Wide-row Seeding Cultivation of the Nematode-suppressive Forage Crop Palisade Grass (*Urochloa brizantha*) cv. MG5 in the Southern Kyushu Region of Japan

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We conducted a serial field experiment study with row seeding cultivation (RSC) of palisade grass (a nematode-suppressive forage crop) and machine intertillage for weed and nematode control. We aimed to examine RSC of palisade grass under several inter-row spacing (IRS) conditions using intertillage with a view to the use of palisade grass in crop rotation for nematode control on cultivating farms, as well as use of the shoots as forage on regional livestock farms. In Field Experiment 1, RSC with IRSs of 60, 80, and 100 cm showed no significant differences in yield between these IRS conditions. In Field Experiment 2 and Field Experiment 3, IRSs were set at 80 and 120 cm, and plant-parasitic nematode densities were suppressed to suitably low levels in Field Experiment 2. There was no significant difference in yield between the 80 and 120 cm IRS treatments after three months of cultivation in Field Experiment 3. Comparing RSC with a 120 cm IRS with broadcast seeding cultivation (BSC) in Field Experiment 4, the yield from RSC tended to be higher than that from BSC. Weed dry weight was higher in the BSC system than in the RSC system after two rounds of intertillage in RSC until 127 days after sowing. In Field Experiment 5, an RSC treatment with a 120 cm IRS was constructed in a farmer’s field, and the root-knot nematode density was clearly suppressed on the palisade grass yield survey date. We concluded that wide-row seeding cultivation with an IRS of 120 cm is one of the practical choices for the combined utilization of palisade grass for forage production and as a nematode-suppressive crop.

**Key Words**: intertillage, nematode-suppressive forage crop, palisade grass, weed control, wide-row seeding cultivation.

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Acronyms:

| Acronym       | Description                  |
|---------------|------------------------------|
| BSC           | broadcast seeding cultivation,|
| DAS           | days after seeding,           |
| IRS           | inter-row spacing,            |
| RSC           | row seeding cultivation,      |
| SRC           | seeding rate condition,       |
| W/CR          | weed/crop ratio               |
1. Introduction

Palisade grass (Urochloa brizantha [Hochst. ex A. Rich.] R.D. Webster syn. Brachiaria brizantha [A. Rich.] Stapf) originated in tropical Africa (Keller-Grein et al. 1996, Kouki and Ebina 2009). Interest in the use of Brachiaria spp. as sown and managed forage began in the 1960s, initially on a limited scale in tropical Australia, and subsequently in tropical South America in the early 1970s (Miles et al. 2004). Several species of Urochloa syn. Brachiaria are widely-grown in lowland agroecosystems of the humid and subhumid South American tropics, and most commercial species are adapted to the low-fertility acidic soils of the tropics (Rao et al. 1995, Rao et al. 1996). Recently, palisade grass as forage has been introduced in tropical areas in eastern Asia, for example in Thailand (Hare et al. 2005), and in subtropical areas in other parts of the world, for example in Florida (Vendramini et al. 2014).

In Japan, palisade grass introduction experiments to assess forage utilization potential have been conducted in areas with subtropical and temperate climates, particularly the Okinawa Prefecture and southern Kyushu region (Hanagasaki et al. 2007, Ishigaki et al. 2018, Kaneko et al. 2012, Kaneko et al. 2014, Kaneko et al. 2015, Kaneko et al. 2017, Kaneko et al. 2018, Nitthaisong et al. 2017). Kaneko et al. (2018) concluded that development of weed control with herbicide or intertillage are required for solving weed problem at the first crop of spring-seeded palisade grass as annual summer grass in southwest Japan. In Okinawa, Kudaka et al. (2010) compared the dry matter and crude protein yields of the Urochloa species U. decumbens cv. Basilisk, U. brizantha cv. Marandu, U. brizantha cv. MG5, U. humidicola, U. ruziizensis, and U. mutica with Chloris gayana Kunth (rhodes grass) cv. Katambora, and reported that U. brizantha cv. MG5 showed the highest dry matter and crude protein yields. These authors suggested that, compared with rhodes grass which was commonly grown in Okinawa at the time, Urochloa spp. showed promise as high yield forage grasses. On the basis of these findings, we selected U. brizantha cv. MG5 for the seeding cultivation experiments reported in this study.

Besides forage crop investigations, experiments on the utilization of palisade grass for the suppression of plant-parasitic nematodes have also been conducted (Dias-Arieira et al. 2002, Uesugi et al. 2015). The nematode-suppressive effect of palisade grass appears to be species-specific. The presence of palisade grass tended to increase populations of Pratylenchus brachyurus and P. zeae (de Carvalho et al. 2013) and these two nematode species were found in association with palisade grass in tropical pastures in Colombia (Stanton et al. 1989) whereas suppressive effects of palisade grass have been reported for Meloidogyne incognita and M. javanica (Dias-Arieira et al. 2002), and P. coffeae (Uesugi et al. 2015). The later report indicated that palisade grass cv. MG5 suppressed the reproduction of P. coffeae in pot and seedling tray experiments and under field conditions. These two species of M. incognita and P. coffeae are commonly known as root-knot and root-lesion nematodes, respectively, and are major plant-parasitic nematodes that cause severe damage to sweet potato and taro plants (Iwahori et al. 2000) in the warm upland farming area in Japan. Used on a crop rotation basis, palisade grass is expected to be a nematode-suppressive crop against these two plant-parasitic nematodes (Uesugi et al. 2015).

The use of nematode-suppressive crops is one of the most intensively studied cultural control methods (Uesugi et al. 2015). Weed control is a key aspect of these control measures because weeds can be hosts for nematode propagation. As alternative hosts for plant-parasitic nematodes, weeds have been recognized for their ability to maintain nematode populations targeted for suppression by various management strategies (Thomas et al. 2005). Studies about palisade grass cropping patterns for successful nematode suppression on cultivating farms are limited but necessary because of the challenges to achieving successful weed control. For example, cultivating palisade grass by broadcast seeding in large fields makes weeding by hand non-viable and as yet there are no registered herbicides in Japan for chemical control of weeds in palisade
grass fields after seeding. In addition, weed control improves crop production by reducing competition for soil nutrients and light. It also decreases weed seed propagation and storage in the soil seedbank, which potentially reduces the occurrence of weeds in successive cropping.

Row-seeding cultivation (RSC) of palisade grass has been investigated in other studies. In Northeast Thailand, Hare et al. (2009) conducted RSC experiments that included palisade grass sown at a density of 1 g germinable seed m$^{-2}$ with inter-row spacing (IRS) of 50 cm to compare dry matter yield and seed production among the grasses. Kaneko et al. (2018) conducted palisade grass cultivation experiments using RSC with IRSs of 27 and 54 cm by an unplowed reseeding machine under partial tillage conditions after Italian ryegrass (Lolium multiflorum Lam.) cultivation, and broadcast seeding under different seeding densities to investigate annual summer forage production in the temperate zone. In addition to pure forage cultivation, intercropping of crop plants including maize (Zea mays L.), soybean (Glycine max L.), and sorghum (Sorghum bicolor [L.] Moench) with perennial forages such as palisade grass is becoming popular in Brazil in intensive and family agriculture (Crusciol et al. 2012). This type of intercropping has many benefits and is known as crop-livestock integration (CLI), a mixed system of cultivation in which a cash crop is intercropped with a forage species that can be used for animal grazing after crop harvesting (Crusciol et al. 2012). A number of studies have investigated CLI. Borghi and Crusciol (2007) and Borghi et al. (2012) cultivated maize at IRSs of 45 and 90 cm intercropped with palisade grass. Borghi et al. (2013) cultivated sorghum at an IRS of 80 cm with intercropped palisade grass or guinea grass (Panicum maximum Jacq.), and Crusciol et al. (2014) cultivated soybean at an IRS of 45 cm intercropped with palisade grass in no-tillage systems. Single crop cultivation experiments using palisade grass include a study by Brandan et al. (2017) who assessed the effect of palisade grass as a cover crop on soil biochemical properties in a degraded agricultural soil in a subtropical region of Argentina. This cover crop experiment was conducted using an IRS of 125 cm (sown using a seed drill at a dose of 4–5 kg ha$^{-1}$ with 12 rows in 15 m widths) under no till conditions.

In the present study, we tested a new cropping management system based on using RSC with machine intertillage for weed control during palisade grass cultivation as annual summer grass. The purpose of this study, therefore, was to examine RSC of palisade grass under several IRS conditions using intertillage for weed and nematode control with a view to the combined use of palisade grass in crop rotation for nematode control on cultivating farms, as well as use of the shoots as forage for animals on regional livestock farms. We first conducted RSC of palisade grass under 60, 80, and 100 cm IRS conditions with intertillage using a walking-type cultivator (Field Experiment 1), then extended the IRS to 120 cm for the purpose of controlling weeds by machine intertillage using a 10 kW-level tractor with a rotary tiller, because we realized that using a walking-type cultivator for intertillage was laborious, and that intertillage by tractor was preferable to reduce the weed control workload. Consequently it was necessary to elucidate the yield properties of palisade grass under RSC with a 120 cm IRS, we compared dry matter yield, plant length, and stem number between RSCs with 80 and 120 cm IRSs (Field Experiments 2 and 3), and between RSC with a 120 cm IRS and broadcast seeding cultivation (Field Experiment 4).

2. Materials and Methods

Field Experiment 1 (2010): Row seeding cultivation with inter-row spacing of 60, 80, and 100 cm

This RSC experiment (Field Experiment 1) was conducted in 2010 in a field (31°45′N, 131°01′E, elevation 183.2 m) at the Miyakonojo Research Station, NARO Kyushu Okinawa Agricultural Research Center (NARO/KARC), Miyakonojo, Miyazaki Prefecture. The soil in the field was an Andosol with a loam texture (27.4% coarse sand, 35.1% fine sand, 27.3% silt, and 11.2% clay). The area of the field experiment was 5.5 a. Cattle manure and lime were applied at a rate of 30 t ha$^{-1}$ and 600 kg ha$^{-1}$, respectively, and chemical fertilizer
containing N 60 kg ha\(^{-1}\), P\(_2\)O\(_5\) 60 kg ha\(^{-1}\), and K\(_2\)O 48 kg ha\(^{-1}\) was also applied. Row seeding cultivation was examined under three IRS conditions: 60, 80, and 100 cm, replicated twice. Seeding was conducted using a seeding machine with a seeding rate of 2.4 g m\(^{-1}\) on the row, consequently seeding densities were 4 g m\(^{-2}\), 3 g m\(^{-2}\), and 2.4 g m\(^{-2}\), respectively, for the IRS conditions of 60, 80, and 100 cm. The seeding date was July 21, 2010 and weed control, through intertillage using a walking-type cultivator, was conducted 13 and 28 days after seeding (DAS) during the first crop. The first shoot harvesting survey was conducted on 9 and 10 September (50 and 51 DAS, respectively). Weed dry matter was also determined and the weed/crop ratio (W/CR) calculated. After the survey, the shoots were harvested at a height of approximately 15 cm above the ground and removed from the field at 55 DAS (14 September). After the first harvest, regrowth cultivation was supported. During the second crop (regrowth cultivation), intertillage was conducted once at 70 DAS (September 29) using a walking-type cultivator, and topdressing fertilizer was applied at the rate of N 30 kg ha\(^{-1}\) and K\(_2\)O 24 kg ha\(^{-1}\). The second harvest survey was conducted on 15 December at 156 DAS.

The nematode-suppressive effects of the palisade grass were estimated in the two plots where the nematode-susceptible sweet potato cultivar Koganesengan was cultivated in 2010. Each of the 80 and 120 cm IRS treatment plots was divided into two subplots (one subplot: 6 m × 18 m) and nematode densities were determined from the inter-hill (on the row) and the inter-row sites in each subplot. Soils were sampled from the 0–15 cm layer. To determine the density of nematodes before and after palisade grass cultivation, soils were sampled on July 4 and on December 15, respectively. Over three day periods, the Baermann funnel method was used to extract nematodes from fresh 20 g subsamples of composite soil samples collected from each of the IRS treatment subplots. The numbers of root-knot (Meloidogyne spp.) and root-lesion (Pratylenchus spp.) nematodes were counted under a microscope (Olympus, BX41) and the average of two subsamples was used to reflect the population of nematodes in the composite soil samples from each subplot.

Field Experiment 2 (2011): Row seeding cultivation with inter-row spacing of 80 and 120 cm in relation to plant-parasitic nematode densities before and after palisade grass cultivation

Field Experiment 2 was conducted in 2011 in a 9 a field adjacent to that used for Field Experiment 1. The field was divided into four plots (one plot: 6 m × 36 m) where two plots were cultivated with sweet potato (Ipomoea batatas [L.] Lam.) cv. Koganesengan, a nematode-susceptible crop, during the summer of 2010. The other two plots were bare fallow at the corresponding time. All four plots were fertilized with cattle manure and lime, applied at a rate of 30 t ha\(^{-1}\) and 600 kg ha\(^{-1}\), respectively. Chemical fertilizer containing N 60 kg ha\(^{-1}\), P\(_2\)O\(_5\) 60 kg ha\(^{-1}\), and K\(_2\)O 48 kg ha\(^{-1}\) was also applied. Row seeding cultivation was examined under two IRS conditions of 80 and 120 cm. Each IRS condition was applied to one of each pair of plots with and without sweet potato cultivation in 2010. A seeding machine was adjusted to a seeding rate of 3.2 g m\(^{-1}\) on the row; hence, seeding densities were 4 g m\(^{-2}\) for the 80 cm IRS and 2.7 g m\(^{-2}\) for the 120 cm IRS condition. The seeding date was July 12, 2011 and weed control intertillages were conducted twice at 20 and 38 DAS using a walking-type cultivator (TR7000, 4.6 kW) for the 80 cm IRS and a 9.9 kW tractor (Ke-3) with a rotary tiller for the IRS of 120 cm (width of tillage: 95 cm) during the first crop. The shoot survey in the first harvest was conducted on September 13 (63 DAS). The shoots were harvested on 14 September (64 DAS) and regrowth cultivation was supported. During the second crop (regrowth cultivation), intertillage was implemented once at 79 DAS (September 29), and topdressing fertilizer was applied at the rate of N 30 kg ha\(^{-1}\) and K\(_2\)O 24 kg ha\(^{-1}\). The second harvest survey was conducted on 15 December at 156 DAS.

Field Experiment 3 (2013): Row seeding cultivation with inter-row spacing of 80 and 120 cm under two levels of seeding rate conditions

Field Experiment 3 was conducted in 2013 using a
Field Experiment 4 (2013): Comparison between row seeding cultivation with inter-row spacing of 120 cm and broadcast seeding cultivation

Field Experiment 4 was conducted in 2013 using a 4.8 a field adjacent to those used for Field Experiments 1, 2 and 3. Cattle manure and lime were applied at a rate of 30 t ha\(^{-1}\) and 1 t ha\(^{-1}\), respectively, and chemical fertilizer containing N 60 kg ha\(^{-1}\), P\(_2\)O\(_5\) 60 kg ha\(^{-1}\), and K\(_2\)O 48 kg ha\(^{-1}\) was also applied. Row seeding cultivation was compared with broadcast seeding cultivation (BSC) with two replicates. Row seeding cultivation was conducted under an IRS of 120 cm with a seeding density of 1 g m\(^{-2}\). Broadcast seeding cultivation was conducted with a seeding density of 4 g m\(^{-2}\). In RSC under a 120 cm IRS, intertillage for weed control was conducted twice (19 and 35 DAS) using a 9.9 kW tractor with a rotary tiller; however, in BSC, no weed control measures were implemented. The seeding date was July 11, 2013, and a harvest survey was conducted on November 15 at 127 DAS without regrowth cultivation. Shoot yield and weed dry matter surveys were conducted at 46, 68, 92, and 127 DAS and palisade grass plant length was measured regularly.

Field Experiment 5: Wide-row seeding cultivation with an inter-row spacing of 120 cm in relation to plant-parasitic nematode densities before and after palisade grass cultivation

Field Experiment 5 was conducted in 2012 in a farmer’s field (32°00′N, 131°29′E, elevation 67.5 m) in Demizubaru, Kunitomi-cho, Higashimorokata, Miyazaki Prefecture. The experiment was conducted over a 38 a area (39 m × 98 m). The field was cultivated with the nematode-susceptible sweet potato cv. Koganesengan during the summer of 2011, and with spinach (Spinacia oleracea L.) from October 2011 to March 2012. Swine manure and lime were applied at rates of 40 t ha\(^{-1}\) and 1 t ha\(^{-1}\), respectively, and no chemical fertilizer was applied. Row seeding cultivation under these conditions was investigated under an IRS of 120 cm. Seeding was accomplished using a seeding machine with a seeding density of 2.25 g m\(^{-2}\). The seeding date was May 18, 2012 and weed control through intertillage was conducted twice (at 24 and 48 DAS) using 10 kW-level tractors. The total area of the farmer’s field was divided into 20 plots measuring 10 m × 20 m each to measure palisade grass shoot yield and plant length, weed dry matter, and nematode density. The shoot yield survey was conducted on August 22, at 96 DAS. To determine the density of nematodes before and after palisade grass cultivation, soils were sampled on May 18 (seeding date) and on August 22 (yield survey date; 96 DAS). Soils were sampled from the 0–20 cm layer of inter-hill (on the row) and inter-row sites in each plot. Statistical analysis was conducted using Analysis of Variance (ANOVA).

### 3. Results

Field Experiment 1 (2010): Row seeding cultivation with inter-row spacing of 60, 80, and 100 cm

Shoot harvesting surveys were conducted twice at 50 and 110 DAS. The shoot dry matter yields...
Table 1. Shoot dry matter yield, weed dry matter, and weed/crop ratio in Field Experiment 1 conducted in 2010 using row seeding cultivation under inter-row spacing conditions of 60, 80, and 100 cm for two harvests in the first crop and the second crop (regrowth cultivation).

| Inter-row spacing condition | Shoot dry matter yield (g m⁻²) | Weed dry matter (g m⁻²) | Weed/crop ratio |
|----------------------------|-------------------------------|------------------------|----------------|
|                            | 1st harvest (50 DAS)          | 2nd harvest (110 DAS)  | 1st harvest    | 2nd harvest (regrowth) survey |
|                            |                               |                        | 1st harvest    | 2nd harvest (regrowth) survey |
|                            |                               |                        | 50 DAS         | 110 DAS                     |
| 60 cm                      | 495 ± 141                     | 382 ± 21               | 480 ± 112      | 6.1 ± 0.2                   | 0.392 0.170 |
| 80 cm                      | 384 ± 46                      | 370 ± 18               | 247 ± 79       | 13.9 ± 0.1                  | 0.643 0.038 |
| 100 cm                     | 475 ± 74                      | 388 ± 23               | 129 ± 74       | 14.9 ± 5.2                  | 0.272 0.038 |

Intertillages were conducted twice during the first crop at 13 and 28 days after seeding using a walking-type cultivator. Intertillage was conducted once during the second crop (regrowth cultivation) at 70 days after seeding using a walking-type cultivator. DAS: days after seeding.

Table 2. Shoot dry matter yield, weed dry matter, and weed/crop ratio in Field Experiment 2 conducted in 2011 using row seeding cultivation under inter-row spacing conditions of 80 and 120 cm for two harvests in the first crop and the second crop (regrowth cultivation).

| Inter-row spacing condition | Shoot dry matter yield (g m⁻²) | Weed dry matter (g m⁻²) | Weed/crop ratio |
|----------------------------|-------------------------------|------------------------|----------------|
|                            | 1st harvest (63 DAS)          | 2nd harvest (156 DAS)  | 1st harvest    | 2nd harvest (regrowth) survey |
|                            |                               |                        | 63 DAS         | 156 DAS                     |
| 80 cm                      | 781 (694, 868)                | 340 (353, 327)         | 4.9 (2.3, 7.1) | 46.0 (26.6, 65.4)           | 0.006 0.135 |
| 120 cm                     | 623 (609, 638)                | 253 (241, 265)         | 3.8 (6.5, 1.0) | 43.1 (57.3, 29.0)           | 0.006 0.170 |

Shoot dry matter yields are averages of the values in two plots with and without previous season sweet potato cultivation in 2010. Intertillages were conducted twice during the first crop at 20 and 38 days after seeding using a walking cultivator for the 80 cm inter-row spacing (IRS) and a 9.9 kW tractor with a rotary tiller for the 120 cm IRS. Intertillage was conducted once during the second crop (regrowth cultivation) at 79 days after seeding using a walking-type cultivator for the 80 cm IRS and a 9.9 kW tractor with a rotary tiller for the 120 cm IRS. DAS: days after seeding.

from the first harvest survey were slightly higher for the IRSs of 60 and 100 cm than for the IRS of 80 cm; however, these differences were not significant (Table 1). The relatively low shoot dry matter yield for the 80 cm IRS condition could reflect the impact of weeds because there was a relatively high weed dry matter weight for this IRS in comparison with the others (Table 1). Even though weed control intertillages were conducted twice (13 and 28 DAS), the first harvest weed dry matter weights were high (129–247 g m⁻²) for all IRS treatments. The second harvest survey (110 DAS) shoot dry matter yields for all IRS treatments were similar (370–388 g m⁻²) and the weed dry matter weights were lower than those in the first harvest survey. Consequently, the W/CRs were comparatively high at the time of the first survey (0.27–0.64) but had decreased to 0.02–0.04 by the second survey. We determined that there was no significant differences in shoot yield between these IRS conditions in ANOVA analysis, realized that using a walking-type cultivator for intertillage was laborious, and then extended the IRS to 120 cm for the purpose of controlling weeds using a 10 kW-level tractor with a rotary tiller in Field Experiments 2, 3, 4, and 5.

Field Experiment 2 (2011): Row seeding cultivation with inter-row spacing of 80 and 120 cm in relation to plant-parasitic nematode densities before and after palisade grass cultivation

Shoot dry matter yields under the 80 cm IRS condition in both harvest surveys (63 and 156 DAS) were higher than those under the 120 cm IRS condition (Table 2). Weed dry matter weights in the first harvest survey (63 DAS) were sufficiently low and the W/CR was 0.006 for both IRS conditions. By the second harvest survey (156 DAS), weed dry matter weights had increased to 43–46 g m⁻², and the W/CRs also showed an increase (0.135 and 0.170) for the 80 and 120 cm IRS conditions, respectively. However, the plant-parasitic nematode densities of both the root-knot and root-lesion nematodes...
after palisade grass cultivation were suppressed to lower levels in comparison with the densities before palisade grass cultivation (Table 3). Since weeds can be hosts for nematode propagation (Thomas et al. 2005), weed control is required for effective nematode-suppression. We found that the densities of the root-knot and root-lesion nematodes were suppressed to suitably low levels (0–0.3 individuals per 20 g of fresh soil for the root-knot nematode, and 0–2.5 individuals per 20 g of soil for the root-lesion nematode) after palisade grass RSC under 80 and 120 cm IRS conditions (Table 2). This suppression occurred both in inter-hill (on the row) and inter-row soils; however, the densities in the inter-row soils tended to be lower than those in the inter-hill soils. This finding may be related to the presence of weeds in the inter-hill sites, because intertillage weeding can control weeds only in the inter-row areas. Overall, these results suggest that palisade grass RSC could suppress the propagation of plant-parasitic nematodes when cultivated on a crop rotation basis.

Field Experiment 3 (2013): Row seeding cultivation with inter-row seeding of 80 and 120 cm under two levels of seeding rate conditions

At 61 DAS shoot dry matter yield was significantly higher in the 80 cm than in the 120 cm IRS treatment (Table 4). Thereafter, at 88, 111, and 130 DAS, the differences between the 80 and 120 cm IRS treatments were not significant. The effect of seeding rate on the row (1.2 and 2.4 g m\(^{-1}\)) was not significant at 61, 88, and 111 DAS; however, at 130 DAS, the SRC of 2.4 g m\(^{-1}\) showed increased shoot yield (significant at 5%) compared to the SRC of 1.2 g m\(^{-1}\). Fluctuations of plant length indicate a
similar pattern among the four treatments (Table 5). At 98, 113, and 133 DAS (after three months of cultivation), plant lengths were over 200 cm in all treatments. Regarding weed control, weed dry matter weights were highest at 61 DAS (30–45 g m$^{-2}$) indicating poor control; thereafter, the weed dry matter weights gradually decreased to below 10 g m$^{-2}$ at 111 DAS in all treatments (Table 6). The W/CRs gradually decreased and, at 88 DAS, the values were less than 0.03 in all treatments; thereafter, the values remained low (Table 7). The Field Experiment 3 results indicate that RSC with a 120 cm IRS could enable effective weed control by intertillage using a 10 kW-level tractor with a rotary tiller, and could also result in a saving of seeds due to a low seeding density requirement (1–2 g m$^{-2}$).

Field Experiment 4 (2013): Comparison between row seeding cultivation with inter-row spacing of 120 cm and broadcast seeding cultivation

Shoot dry matter yield from BSC was higher than from RSC with an IRS of 120 cm at 46 DAS, but at 68 DAS, the yield from RSC was higher than from BSC (Table 8). Thereafter, shoot yields tended to be higher from RSC than from BSC. Regarding fluctuations in palisade grass plant length (Fig. 1), at

Table 5. Palisade grass plant length in Field Experiment 3 conducted in 2013.

| Seeding rate on the row spacing (g m$^{-1}$) | 19 DAS | 27 DAS | 40 DAS | 54 DAS | 64 DAS |
|-------------------------------------------|--------|--------|--------|--------|--------|
| 80 cm 1.2                                 | 23.8 ± 0.2 | 52.1 ± 1.9 | 101.3 ± 2.7 | 154.4 ± 4.2 | 171.0 ± 1.5 |
| 80 cm 2.4                                 | 26.9 ± 0.6 | 56.8 ± 1.8 | 109.3 ± 2.1 | 154.2 ± 1.6 | 170.3 ± 0.4 |
| 120 cm 1.2                                | 26.6 ± 0.5 | 57.1 ± 0.8 | 101.5 ± 2.8 | 148.1 ± 1.5 | 168.6 ± 1.1 |
| 120 cm 2.4                                | 28.9 ± 2.9 | 58.0 ± 4.9 | 104.8 ± 2.7 | 148.5 ± 0.9 | 163.1 ± 1.4 |

Intertillages were conducted twice at 21 and 35 or 36 days after seeding. Values are average ± standard deviation of two replicates. DAS: days after seeding.

Table 6. Weed dry matter in Field Experiment 3 conducted in 2013.

| Seeding rate on the row spacing (g m$^{-1}$) | 61 DAS | 88 DAS | 111 DAS | 130 DAS |
|-------------------------------------------|--------|--------|---------|---------|
| 80 cm 1.2                                 | 44.6 ± 8.0 | 11.7 ± 2.3 | 6.7 ± 3.5 | 2.8 ± 2.0 |
| 80 cm 2.4                                 | 30.0 ± 12.8 | 6.8 ± 2.5 | 4.0 ± 2.5 | 2.2 ± 1.0 |
| 120 cm 1.2                                | 35.3 ± 0.2 | 9.8 ± 0.3 | 5.9 ± 3.0 | 2.6 ± 2.0 |
| 120 cm 2.4                                | 30.1 ± 3.4 | 25.3 ± 10.1 | 2.3 ± 1.7 | 3.6 ± 0.6 |

Intertillages were conducted twice at 21 and 35 or 36 days after seeding. Values are average ± standard deviation of two replicates. DAS: days after seeding.

Table 7. Weed/crop ratio on a dry matter basis in Field Experiment 3 conducted in 2013.

| Seeding rate on the row spacing (g m$^{-1}$) | 61 DAS | 88 DAS | 111 DAS | 130 DAS |
|-------------------------------------------|--------|--------|---------|---------|
| 80 cm 1.2                                 | 0.073 | 0.003 | 0.005 | 0.003 |
| 80 cm 2.4                                 | 0.064 | 0.007 | 0.003 | 0.001 |
| 120 cm 1.2                                | 0.078 | 0.011 | 0.005 | 0.002 |
| 120 cm 2.4                                | 0.061 | 0.027 | 0.002 | 0.003 |

Intertillages were conducted twice at 21 and 35 or 36 days after seeding. IRS: inter-row spacing, DAS: days after seeding.
Table 8. Shoot dry matter yield in Field Experiment 4 conducted in 2013.

| Cultivation pattern (RSC/BSC) | Shoot dry matter yield (g m$^{-2}$) | Yield survey date (DAS) |
|------------------------------|-------------------------------------|-------------------------|
| 120 cm-RSC                  | 284 ± 37                            | 68 DAS                  |
|                              | 1289 ± 108                          | 92 DAS                  |
| BSC                          | 383 ± 50                            | 127 DAS                 |
|                              | 1399 ± 104                          | 120 cm-RSC

ANOVA, one factor

Cultivation pattern ns ** ns ns

Intertillages were conducted twice at 19 and 35 dys after seeding.

Values are average ± standard deviation of two replicates.

“**” indicates a significant difference between the levels of the factor at 1% level in ANOVA analysis.

“ns” indicates no significant difference in ANOVA analysis.

RSC: row seeding cultivation, BSC: broadcast seeding cultivation, DAS: days after seeding.

Fig. 1  Fluctuations of palisade grass plant length in Field Experiment 4 conducted in 2013. Vertical bars indicate standard deviations of two replicates. RSC: row seeding cultivation, BSC: broadcast seeding cultivation, DAS: days after seeding.

25 and 38 DAS, plant length in the BSC treatment was greater than in the RSC treatment; thereafter, greater plant lengths were recorded from RSC than from BSC. Weed dry matter weights showed a substantial initial increase in the BSC treatment (240 g m$^{-2}$ at 46 DAS) and then fluctuated from 171 g m$^{-2}$ at 68 DAS to 93 g m$^{-2}$ at 127 DAS. In comparison, weed dry matter weights from RSC were sufficiently low (below 4 g m$^{-2}$) after three months of cultivation (Fig. 2). Hence, weed dry weight was higher under the BSC system than under the RSC system after the two rounds of intertillage in RSC until 127 DAS.

Fluctuations of W/CR showed effective control of weeds in RSC and insufficient control in BSC (Fig. 3). At 68, 92, and 127 DAS, the W/CR was very low (0.002–0.012) in the RSC treatment, but high (0.072–0.294) in the BSC treatment. The Field Experiment 4 results confirm that using RSC with a 120 cm IRS could produce suitable palisade grass shoot yields and sufficiently low W/CRs in comparison with BSC.
Field Experiment 5: Wide-row seeding cultivation with an inter-row spacing of 120 cm in relation to plant-parasitic nematode densities before and after palisade grass cultivation

On the yield survey date (96 DAS), shoot dry matter yield was 1161 ± 155 g m\(^{-2}\) (average ± standard deviation (SD) among 20 plots), plant length was 223 ± 7 cm (n = 20), and weed dry weight was 0.05 ± 0.22 g m\(^{-2}\) (n = 19). Hence, the W/CR was sufficiently low (< 0.0001). Root-knot nematode densities on the seeding date ranged from 0 to 12.0 individuals per 20 g soil, and the average ± SD (n = 20) was 3.12 ± 3.29 individuals per 20 g soil (Table 9). On the yield survey date, root-knot nematode density in the inter-hill site soils was zero in 18 out of the 20 plots, and the average was 0.05 ± 0.16 (n = 20), whereas the density in the inter-row site soils was zero in 19 of the 20 plots with an average of 0.03 ± 0.15 (n = 20). Root-lesion nematodes were not detected at any plot during Field Experiment 5. The clear suppression of root-knot nematodes in Field Experiment 5 could be owing to the high yield (1161 g m\(^{-2}\)) and extremely low W/CR.

Table 9. Root-knot nematode density sampled on the date of seeding and of the yield survey in Field Experiment 5 (Farmer’s Field Introduction Test) conducted in 2012 using wide-row seeding cultivation with an inter-row spacing of 120 cm.

| Sampling date          | Sampling site | Nematode density (individual no. per 20 g soil) | Average ± SD (n=20) |
|------------------------|---------------|-----------------------------------------------|---------------------|
| 18 May 2012 (on the seeding date) | Inter-hill | 0.115 0.012 0.157 0.072 0.127 0.294 | 0.002 ± 0.002 |
| 22 August 2012 (on the yield survey date) | Inter-row | 0.03 0.00 0.07 0.00 0.00 0.00 | 0.000 ± 0.000 |

**Note:** The area of the farmer’s field was 38 a (39 m × 98 m) and was divided into twenty 10 m × 20 m plots (A to T) for examination of the nematode density. Intertillages were conducted twice at 24 and 48 days after seeding using 10-kW-level tractors with rotary tillers in the 120 cm inter-row spaces.

Fig. 3 Fluctuations of weed/crop ratio on a dry matter basis in Field Experiment 4 conducted in 2013.

RSC: row seeding cultivation, BSC: broadcast seeding cultivation, DAS: days after seeding.
4. Discussion

The purpose of this study was to investigate the utilization of palisade grass for nematode control in crop rotation on cultivating farms, as well as use of the shoots as forage for animals on regional livestock farms. At the time of this study, palisade grass had not yet been introduced as part of the crop rotation system on cultivating farms in the Kyushu region. Since weeds can be hosts for nematode propagation (Thomas et al. 2005), weed control is required for effective nematode-suppression. Consequently, we had to establish a suitable cultivation method, both for forage production and weed control, and had to confirm the nematode-suppressive effect of palisade grass as part of the crop rotation system. As one of the solutions, we aimed to develop a wide-row seeding cultivation method for this nematode-suppressive forage crop for use on a crop rotation basis for nematode control on cultivating farms. This serial field experiment study revealed that RSC of a nematode-suppressive forage crop, palisade grass cv. MG5, with an IRS of 120 cm, (which we refer to as wide-row seeding cultivation), could produce a suitable forage yield (over 1 kg dry matter m\(^{-2}\) in Field Experiments 3, 4, and 5), in association with weed control by intertillage using a 10 kW-level tractor with a rotary tiller.

Kaneko et al. (2012) and Uesugi et al. (2015) conducted palisade grass cultivation experiments with BSC at a seeding density of 4 g m\(^{-2}\), while Hanagasaki et al. (2008) and Nitthaisong et al. (2017) used a seeding density of 3 g m\(^{-2}\). Kaneko et al. (2018) also conducted BSC of palisade grass at seeding densities of 2 and 4 g m\(^{-2}\), and suggested that the lower seeding density (2 g m\(^{-2}\)) tended to reduce the forage yield in the first harvest, and it was difficult to control weeds using BSC with a seeding density of less than 4 g m\(^{-2}\). We used a seeding density of 4 g m\(^{-2}\) for BSC in our Field Experiment 4, and obtained very high W/CRs, suggesting that palisade grass sown using BSC at this seeding density is a weak competitor in comparison with weeds, especially during the initial growth stage. Given that, at the time of this study, there was no registered herbicide for palisade grass after seeding, we conducted RSC of palisade grass with a view to investigating alternative weed control methods. This approach to palisade grass cropping has been used in other studies. Hare et al. (2009) conducted RSC experiments in Northeast Thailand that included palisade grass sown at a seeding density of 1 g germinable seed m\(^{-2}\) using a 50 cm IRS. In the temperate zone in Japan, Kaneko et al. (2018) conducted RSC of palisade grass using a 54 cm IRS and a seeding density of 2.4 g m\(^{-2}\). However, in a subtropical region of Argentina, Brandan et al. (2017) cultivated palisade grass as a cover crop using an IRS of 125 cm and seeding density of 0.4–0.5 g m\(^{-2}\). The advantages of RSC versus BSC include a reduction in seeding density per area (hence a saving of seeds) and the possibility of controlling weeds by intertillage measures using machinery. In Field Experiments 2 and 3, we noted both of these advantages at an IRS of 120 cm in comparison with an IRS of 80 cm where the former IRS enabled us to save seeds and to reduce the intertillage weed control workload by using a 10 kW-level tractor with a rotary tiller for weeding. In addition, this approach to palisade grass cultivation provided a suitable shoot yield.

To investigate weed control, in the absence of a registered herbicide for palisade grass, we implemented intertillage measures using walking-type cultivators for the RSC with 60, 80, and 100 cm IRSs, and 10 kW-level tractors with rotary tillers for the IRS of 120 cm. Although weed conditions were different between fields and years, the intertillage measures were mostly successful for weed control and, in Field Experiments 3, 4, and 5, reduced the W/CRs to below 0.03 after three months of cultivation. Use of a tractor with a rotary tiller for weed control would reduce workload more than use of a walking-type cultivator, and being more powerful, would do more damage to the weeds. The apparent advantage and success of weed control using a tractor, as demonstrated in this study, is one of the reasons why we recommend RSC with a 120 cm IRS for palisade grass cropping.

In summary, we conclude that wide-row seeding
cultivation is one of the practical choices for the combined utilization of palisade grass for forage production and as a nematode-suppressive crop. Further studies are required to establish crop rotation systems in which palisade grass acts as the key nematode-suppressive measure and the use of nematicides in the rotation systems is not required.

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要旨

雑草と線虫を抑制するための機械中耕を伴う線虫抑制性飼料作物パリセードグラスの条播栽培の一連の圃場試験を実施した。地域の畜産農家による地上部の飼料としての利用のみならず、耕種農家による輸作の中で線虫抑制のための利用の視点
を持ちながら、中耕を伴ういくつかの条間条件下のバリセードグラスの条播栽培の試験をめざした。圃場試験 1 では条間 60、80、100 cm の条件で条播栽培を行い、3 つの条間条件の間に収量の有意な差は見られなかった。圃場試験 2 と圃場試験 3 では条間は 80 と 120 cm に設定し、圃場試験 2 では土壌中的植物寄生性線虫密度が十分に低く抑制された。圃場試験 3 では 3 カ月間栽培した時の条間 80 と 120 cm の処理区の間の収量の有意な差はなかった。圃場試験 4 では条間 120 cm の条播栽培と散播栽培を比較し、条播栽培区の収量は散播栽培区よりも高くなる傾向があった。雑草干物重は、条播栽培区の 2 回の中耕後から播種後 127 日目にかけて、散播栽培区で条播栽培区よりも高かった。圃場試験 5 では農業生産者の圃場で条間 120 cm の条播栽培を行い、収量調査時のネコブセンチュウ密度が明瞭に抑制された。以上の結果から、バリセードグラスを飼料生産のため、加えて線虫抑制作物としても利用する際には、条間 120 cm の広条播種栽培は実用的な選択肢の一つであると結論付けた。

キーワード
広条播種栽培、雑草制御、線虫抑制性飼料作物、中耕、バリセードグラス