitioning into storage root tissues even under field conditions and thereby improve crop performance and yield under the less-than-ideal growing conditions. The mechanical stress response of the crops tested here was apparently saturated by the normal disturbance present under field conditions. Based on the current research, we would not recommend addition of a brushing treatment for improvement of storage root quality of root crops.

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