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Evaluation of early vigor under direct planting cultivation in sweet potato

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ABSTRACT

Direct planting – in which small storage roots are planted instead of transplanting stem cuttings – has been studied as a labor-saving system in sweet potato. Early vigor is important for cultivars used in direct planting because it affects their ability to compete with weeds. In this study, the genotypic difference in early vigor was evaluated. Twelve genotypes were tested in 2018 and 2019. Days to emergence, shoot dry matter yield, plant height, and NDVI were investigated as indicators of early vigor. Significant differences in days to emergence and shoot dry matter yields were observed among genotypes in both years. ‘Kyushu No.198’ was outstanding in terms of early vigor. A strong relationship between plant height and shoot dry matter yield was observed; this relationship was also observed with NDVI. Growth traits that can be monitored in a non-destructive way, such as plant height, are reliable predictors of shoot dry matter yield during early growth.

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Introduction

Sweet potato (*Ipomoea batatas* Lam.) is an important crop because its roots are rich in carbohydrates, vitamins, and dietary fiber. Sweet potato is grown in approximately 120 countries, from tropical to temperate zones (FAO, 2018). Japan is the fifteenth largest sweet potato producer in the world, with an annual production of about 796 thousand tons and the southern Kyushu region, including Kogashima and Miyazaki prefectures, accounts for approximately half of Japan’s total production (MAFF, 2018). In this region, sweet potato is cultivated not only for table use but also for processed food materials, such as starch and distilled spirits.

In general, sweet potato is propagated using stem cuttings. The labor required from the preparation of stem cuttings to transplanting is over one-third of the total hours of cultivation. The present propagation system has not yet been mechanized, resulting in high labor demands. An alternative system is necessary to reduce production costs, particularly in the southern Kyushu region as sweet potato cultivated in this region is mainly used for processed food, which is cheaper than crops for table use. Direct planting systems have been studied since the 1940s in Japan and the USA reviewed by George et al. (2011). In temperate zones, small storage roots are planted as seeds in the spring, instead of transplanting stem cuttings. This is similar to the propagation system of potato (*Solanum tuberosum* L.), which is already mechanized. For this reason, direct planting of sweet potato can reduce labor requirements and, consequently, production costs.

In contrast to the situation for potato, this type of planting has not been widely adopted for sweet potato. A major problem is ‘mother root enlargement’ (George et al., 2011; Kobayashi, 1968; Kodama, 1962). When grown from storage roots, different types of roots are observed at harvest. One type is the ‘mother root’, which results from the planted seed root. In most sweet potato genotypes, the mother root is enlarged (Kobayashi, 1968) because it works as a sink for photosynthetic products. Unfortunately, the mother root is often deformed and the quality is low for processed foods; therefore, it has no commercial value except as livestock feed. The other root type is the ‘daughter root’, which arises from the planted seed root. Since the formation mechanism of these roots is identical to the roots grown by transplanting, the daughter roots have commercial value. Clones adaptable to direct planting have been studied by developing breeding material (Akita et al., 1968; Kobayashi, 1968; Kusahara et al., 1972). A Japanese cultivar, ‘Naeshirazu’, with low enlargement of the mother root was the first to be registered (Shikata et al., 1975). In the 2000s, ‘Murasakimasari’ (Kumagai et al., 2002), ‘Tamaakane’ (Sakai et al., 2011), and ‘Suzukogane’ (unpublished but registered in 2016) were released in Japan as cultivars with low enlargement of the mother root.

Despite these improvements in mother root enlargement, few farmers have shifted from transplanting to direct planting. Farmers have noted that an improvement in early vigor is also necessary to promote this type of planting. The planting holes are larger in direct planting than those used for transplanting because the

diameter of storage roots is much larger than that of stems. Weeds in the planting hole emerge more quickly than the sweet potato plants; therefore, the sweet potato is often shaded by weeds in direct planting cultivation. Consequently, farmers need labor for manually weeding the planting holes to ensure a good crop start; weeds in the interrow space can be controlled using herbicides. Hence, information on early vigor is very important in direct planting to reduce the labor required for weeding.

Sweet potato breeders have not paid much attention to early vigor in direct planting because mother root enlargement was the main issue. Thus, there are few scientific reports on genotypic differences in early vigor, except for breeders' observations or a few studies of historical cultivars (Kusuhara et al., 1972). In this study, we aimed to identify genotypes with good early vigor in direct planting, by examining traits such as emergence and shoot yield. We also validated the relationship between non-destructive growth traits and shoot yield for the purpose of predicting yield.

Materials and methods

In 2018 and 2019, field trials were conducted at the Kyushu Okinawa Agricultural Research Center, NARO in Miyakonojo, Miyazaki Prefecture, Japan (31°45' N, 131°00' E). A total of 12 genotypes were tested. Four of the 12 were major cultivars for processed food use ('Koganesengan', 'Norin. No.1', 'Norin No.2', and 'Shiroyutaka'); the other eight included the cultivars 'Murasakimasari', 'Suzukogane', and 'Tamaakane' and the breeding lines 'Chugoku No.25', 'Kyukei 327', 'Kyukei 335', 'Kyukei 342', and 'Kyushu No.198', which were bred for direct planting and show low enlargement of the mother root. 'Suzukogane' is regarded as a standard cultivar for direct planting.

The experiment had a randomized block design with two replicates. To establish the plot, small storage roots were planted on 27 March 2018 at a planting density of 4.04 roots m⁻² (row space 75 cm, interhill space 33 cm). The area of each plot was 0.74 m², which consisted of three serial hills. The weight of seed roots ranged from 72 g to 141 g per root. These roots were harvested the prior fall and kept in a storehouse. Chemical fertilizer was applied as a basal dressing (4 g N m⁻², 6 g P₂O₅ m⁻², and 10 g K₂O m⁻²). A clear plastic mulch was used in 2018 and laid on the ridge of the experimental plot to warm the soil. Soil temperature was measured at 5 cm below the top of the ridge with a thermometer (Ondotori, T & D Co. Ltd., Nagano, Japan). Two sensors were placed between hills to measure soil temperature. Air temperature data were obtained from the nearest Automated Meteorological Data

Acquisition System (AMeDAS) site, which was 5 km from the experimental site.

The number of emergent shoots was counted at least every 3 days until full emergence. Shoot dry matter yield and plant height were recorded at 43 days after planting (9 May 2018). Shoots were cut by hand and dried at 80°C to determine the dry matter yield. Plant height was defined as the length from the top of the ridge to the leaf tip of the longest stem.

In 2019, seed roots were planted on March 20. The weights ranged from 95 g to 153 g per root. The cultivation practices were almost identical to those of 2018, except that a black plastic mulch was used in 2019. The number of emergent shoots was counted until full emergence. Shoot dry matter yield, plant height, and the normalized difference vegetation index (NDVI) were recorded at 62 days after planting (21 May 2019). NDVI was measured above the crop at a height of about 1 m using an NDVI meter (GreenSeeker, Nikon Trimble, Tokyo, Japan). NDVI was determined as: $NDVI = (R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED})$, where R_{NIR} and R_{RED} are the canopy reflectances of the near infra-red and red spectra, respectively.

Weeds in planting holes were occasionally removed by hand not to inhibit shoot growth. Thus, we did not survey the amount of weeds in both 2018 and 2019.

Statistical analyses were conducted using the software package SPSS ver. 21.0 (IBM). One-way ANOVA and Tukey's HSD test ($P < 0.05$) were performed to assess genotypic differences. For correlation analysis, Pearson's correlation coefficient (r) was calculated. To validate the prediction accuracy of the regression, the coefficient of determination (R^2) was also calculated.

Results

Soil and air temperatures during early growth

The soil temperature during early growth was higher in 2018 than in 2019; there was a 5.8°C difference in the monthly average temperature for April between 2018 and 2019. In contrast to the soil temperature, the monthly average air temperature for April only differed by 1.3°C between 2018 and 2019. This result indicates that the clear mulch used in 2018 likely had a greater effect on warming the soil than the black mulch used in 2019.

Days to emergence in direct planting

The days to emergence varied significantly among genotypes in 2018 and 2019 (Tables 1 and 2). In 2018, two breeding lines, 'Kyushu No.198' and 'Kyukei 335', in the earliest emergence group took only 16 days to emerge. 'Kyukei 342' took 32 days

Table 1. Days to emergence and shoot traits at early growth stage in 2018.

Genotype	Days to emergence (days)	Shoot dry matter yield (g per hill)	Plant height (cm)
Koganesengan	21.5 ab	10.4 bc	18.3 bcd
Norin No.1	22.2 ab	12.4 ab	24.2 ab
Norin No.2	22.2 ab	5.1 bcd	15.0 cde
Shiroyutaka	19.0 ab	9.1 bc	20.8 bc
Chugoku No.25	26.2 ab	1.4 d	10.0 ef
Kyukei 327	25.8 ab	3.6 cd	13.8 cde
Kyukei 335	16.2 a	10.4 bc	20.8 bc
Kyukei 342	32.0 b	0.9 d	5.5 f
Kyushu No.198	15.2 a	18.8 a	30.2 a
Murasakimasari	23.5 ab	4.8 bcd	15.2 cde
Suzukogane	22.0 ab	6.5 bcd	15.8 cde
Tamaakane	24.3 ab	3.1 cd	11.2 def
ANOVA	*	**	**

Shoot dry matter yield and plant height were recorded at 43 days after planting.

Clear plastic mulch was used in 2018 to warm soil.

** and * indicate the significant difference at the 1% and 5% level of probability according to ANOVA.

Different alphabets indicate the significant difference at 5% level of probability by Tukey's HSD test.

Table 2. Days to emergence and shoot traits at early growth stage in 2019.

Genotype	Days to emergence (days)	Shoot dry matter yield (g per hill)	Plant height (cm)	NDVI
Koganesengan	33.5 abcd	12.1 abcd	20.0 bc	0.86 ab
Norin No.1	31.7 abc	20.5 a	27.3 ab	0.89 a
Norin No.2	40.7 bcde	4.4 bcd	14.2 cd	0.72 abc
Shiroyutaka	30.2 ab	15.6 ab	25.2 ab	0.89 a
Chugoku No.25	41.0 cde	3.0 cd	13.2 cd	0.62 abc
Kyukei 327	43.7 de	3.2 cd	14.8 cd	0.75 abc
Kyukei 335	31.3 abc	22.2 a	28.5 a	0.89 a
Kyukei 342	40.3 bcde	1.4 e	9.8 d	0.59 bc
Kyushu No.198	29.7 a	17.9 a	28.3 ab	0.89 a
Murasakimasari	32.0 abc	11.3 abcd	24.2 ab	0.87 ab
Suzukogane	33.5 abcd	13.9 abc	23.3 ab	0.88 ab
Tamaakane	47.8 e	1.6 e	7.2 d	0.49 c
ANOVA	**	**	**	**

Shoot dry matter yield, plant height, and NDVI were recorded at 62 days after planting.

Black plastic mulch was used in 2019 to warm soil.

** indicates the significant difference at the 1% level of probability according to ANOVA.

Different alphabets indicate the significant difference at 5% level of probability by Tukey's HSD test.

to emerge and this period was twice as long as that of the earliest group. In 2019, the earliest group, such as 'Kyushu No.198', took 30 days to emerge; the final genotype to emerge, 'Tamaakane', took 48 days.

A significant correlation was observed in the days to emergence among genotypes between 2018 and 2019 (Figure 1). All genotypes took longer to emerge in 2019 than in 2018 (Figure 1, Tables 1 and 2). According to the results for both years, 'Kyushu No.198' was the earliest genotype to reach emergence (Tables 1 and 2). 'Suzukogane', which is a standard cultivar for direct

planting, ranked in the middle of the 12 genotypes tested.

Shoot traits of early growth in direct planting

In 2018, shoot dry matter yield and plant height were measured 43 days after planting. There were large and significant differences in shoot dry matter yield and plant height among genotypes (Table 1). 'Kyushu No.198' had the largest shoot dry matter yield at 18.8 g per hill, whereas the lowest yielding genotypes, 'Kyukei 342' and 'Chugoku No.25', produced only 0.9 and 1.4 g per hill, respectively. In 2019, NDVI was also investigated at 62 days after planting in addition to shoot dry matter yield and plant height. In accordance with the results from 2018, large variations were observed in these shoot traits (Table 2). 'Kyukei 335', 'Norin No.1', and 'Kyushu No.198' ranked as the highest yielding genotypes, with yields of 22.2, 20.5, and 17.9 g per hill, respectively. 'Kyukei 342' and 'Tamaakane' had the lowest yields of 1.4 and 1.6 g per hill, respectively. A strong significant correlation in shoot dry matter yield during early growth among genotypes was observed between 2018 and 2019 (Figure 1). 'Kyushu No.198' had the highest shoot dry matter yield among the 12 genotypes for both years; 'Kyukei 342' had the lowest shoot dry matter yield and its average was less than one-fifteenth of that of 'Kyushu No.198' (Tables 1 and 2). 'Suzukogane' ranked in the middle of the 12 genotypes tested.

Days to emergence and shoot dry matter yield at early growth stage were significantly correlated in both 2018 ($r = -0.839$, $P < 0.01$) and 2019 ($r = -0.896$, $P < 0.01$). As expected, days to emergence were strongly related to shoot dry matter yield at the early growth stage.

We found strong relationships between plant height and shoot dry matter yield during the early growth stage ($R^2 = 0.925$) and between NDVI and shoot dry matter yield ($R^2 = 0.917$) (Figure 2).

Discussion

Our study revealed that 'Kyushu No.198', 'Kyukei335', and 'Shiroyutaka' emerged early in direct planting. Cultivar registration records have noted the emergence characteristics of different sweet potato cultivars in nursery beds. According to these records, 'Shiroyutaka' has earlier emergence than 'Koganesengan' (Sakamoto et al., 1987), and this result coincides with the results of our study performed under field conditions in the spring. Thus, studies in nursery beds might be helpful to screen clones for direct planting. On the other hand, soil temperatures are likely to be much cooler in the field than in nursery beds because the latter are established in greenhouses to warm the soil. Therefore, the results from our

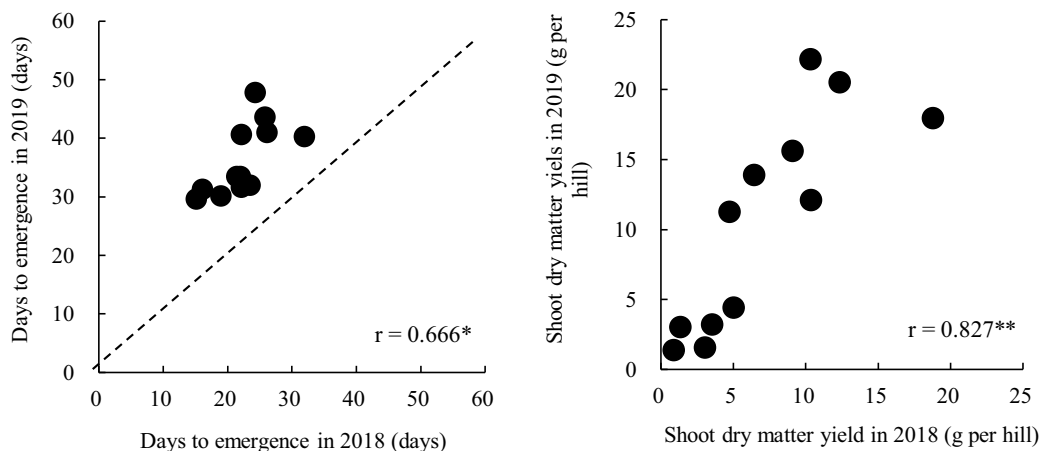


Figure 1. Comparison between 2018 and 2019 in days to emergence and shoot dry matter yield at early growth stage. Clear and black plastic mulches were used in 2018 and in 2019, respectively. r indicates correlation coefficients. **, * indicate the significant differences at the 1%, 5% level of probability, respectively. The broken line on the left graph describes 1:1 ratio line.

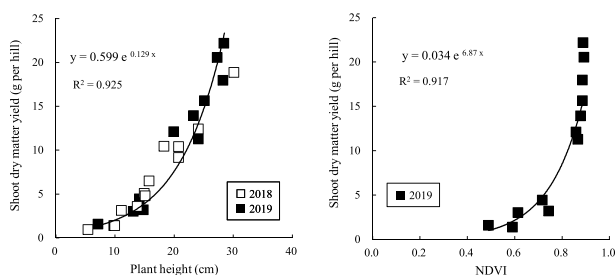


Figure 2. Relationship between non-destructive growth traits and shoot dry matter yield during early growth stage. R^2 indicates the coefficient of determination. White and black symbols indicate the data in 2018 and 2019, respectively.

field evaluation are likely to be more reliable for screening genotypes with early emergence in the spring than those from a nursery experiment. Iura (1968) indicated that cultivar sprouting differences depend on the ability of bud primordia to penetrate the epidermis. Anatomical studies are necessary to clarify these genotypic differences in emergence.

Genotypes such as 'Kyushu No.198', 'Norin No.1', and 'Kyukei 335' indicated high shoot dry matter yield during early growth. In particular, 'Kyushu No.198' was an outstanding genotype in terms of both emergence and shoot yield during early growth. Shoot yield is associated with a competitive advantage over weeds. While shoot dry matter yield is a good indicator of early vigor, testing this indicator is destructive. In breeding programs, the shoots cannot be cut until harvest time. Therefore, we studied whether other 'non-destructive' growth traits are reliable predictors of shoot yield and found a strong relationship between plant height and shoot dry matter yield during the early growth stage. NDVI is a well-known

vegetative index and is also used to evaluate the shoot biomass of crops in the field (Iseki & Matsumoto, 2019; Teal et al., 2006). Although NDVI data were only collected in 2019, a strong relationship between NDVI and shoot dry matter yield was observed during early growth. In this study, the coefficient of determination was slightly higher for plant height than for NDVI, and we concluded that plant height was better able to predict shoot dry matter yield at the early growth stage in direct planting. 'Kyukei 327', 'Kyukei 335', 'Kyukei 342', and 'Kyushu No.198' are recent breeding lines that were screened as having low enlargement of mother root under direct planting cultivation. Interestingly, there was considerable variation in early vigor among these elite breeding lines. Predictive curves for shoot yield are helpful to exclude clones with inferior early vigor in actual breeding programs.

Breeding lines with early vigor such as 'Kyushu No.198' and 'Kyukei 335' should have a competitive advantage over weeds in direct planting. In addition to this advantage, vigorous early growth might elevate the productivity of sweet potato. According to Tsuno and Fujise (1965), the optimum leaf area index for dry matter production of sweet potato was 3.2 at the middle growth stage. Genotypes with early vigor were assumed to reach the optimum leaf area index faster than genotypes with inferior early vigor. Taking the leaf area index into consideration, genotypes with early vigor could be preferable for crop production. As mentioned previously, daughter root yield at harvest is the priority for direct planting. In this study, investigation of root yield was not performed, but 'Kyushu No.198' indicated higher daughter root yield than a standard cultivar 'Suzukogane' in our yield trials under direct planting (unpublished). As a next step, we need to clarify the

effect of vigorous early growth on daughter root yield in direct planting.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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