Effects of ratoon harvesting on the root systems of processing spinach

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Abstract: The mechanical harvesting of processing spinach (spinach used in production of processed food) is potentially becoming a common practice in Japan. Root distribution affects water and nutrient absorption, but how the roots spread in the soil profile during the regrowth period of spinach remains unknown. In this study, we investigate the root systems of processing spinach in topsoil (5 and 15 cm deep) and deeper soil layers (25, 35, 45, and 55 cm deep) cultivated using ratoon harvesting system. The total root length densities (calculated using the average of the densities at 0 and 15 cm horizontal distance from the row for each depth) in the second harvest were more than two-fold greater than those in the first harvest. The root length percentage in the topsoil and root depth indexes indicate that root systems are in shallower soil layers at the second harvest than at first harvest.

Keywords: improved soil profile method, mechanical harvesting, ratooning, regrowth, Spinacia oleracea

Introduction

Spinach (Spinacia oleracea L.) is mainly cultivated for use as fresh vegetable or in processed food industry in Japan. The spinach crop area covered 20500 ha in 2017 (Ministry of Agriculture, Forestry and Fisheries 2018). Processing spinach (spinach used in production of processed food) accounts for 9% of total spinach use in Japan, 64% of which originates from Miyazaki Prefecture in Kyushu (Ministry of Agriculture, Forestry and Fisheries 2018).

Processing spinach is generally harvested by mechanical means in Japan. In this form of harvesting, the clippers cut only the leaves, which allows regrowth of the plant and subsequent harvesting of the ratoon. Iwasaki (2008) reported on the use of a multiple harvesting system in temperate regions of Japan. Previously, we investigated the effectiveness of a ratoon harvesting system on the production of spinach in a warm upland farming area in Miyazaki Prefecture (Suzuki et al. 2018). In ratoon cropping system where plants are sown in late September or early October, the ratoon plants grow fast (Suzuki et al. 2016) and they can be harvested in January and February, whereas growth of spinach cultivated using traditional cultivation method in the same time period is usually stagnant.

In leafy vegetable cropping, nutrients and water should be supplied continuously as the crops are usually harvested during the growing period. In addition, in Japan, processing spinach plants are often harvested when they are larger than the plants that are intended for household use, and therefore, they require more nutrients. Suzuki et al. (2018) reported the effectiveness of additional fertilizer for growth of aerial parts of spinach plants in ratoon cropping. Therefore, understanding the root growth during regrowth period of processing spinach is necessary for improving cultural management practices related to nutrient and water absorption.

The roots of spinach plants grow into deeper soil layers relatively soon after sowing (Weaver and Bruner 1927, Nakano 2004). After 10 weeks (from sowing), which corresponds approximately to the growth period of processing spinach, many lateral roots develop in the topsoil and elongate downwards.

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(Weaver and Bruner 1927). However, root distribution in the soil profile during the regrowth period of processing spinach remains unknown. Therefore, in this study, we detail the root system features of processing spinach cultivated by ratoon cropping.

Materials and Methods

The experimental fields were located at the Miyakonojo Research Station, Kyushu Okinawa Agricultural Research Center (KARC), NARO, Miyakonojo, Miyazaki, Japan (31°45′ N, 131°01′ E). The monthly average temperatures, the accumulated total precipitation and the accumulated duration of sunshine during the growth period are shown in Fig. 1. The soil type in the field was Andosol and the texture was loam. Chemical properties of the soil were as follows: pH 6.4, P_2O_5 absorption coefficient of 1502, 137 mg kg^(-1) available P_2O_5, 34 mg kg^(-1) NH_4^+ N, 23 mg kg^(-1) NO_3^− N, 441 mg kg^(-1) K_2O, 3044 mg kg^(-1) CaO, and 828 mg kg^(-1) MgO. Basal fertilizer was applied at a density of 20 g of N, 20 g of P_2O_5, and 20 g of K_2O per square meter.

The field experiment was carried out as part of Experiment 3 (which was conducted in 2016–2017) in our previous study (Suzuki et al. 2018). This experiment consisted of two replicates. Seeds of the spinach cultivar ‘Kuronosu’ (Sakata Seed Corporation, Yokohama, Japan) were sown in four rows that were separated by 30 cm, in one bed on September 26, 2016. The first harvest was performed on November 28, 2016. Additional fertilizer was applied at a density of 10 g of N, 10 g of P_2O_5, and 8 g of K_2O per square meter after the first harvest. Average interplant distance within a row was 11 cm at the time of first harvest and 12 cm at the time of second harvest (February 21, 2017). Conventional weed and insect pest control methods were applied. Harvesting was conducted using a harvesting machine (MNSH-1300, Cleaning Nishizawa Co., LTD, Tadotsu, Japan) with the height from ground level set at 5 cm.

Soils were sampled for root system analysis on December 6, 2016 (after the first harvest) from an area where the spinach had not been harvested, and on February 22, 2017 (after the second harvest) using an improved soil profile method (Morita et al. 2013). Namely, a trench was dug for each plot at each sampling time. The profile perpendicular to the direction of the rows was then cleared and soil was sampled using metallic 100 cm^2 cylinders (5.5 cm in diameter) from the profile at depths of 5, 15, 25, 35, 45, and 55 cm, and at horizontal distances of 0 cm (directly under the plant row), 7.5 cm (only for depths of 5, 15, 25, and 35 cm), and 15 cm (mid-way between plant rows) (Fig. 2). The soil was sampled at two places for each profile, but some values were not obtained due to the investigation mistakes. Large root debris that could be observed with the naked eye was removed by hand and the soil was then mixed with water and shaken to separate fine roots. The mixture was left to rest and the top liquid layer was sieved through a 250 μm sieve and the fine root debris was collected. Roots were placed in a tray filled with water and scanned at 400 dpi. The lengths and average diameters of the roots were measured using an image analysis system (WinRhizo 2009c, Regent Instruments Inc., Quebec, Canada), and their dry weight was determined. The mean of the two samples from each profile was used as the representative value for each replicate. In the case of one value from each profile missing, the other was adopted as the representative one. The average root length density, calculated by adding the average density values for each depth (5–55 cm), were obtained using the densities at horizontal distances of 0 and 15 cm from the row. The top/root (T/R) ratio was determined from the ratio of dry weight of the aerial plant parts to that of the roots. Root depth index was calculated using the method described by Oyanagi et al. (1993) to represent the root vertical distribution based on root length density data. Plant length and dry weight of the aerial plant parts were determined on the day before soil sampling.

Results

In 2016–2017, the monthly average temperatures from September to December were high, which approximately coincided with the growth period before the first harvest. The accumulated total precipitation was high from September to November (corresponding approximately to the period before the first harvest), and it was low in January and February during the regrowth period. The accumulated sunshine duration was low in September and October (before the first harvest) and high from November to February (mainly during the regrowth period) (Fig. 1).

Traits of the aerial plant parts and dry weight of the roots at first and second harvest are shown in Table 1. The dry weight of aerial plant parts and roots was slightly greater at second harvest than at first harvest, but the T/R ratio did not change greatly. The roots were found at a depth between 5 and 55 cm in both the first and second harvest. The average root length densities in the second harvest were more than two-fold greater compared to those in the first harvest (Table 1).

The root length density in the topsoil was 67% and 82% of the average total density at horizontal
Fig. 1. Climatic conditions during the growth period. These climatic data were obtained from Miyakonojo observatory, Japan Meteorological Agency, which is located approximately 7 km from the experimental field.

Fig. 2. Soil sampling positions for root system analysis on the profile.

Table 1. Spinach traits at 1st and 2nd harvest

| Traits                              | 1st harvest | 2nd harvest |
|-------------------------------------|-------------|-------------|
| Plant length (cm)                   | 45.0        | 33.5        |
| Dry weight of aerial plant parts (g plant⁻¹) | 10.7        | 16.9        |
| Dry weight of roots (g plant⁻¹)     | 2.3         | 3.1         |
| T/R ratio                           | 4.7         | 5.5         |
| The average root length density (cm cm⁻³) | 1.4         | 3.3         |
| Root depth index (cm)               | 18.6        | 14.7        |

T/R: Top/root ratio, determined from the ratio of dry weight of the aerial plant parts to that of the roots.

distances of 0 and 15 cm from the row at the first and second harvest, respectively (Fig. 3). Root depth indexes at the first and second harvest were 18.6 cm and 14.7 cm, respectively (Table 1). The densities in the topsoil were slightly higher closest to the row at the first harvest, but not at the second harvest. However, the densities in deeper soil layers did not differ with respect to the horizontal distance from the row at both the first and second harvest (Fig. 3). The percentage of the average root diameter at the second harvest compared to that at the first harvest was greater than 100% in the topsoil at horizontal distances of 7.5 and 15 cm from the plant row (Table 2, Fig. 4). This was also true for roots at a depth of 55 cm directly under the plant row (0 cm horizontal distance from the plant row). The percentages of the root length density at the second harvest compared to that at the first harvest were also greater in these positions than in other positions (Table 3).
Table 2. Percentage of average root diameter in the 2nd harvest relative to that in the 1st harvest

| Depth (cm) | 0 cm | 7.5 cm | 15 cm |
|------------|------|--------|-------|
| 5          | 83   | 109    | 122   |
| 15         | 97   | 120    | 121   |
| 25         | 89   | 86     | 86    |
| 35         | 76   | 86     | 84    |
| 45         | 78   | NA     | 91    |
| 55         | 108  | NA     | 90    |

NA: not applicable.

* Sampling position was measured from the plant row.

Fig. 3. Root length densities at 1st and 2nd harvest in spinach. NA: not applicable.

Fig. 4. Average root diameter at 1st and 2nd harvest in spinach. NA: not applicable.

Table 3. Percentage of root length densities in the 2nd harvest relative to that in the 1st harvest

| Depth (cm) | 0 cm | 7.5 cm | 15 cm |
|------------|------|--------|-------|
| 5          | 214  | 313    | 351   |
| 15         | 228  | 327    | 445   |
| 25         | 138  | 313    | 179   |
| 35         | 82   | 96     | 91    |
| 45         | 148  | NA     | 119   |
| 55         | 236  | NA     | 134   |

NA: not applicable.

* Sampling position was measured from the plant row.
Discussion

The results of this study show that the roots were well developed even during the regrowth period. The T/R ratio did not greatly differ between the first and second harvest and was similar to the value reported in a previous study (Nakano 2004). In addition, although the plant length at second harvest is shorter than that at first harvest, dry weight of aerial plant parts is greater at second harvest. This reflects larger stem and more leaves at second harvest. However, at second harvest, the increase of the average root length density was greatly more compared with the increase of dry weight of aerial plant parts and roots, suggesting that many roots were developed during the regrowth. Moreover, roots may have decayed between the two harvests and thus the value obtained at the second harvest did not include them. Therefore, it is possible that more roots grew during the regrowth period than the difference between at first and second harvests.

The root length densities were higher in the topsoil than in deeper soil layers at the time of both harvests. The percentage of the root length in the topsoil and the root depth indexes indicated that at the second harvest, spinach plants had shallower root systems when compared with the root systems observed at the time of first harvest. These results underline the importance of nutrient supply in the topsoil where fertilizer is usually applied. Similarly, Schenk et al. (1991) reported about the presence of shallow spinach root systems and the importance of nitrogen supply in the topsoil.

In contrast, substantial amounts of roots were found in the subsoil. These roots can absorb water from deeper soil layers under dry conditions to avoid the suppression of plant growth due to drought. In our ratoon harvesting system, the regrowth period coincided usually with the dry season, which was further worsened by unusually small precipitation in 2016, resulting in dry soil. Sugar beet, which belongs to the same family as spinach, with shallower root systems (due to soil type or beet cultivar) wilts more promptly in summer dry season (Hayashi et al. 2004, Itoh et al. 2008). Therefore, roots in the subsoil would facilitate a smooth growth of the plants in dry conditions. Additionally, when deeper soil layers are rich in nutrients, spinach roots will absorb considerable amounts of nutrients from this layer. Hayashi and Nagao (2010) have described a diagnostic method for measuring nitrogen content in the subsoil to reduce nitrate accumulation in spinach growing in nitrogen-rich subsoil. The roots in subsoil would also ensure efficient nutrient utilization. Fujiwara et al. (2003) also pointed out that direct seeding cultivation with deeper roots could promote absorption of nutrients and water and growth at late growth stage in spinach in comparison with transplant cultivation. Cultivation systems that promote root development in the soil lower layer, e.g., irrigation or selection of suitable cultivars, would contribute to the stable production of spinach.

Shallower root systems at second harvest probably due to the difference in root system formation. In this study, no trampling influences the root growth because the wheels of the harvesting machine pass outside the bed. In direct sowing cultivation of spinach, the seminal root elongates downward, and the branch roots are observed in a wide area. On the other hand, in transplant cultivation of spinach, the roots concentrate near the ground surface (Fujiwara et al. 2003). Even in this study, there is a possibility that the roots were distributed mainly in the upper soil due to the absence of the seminal root during the regrowth period. Actually, the root length densities hardly differed at varying horizontal distances from the row at the time of the second harvest; however, this did not apply to the topsoil at the time of the first harvest. The results suggest that new roots developed vigorously during the regrowth period after the first harvest despite the severe winter season. The average diameter of the roots located far from the seeding position was larger at the second than at the first harvest. The root length densities were large in the same positions. Therefore, it is probable that in these places, the thick roots develop first and then the fine roots branch from them. In other crops, such as sugar cane (Ball-Coelho et al. 1992) and rice (Slaton et al. 1990), development of the root system in the ratoon cropping period (period between first and second harvest) has been described. However, in grasses, the root biomass has been reported to decrease due to defoliation (Ferraro and Oesterheld 2002). The dynamics of root development in the ratoon cropping period likely differ depending on the crop variety and growth environment.

This study quantitatively describes the features of the roots of processing spinach in the context of ratoon harvesting system. It will now be necessary to investigate the activity of these roots and the relationships between root development and absorption of water and nutrients. In Japan, a useful harvesting system is assembled using the above-mentioned harvesting machine in an attempt to expand spinach production; the results are summarized in a manual for farmers (KARC/NARO et al. 2018). A greater understanding of the root system in ratoon harvesting system will help the
development of protocols for more efficient use of water and nutrients and thus contribute to better cultivation in the system.

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References

Ball-Coelho B, Sampaio EVSB, Tiessen H, Stewart JWB 1992 Root dynamics in plant and ratoon crops of sugar cane. Plant Soil 142: 297-305.
Ferraro DO, Oesterheld M 2002 Effect of defoliation on grass growth. A quantitative review. Oikos 98: 125-133.
Fujiwara T, Kumakura H, Yoshida Y 2003 Relation between patterns of growth and internal quality component in transplant cultivation of spinach. J. Jpn. Soc. Hort. Sci. Suppl. 72: 408. (in Japanese)
Hayashi S, Ito H, Yoshida H, Yamazaki K, Komatsu T 2004 Dependence of productivity and leaf wilting in sugar beet (Beta vulgaris L.) on depth of fibrous root distribution in different soil types. Jpn. J. Soil Sci. Plant Nutr. 75: 659-666. (in Japanese with English abstract)
Hayashi T, Nagao A 2010 A diagnostic method for measuring nitrogen in subsoil to decrease the nitrate accumulation in spinach. Jpn. Soc. Soil Sci. Plant Nutr. 81: 263-266. (in Japanese)
Itoh H, Yokota K, Yoshida H, Komatsu T 2008 A leaf wilting in sugar beet (Beta vulgaris L.) based on varietal difference of root system. Root Res. 17: 91-98. (in Japanese with English abstract)
Iwasaki Y 2008 Ratoon cropping for commercial fragile leafy greens. Agric. Hortic. 63: 54-56. (in Japanese, translation by authors)
KARC/NARO, Miyazaki Prefecture, Kumamoto Prefecture, Cleaning Nishizawa Co., LTD, Kumarei Co., Ltd. 2018 Spinach mechanical harvest systems manual for processing. Ishii T ed. http://www.naro.affrc.go.jp/publicity_report/publication/pamphlet/tech-pamph/081362.html (latest update: March 30, 2018). (in Japanese, translation by authors)
Ministry of Agriculture, Forestry and Fisheries 2018 Vegetable production shipment statistics. https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&output=&view=00500215%26stat=000001013427%26cycle=7%26year=2017%26month=0%26class1=000001032286%26class2=000001032933%26class3=000001121095 (in Japanese, translation by authors) (latest update: November 12, 2018).
Morita S, Sekiya N, Abe J 2013 Grasping root system morphology. Root Res. 22: 9-17. (in Japanese with English abstract)
Nakano A 2004 What kind of root is it? 10th spinach. Root Res. 13: 57-59. (in Japanese, translation by authors)
Oyanagi A, Nakamoto T, Wada M 1993 Relationship between root growth angle of seedlings and vertical distribution of roots in the field in wheat cultivars. Jpn. J. Crop. Sci. 62: 565-570.
Schenk M, Heins B, Steingrobe B 1991 The significance of root development of spinach and kohlrabi for N fertilization. Plant Soil 135: 197-203.
Slaton NA, Beyrouty CA, Wells BR, Norman RJ, Gbur EE 1990 Root growth and distribution of two short-season rice genotypes. Plant Soil 121: 269-278.
Suzuki T, Kamada E, Ishii T, Adachi K, Niimi H 2016 Effects of spinach cultivars and additional fertilization on growth in ratoon cropping. Jpn. J. Farm Work Res. 51(Extra issue 1): 3-4. (in Japanese, translation by authors)
Suzuki T, Kamada E, Ishii T, Adachi K, Niimi H 2018 Effects of spinach cultivars and cultivation conditions on leaf yield and appearance quality in ratoon cropping for processing use. Jpn. J. Farm Work Res. 55: 33-41. (in Japanese with English abstract)
Weaver JE, Bruner WE 1927 Chapter X: Spinach. In: Sinnott E. W., Ed., Root development of vegetable crops. McGraw-Hill Book Company, Inc., New York, pp. 95-100.