Development and establishment of centipede grass (*Eremochloa ophiuroides*) in south-western Japan

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Abstract

Five experiments were conducted at 2 sites in Miyazaki Prefecture, south-western Japan, to obtain information on the establishment of centipede grass (*Eremochloa ophiuroides*) as a pasture species for low-input grassland systems. Aspects studied were: the effects of seeding rate and fertiliser nitrogen on the development (increase in coverage) of centipede grass sown into a bahia grass pasture; the effects of seeding rate on the development of 2 centipede grass cultivars sown into an annual grass pasture after the final harvest; the development of centipede grass planted as sprigs at 2 densities; the effects of slope aspect (north, east, south and west) and seedbed preparation method (ND, no disturbance; BT, band tillage) on the development of centipede grass sown on a hill pasture; and the development of centipede grass sown at different times between spring and autumn at an elevation of 630 m. The results showed that: (a) centipede grass is well adapted to both cool winters and warm summers; (b) seeding rate can be reduced to 5–10 kg/ha when sufficient time is allowed for the grass to establish fully; (c) nitrogen fertiliser should be minimised, at least in the initial year; (d) the grass is well adapted to all slope aspects; (e) BT provides more rapid coverage of grass than ND, but both methods provide satisfactory grass cover in the long term; and (f) late spring is the best sowing time for centipede grass under elevated situations.

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Introduction

In south-western Japan, excepting subtropical regions (mainly the Ryukyu Islands), the major grasses recommended for sowing as permanent pastures are: cocksfoot (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*) and Kentucky blue grass (*Poa pratensis*) for regions with mean annual air temperature of 8–14°C; tall fescue (*Festuca arundinacea*) and redtop (*Agrostis alba*) for regions of 12–16°C; and bahia grass (*Paspalum notatum*) (>16°C) (Livestock Industry Bureau, MAFF of Japan 1988; 1996). However, there are deficiencies or problems with these grasses, *i.e.*, the temperate grasses are generally short-lived (<5 years) due to summer depression and invasion of weeds (Livestock Industry Bureau, MAFF of Japan 1996), and herbage quality of bahia grass rapidly degrades after spring or when allowed to grow rank (Hirata *et al.* 1996, 2006b; Ogura *et al.* 2002).

Centipede grass (*Eremochloa ophiuroides*) is a warm-season perennial, native to central-southern China (Hanna and Burton 1978; Hanna and Liu 2003) and widely distributed in south-east Asia, southern USA, South America, West Indies and parts of Africa and tropical north and east Australia (Islam and Hirata 2005). It is adapted to a range of environments, showing superior cold tolerance (down to <–10°C) to most warm-season grasses and growing on a range of soils (sandy to heavy soils, pH 4.5–8.5; well adapted to infertile soils). Centipede grass forms a short, dense sward with rapidly spreading leafy stolons, making it effective for soil conservation and weed control. Centipede grass is often named 'lazy man's grass' or 'poor man's grass' as it requires low maintenance or little care. Although it has not been regarded as a good forage species because of the poor quality (Hanna and Liu 2003), recent studies in Japan demonstrate that the grass has acceptable quality and palatability to animals as a warm-season grass (Hirata *et al.* 2002a; 2002b; 2004; 2006a). Farmers and researchers in central to southern parts of Japan are interested in using it in low-input grassland systems (particularly for grazing by breeding beef cows), aiming at sustainable production and environmental conservation. However, since it has been used mainly as a turfgrass, little information is available on the establishment, management and utilisation of centipede grass as a forage resource (Islam and Hirata 2005).

This paper presents findings from 5 experiments on the development and establishment of centipede grass planted as pastures in south-western Japan. Experiments 1–3 were conducted at a site in the low-altitude region of Kyushu, where bahia grass has been a recommended perennial grass. Experiment 1 investigated the effects of seeding rate and fertiliser nitrogen on the development of centipede grass sown into a bahia grass pasture, assuming a case of replacing bahia grass with centipede grass. Experiment 2 examined the effects of seeding rate on the development of 2 centipede grass cultivars sown into an annual grass pasture after the final harvest, assuming a case with no strong competitors. Experiment 3 followed the development of centipede grass planted at 2 densities as sprigs (stolons) to test the alternative to seeding.

Experiments 4 and 5 were conducted at a site in the mid-altitude region of Kyushu, where temperate grasses have been recommended. This region is hilly, which presents problems for development and establishment of sown species (Nikki *et al.* 1980; Sugimoto *et al.* 1985). On hilly lands, seedbed preparation that avoids or minimises soil erosion by rainfall is an important consideration in pasture establishment (Livestock Industry Bureau, MAFF of Japan 1988). The warm season in this region is short, which may limit the sowing time of warm-season grasses that can be sown from spring through autumn in the low-altitude region (Livestock Industry Bureau, MAFF of Japan 1988). Therefore, Experiment 4 investigated the effects of slope aspect and seedbed preparation on the development of centipede grass sown on a hill pasture, while Experiment 5 monitored the development of centipede grass sown at different times between spring and autumn.

Materials and methods

The experiments were conducted at 2 sites in Miyazaki Prefecture, south-western Japan. Experiments 1–3 were conducted at the Sumiyoshi Livestock Science Station (Sumiyoshi Livestock Farm until 2000) at Miyazaki University (31°59′N, 131°28′E; 10 m elevation; Sand-dune Regosol), and Experiments 4 and 5 at the Kagamiyama Livestock Farm in Kitagawa Town (32°42′N, 131°46′E; 500–650 m elevation; Brown Forest Soil). All experiments used cultivar Common, the most commonly used centipede grass developed from seed of early introductions into the USA from China (Hanna and Liu 2003; Islam and Hirata 2005). In addition, Experiment 2 used a more recent cultivar TifBlair, which has improved tolerance of cold and low soil pH (Hanna *et al.* 1997), for comparison with Common. In all experiments, coverage was the standard of measurement, because this variable is most suitable for evaluating development of stoloniferous species like centipede grass, with minimal inputs of time, labour and equipment. Meteorological conditions (air temperature, rainfall) at Kagamiyama were measured at an elevation of 630 m.

Experiment 1

Experiment 1 was conducted from 1999 to 2003. In mid-May (late spring) 1999, an area (37.5 m × 67.5 m; level terrain) dominated by bahia grass was cultivated as a seedbed and divided into 45 plots (7.5 m × 7.5 m each) in 3 blocks [37.5 m × 22.5 m (15 plots) each]. Experimental treatments of 5 seeding rates [5 (S5), 10 (S10), 20 (S20), 50 (S50) and 100 (S100) kg/ha] × 3 levels of fertiliser nitrogen (LN, MN and HN) were allocated to the 45 plots following a randomised block design. Seed of Common centipede grass was broadcast on to plots and roller-packed. The 1000-seed weight was 0.906 ± 0.021 g (mean ± SD). The maximal seeding rate of 100 kg/ha is much higher than the suggested rates in lawn establishment (12–24 kg/ha; Higgins 1998; Landry and Murphy 2002), and was selected to avoid a failure of the experiment (unsuccessful establishment of centipede grass at all seeding rates) through severe competition from rapidly regrowing bahia grass, *i.e.*, a less favourable condition for the sown grass than most lawn establishments. We were well aware that such heavy seeding is impractical due to high cost of centipede grass seed (9 000–15 000 yen/kg).

The plots were fertilised 1 (LN), 2 (MN) or 3 (HN) times each year. All plots received common doses of N, P and K in spring (at sowing in 1999; April–May in 2000–2003) as compound fertiliser. Thereafter (summer–autumn), MN and HN plots received additional N as ammonium sulphate in June–July (HN) and August–September (MN and HN). The annual N rates for LN, MN and HN were, respectively, 30, 60 and 90 kg/ha in 1999, 2002 and 2003; 30, 45 and 75 kg/ha in 2000; and 50, 80 and 110 kg/ha in 2001. The P and K rates (common to all plots) were, respectively, 17 and 20 kg/ha in 1999, 2002 and 2003; 13 and 20 kg/ha in 2000; and 29 and 33 kg/ha in 2001.

Following sowing in 1999, the experimental area (45 plots) was cut 5 times between June (early summer) and October (autumn) to a height of 5–10 cm above ground level, to control bahia grass and help centipede grass develop. In the subsequent years (2000–2003), the area was cut (1–3 times) and grazed by dairy and beef cows (549–1232 cow-days/ha under supplementation) during the growing season (May–October or November).

Measurements were conducted 4 or 5 times from April–June (spring–early summer) to October or November (autumn) each year. At each time, coverages of centipede grass and other species were recorded (0–100% at intervals of 5%) for 3 quadrats (50 cm × 50 cm each) randomly placed in each of the 45 plots. The effects of seeding rate and nitrogen rate on coverage were evaluated with ANOVA (block as an independent source of variation) and the means were compared using LSD.

Experiments 2 and 3

Experiments 2 and 3 were conducted from 2002 to 2003. In early June (early summer) 2002, an area (36 m × 83 m; level terrain) of Italian ryegrass (*Lolium multiflorum*) pasture was cultivated after the final harvest to prepare a seedbed. The area was primarily divided into 2 sub-areas for the 2 experiments.

Experiment 2 used one sub-area (36 m × 66 m) as a set of 24 plots (9 m × 11 m each) in 3 blocks [36 m × 22 m (8 plots) each]. Experimental treatments of 2 centipede grass cultivars (Common and TifBlair) × 4 seeding rates [5 (S5), 10 (S10), 25 (S25) and 50 (S50) kg/ha] were allocated to the 24 plots following a randomised block design. Seed was broadcast on to plots and roller-packed. The 1000-seed weights of Common and TifBlair were 0.806 ± 0.010 g and 0.904 ± 0.005 g (mean ± SD), respectively. The maximal seeding rate of 50 kg/ha was selected after centipede grass sown in Experiment 1 had expanded considerably by April 2002 (*i.e.*, immediately before the commencement of Experiment 2) at all seeding rates even under competition with bahia grass.

Experiment 3 used the other sub-area (36 m × 17 m) as a set of 6 plots (12 m × 8.5 m each) in 3 blocks [12 m × 17 m (2 plots) each]. Two densities of vegetative planting (LD and HD) were allocated to the 6 plots, following a randomised block design, and sprigs of Common centipede grass were broadcast and roller-packed. The sprigs were prepared immediately before planting, by collecting a sod (4.5 m^2 in area; about 10 cm deep) from an established sward and cutting or fragmenting the vegetation into small, almost soil-free stolon–tiller pieces (mean weight = 0.87 g; mean tiller number = 3.6). These pieces (total weight = 10.35 kg) were then grouped into 6 portions for LD and HD treatments (3 each) at a 1:2 ratio by weight (1.15 and 2.3 kg, respectively). Thus, vegetative material from sods of 0.5 and 1 m^2 was spread over a plot of 102 m^2 for LD and HD treatments, respectively (*i.e.*, approximately 200 and 100 times expansion in area), with planting densities of 13 and 26 sprigs/m^2.

Following planting in 2002, the experimental area (2 sub-areas; 30 plots) was grazed by beef cows (603 cow-days/ha) during July–November (summer–autumn). In 2003, the area was cut twice to a height of 5–10 cm above ground level and grazed (404 cow-days/ha) during April–October (spring–autumn). No fertilisers were applied in the 2 experiments, because increasing fertiliser nitrogen had suppressed expansion of centipede grass in Experiment 1.

Measurements were conducted 3 times in 2002 (July–November) and 4 times in 2003 (April–November). On each occasion, coverages of centipede grass and other species were recorded (0–100% at intervals of 5%) for 50 cm × 50 cm quadrats (9 in 2002; 3 or 5 in 2003) randomly placed in each of the 30 plots (24 and 6 in Experiments 2 and 3, respectively). The effects of cultivar and seeding rate in Experiment 2 were evaluated with ANOVA (block as an independent source of variation) and the means were compared using LSD. The effect of planting density in Experiment 3 was evaluated using the paired t-test.

Experiment 4

Experiment 4 was conducted from 2000 to 2003 in a hill paddock (2.4 ha, 540 m elevation) with slopes (gradient = about 25°) on 4 aspects (north, east, south and west). At the commencement of the experiment, the vegetation was dominated by Japanese lawn grass (*Zoysia japonica*) on the northern aspect, tall fescue on the eastern aspect, and bahia grass on the southern and western aspects, with mean vegetation cover (for all species present) of 69, 86, 84 and 88% on the northern, eastern, southern and western aspects, respectively. Tall fescue and bahia grass had been sown before the experiment.

In mid-May (late spring) 2000, an experimental area of 6 m (down the slope) × 4 m (across the slope) was established on each of the 4 aspects, and divided into six 2 m × 2 m plots in 3 blocks [4 m × 2m (2 plots) each, from the upper to the lower slope]. Then, 2 seedbed preparation methods (ND, no disturbance; BT, band tillage) were randomly allocated to the 2 plots in each block. Seed of Common centipede grass was broadcast at 100 kg/ha on ND plots without disturbing the original vegetation. The BT plots were partially cultivated across the slope (*i.e.*, to minimise loss of soil and seed by rainfall); 6 bands 15 cm wide alternated with uncultivated strips 18 cm wide so that 45% of the area was cultivated. Seed of Common centipede grass was sown at 100 kg/ha into the bands. The 1000-seed weight was 0.823 ± 0.053 g (mean ± SD). The seeding rate of 100 kg/ha (the maximal rate in Experiment 1) was selected to avoid a failure of the experiment (unsuccessful establishment of centipede grass on all treatments) through competition from the original vegetation, because expansion of centipede grass in Experiment 1 was very slow during 1999 (*i.e.*, before the commencement of Experiment 4) even at 100 kg/ha with full cultivation.

The paddock was grazed by beef cows from spring (late April–early May) to autumn (October–early November) in 2000–2003, at rates of 435–647 cow-days/ha. Compound fertiliser was applied once (spring) or twice (spring and autumn) a year, giving annual totals of 70 kg N + 71 kg K in 2000 and 2002 (March), 93 kg N + 94 kg K in 2001 (split application in April and September), and 58 kg N + 59 kg K in 2003 (April) per ha.

On 4 occasions from May (late spring) or June (early summer) to November (late autumn) or December (early winter) each year, coverages of centipede grass and other species were recorded (0–100% at intervals of 5%) for two 50 cm × 50 cm quadrats in each of the 24 plots (6 plots × 4 aspects). The quadrats were placed randomly in the ND plots and to include 2 cultivated bands in the BT plots (random except this condition). The effects of slope aspect and seedbed preparation method on coverage were evaluated with ANOVA (block as an independent source of variation) and the means were compared using LSD.

Experiment 5

Experiment 5 was conducted from 2000 to 2003 in a paddock (2.1 ha, 630 m elevation) on a north-eastern slope (gradient = 10–20°). Pasture renovation in 1999 had failed, with the topsoil and seeds being washed away due to heavy rains immediately after full cultivation and seeding of the entire area. At the commencement of the experiment (May 2000), the vegetation (mainly cocksfoot and tall fescue sown at the renovation) was sparse (mean vegetation cover = 24%) on the exposed subsoil scattered with stones and gravel.

An experimental area measuring 10 m (down the slope) × 60 m (across the slope) was established and divided into 6 plots (10 m × 10 m each) in 2 blocks [10m × 30 m (3 plots) each]. Then, following a randomised block design, seed of Common centipede grass was broadcast on the plots on May 20 (late spring), 2000, August 3 (summer) in 2000 or September 27 (autumn) in 2001, at a rate of 100 kg/ha with no disturbance of the original vegetation. The vegetation at the second and third sowings had mean coverages of 39 (mainly tall fescue and *Digitaria adscendens*) and 31% (mainly *D. adscendens* and Cyperaceae species), respectively. The 1000-seed weight was 0.823 ± 0.053 g (mean ± SD). The seeding rate of 100 kg/ha was selected for the same reason as in Experiment 4, despite the sparser original vegetation in this fifth experiment.

In 2000, the paddock was grazed by beef cows (37 cow-days/ha) in October with no fertiliser application. In 2001–2003, the paddock was grazed by beef cows from May (late spring) to September–November (autumn) at rates of 144–181 cow-days/ha. The paddock received compound fertiliser as follows: 36 kg N + 37 kg K in 2001 (April) and 2002 (March), and 24 kg N + 24 kg K in 2003 (April) per ha. The eventual absence of grazing and lack of fertiliser application in 2000 plus the low carrying capacity and fertiliser input in the subsequent years (2001–2003) were a reflection of low pasture production as a result of the failure of pasture renovation (described earlier).

Measurements were conducted 4 times from May (late spring) or June (early summer) to November (late autumn) or December (early winter) each year, with plots sown in May 2000, August 2000 and September 2001 being measured 16, 10 and 8 times, respectively. Coverages of centipede grass and other species were recorded (0–100% at intervals of 5%) for four 50 cm × 50 cm quadrats randomly placed in each plot. The effect of sowing time on coverage was evaluated with ANOVA (block as an independent source of variation) and LSD, using data for measurements nearest to 700 and 1200 days after sowing, *i.e.*, May 2002 (711 days in the May 2000 sowing), July 2002 (699 days in the August 2000 sowing) and August 2003 (701 days in the September 2001 sowing) were compared for the post-sowing period of 700 days, and August 2003 (1196 days in the May 2000 sowing) and November 2003 (1186 days in the August 2000 sowing) for the post-sowing period of 1200 days.

Results

Meteorological conditions

Mean monthly air temperature and monthly rainfall at Sumiyoshi (Experiments 1–3) during 1999–2003 varied from 6.3 to 27.1°C and 14 to 645 mm, respectively, with annual means and totals of 17.3–17.5°C and 1792–2762 mm (Figure 1a). Mean monthly air temperature and monthly rainfall at Kagamiyama (Experiments 4 and 5) during 2000–2003 were in the ranges of 2.0–24.5°C and 16–735 mm, with annual means and totals of 13.6–13.8°C and 1802–2938 mm

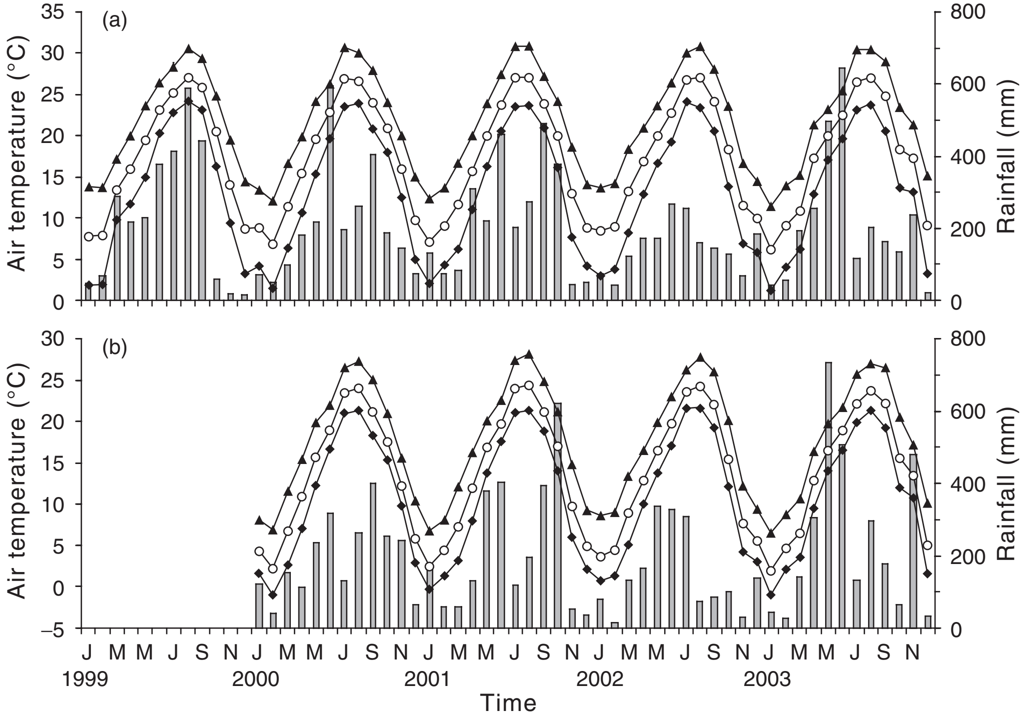

Figure 1. Monthly means of maximum (▲), mean (○) and minimum (◆) daily air temperatures, and monthly totals of rainfall at: (a) Sumiyoshi (Experiments 1–3); and (b) Kagamiyama (Experiments 4 and 5).

(Figure 1b). Although both sites experienced warm, humid summers (June–August) and cool, dry winters (December–February), mean monthly temperatures at Kagamiyama were consistently (2.1–4.8°C) lower than those at Sumiyoshi, reflecting the higher latitude (32°42′N *vs* 31°59′N) and higher elevation (630 m *vs* 10 m). The monthly mean minimum temperature at Kagamiyama usually fell below zero in the coolest month in each year, whereas that at Sumiyoshi always showed positive values. For rainfall, however, there was no such site-specific trend in the monthly values, with similar annual means over 2000–2003 (2391 and 2423 mm at Sumiyoshi and Kagamiyama, respectively).

Experiment 1

Coverage by centipede grass was low (<12%) during the first year, increasing to 47–71% by April (spring) of the fourth year, and levelling off thereafter (Figure 2). The effect of seeding rate was always significant (P<0.01) until August (summer) of the third year, with higher centipede grass coverages under higher seeding rates (S100>S50>S20>S10>S5). This trend continued until June (summer) of the fifth year, though the effect of seeding rate was usually non-significant (P>0.05). Thereafter, centipede grass coverage tended to be lower in S5 than in the other 4 treatments (S100≈S50≈S20≈S10>S5). Although coverage of centipede grass was lower in HN than in LN and MN on all occasions from the second year onwards, differences were significant (P<0.05) mainly from the second half of the fourth year. Interaction between seeding rate and nitrogen rate was always non-significant (P>0.05). Major species other than centipede grass were bahia grass and Cyperaceae species. Total coverage by these species decreased from 49–95% (mean = 72%) in the first year to 21–70% (mean = 42%) in the fifth year, with lower values under higher centipede grass seeding rates and lower nitrogen rates.

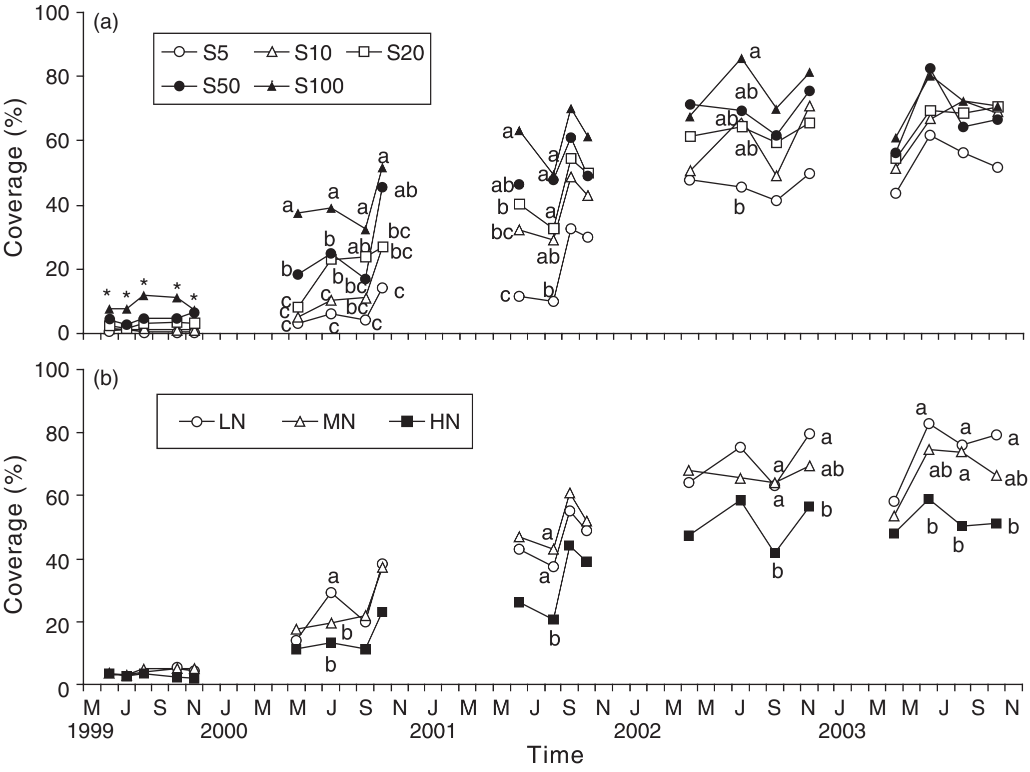

Figure 2. Changes in coverage of centipede grass after sowing as affected by: (a) seeding rate; and (b) nitrogen fertiliser rate (Experiment 1). Refer to text for treatments. Means with different letters within each measurement date are significantly different at P<0.05. For 5 occasions with asterisks in 1999, separation of means across S100, S50, S20, S10 and S5 is, respectively: a, b, c, cd and d in June; a, b, b, b and b in July, August and October; a, ab, b, b and b in November.

Experiment 2

Coverage by centipede grass increased after sowing, reaching 73–89% at the end of the growing season (November) in the second year (Figure 3). The effect of cultivar was always non-significant (P>0.05). The effect of seeding rate was sometimes significant (P<0.05), showing a trend of higher centipede grass coverages under higher seeding rates (S50>S25>S10>S5) until June (summer) in the second year. At the end of the second year (November), centipede grass coverage was similar for the 4 seeding rates. The interaction between cultivar and seeding rate was always non-significant (P>0.05). Major species other than centipede grass were *Eleusine indica*, *D. adscendens*, *Sorghum halepense* and Cyperaceae species. Total coverage by these species decreased from 30–78% (mean = 53%) in the first year to 10–59% (mean = 22%) in the second year, with lower values under higher seeding rates.

Experiment 3

Coverage by centipede grass remained low (<5%) during the first year, and increased to 48–57% at the end of the second growing season (November) (Figure 4). The effect of planting density was always non-significant (P>0.05). Major species other than centipede grass were the same as in Experiment 2, with their total coverage decreasing from 41–77% (mean = 54%) in the first year to 17–61% (mean = 40%) in the second year.

Experiment 4

Coverage by centipede grass increased after sowing to reach 56–86% in August–November (summer–autumn) of the fourth year, with temporary plateauing or decreases during the winter–spring periods (between the last

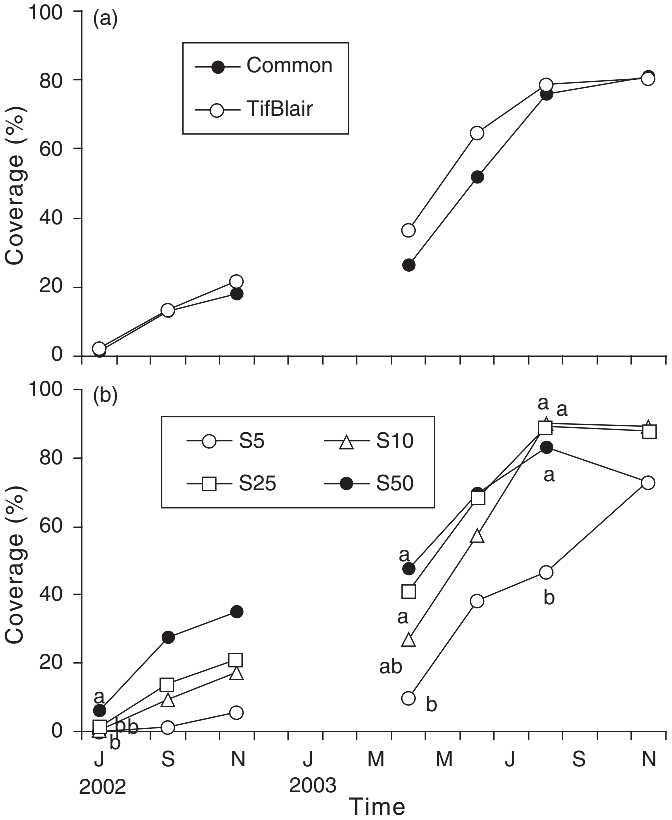

Figure 3. Changes in coverage of centipede grass after sowing as affected by: (a) cultivar; and (b) seeding rate (Experiment 2). Refer to text for treatments. Means with different letters within each measurement date are significantly different at P<0.05.

measurement in each year and the first measurement in the next year) (Figure 5). Although the effect of slope aspect was usually non-significant (P>0.05), the eastern aspect tended to show higher centipede grass coverage than the other 3 aspects. In terms of seedbed preparation, coverage by centipede grass was higher for BT than for ND until the third year, although significant differences were largely confined to the first year. The interaction between slope aspect and seedbed preparation method was usually non-significant (P>0.05). Major species other than centipede grass were Japanese lawn grass, tall fescue, *Pennisetum alopecuroides* and lichens on the northerly aspect; tall fescue, *P. alopecuroides* and Cyperaceae species on the easterly aspect; and bahia grass and Cyperaceae species on the southern and western aspects. Total coverage by these species decreased from 31–85% (mean = 53%) in the first year to 4–45% (mean = 25%) in the fourth year, with lower values on the easterly aspect and in BT.

Experiment 5

Coverage by centipede grass increased after sowing, showing temporary plateauing or decreases during winter–spring (Figure 6; most of the parts unconnected by lines). The rate of increase in coverage was significantly affected by sowing time (P<0.05), as centipede grass covered 61, 36 and 13% of plots sown in May 2000, August 2000 and September 2001, respectively, at 700 days after sowing. At 1200 days after sowing, centipede grass coverage was 84 and 35% in plots sown in May 2000 and August 2000 (P<0.01). Major species other than centipede grass were tall fescue, *Miscanthus sinensis*, *D. adscendens* and Cyperaceae species. Total coverage by these species decreased from 24–39% (mean = 32%) to 9–23% (mean = 17%) during a 700-day period after sowing, with the plots sown in May 2000 showing the lowest values among the 3 treatments.

Discussion

Seeding rate and planting density

Results of Experiments 1 and 2 demonstrated the benefits of higher seeding rates in obtaining rapid coverage of centipede grass after sowing, but that even low rates produced good coverage (>60%) over time, depending on the level of competition from other species. Without strong competitors (Experiment 2), seeding rates of 5–50 kg/ha resulted in similar coverages at the end of the second year. On the other hand, with a strong competitor (*i.e.*, bahia grass; Experiment 1), seeding rates of 10–100 kg/ha gave similar coverages in the second half of the fifth year, though the lowest seeding rate (5 kg/ha) still

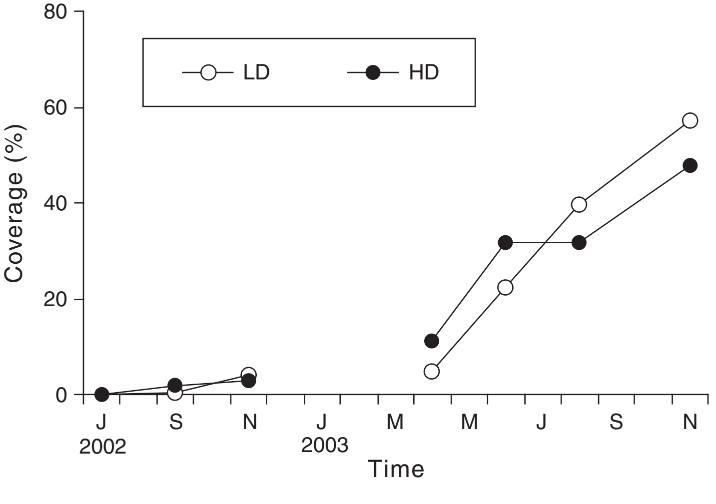

Figure 4. Changes in coverage of centipede grass after vegetative planting at low (LD) and high (HD) density (Experiment 3). Means within each measurement date are not significantly different (P>0.05).

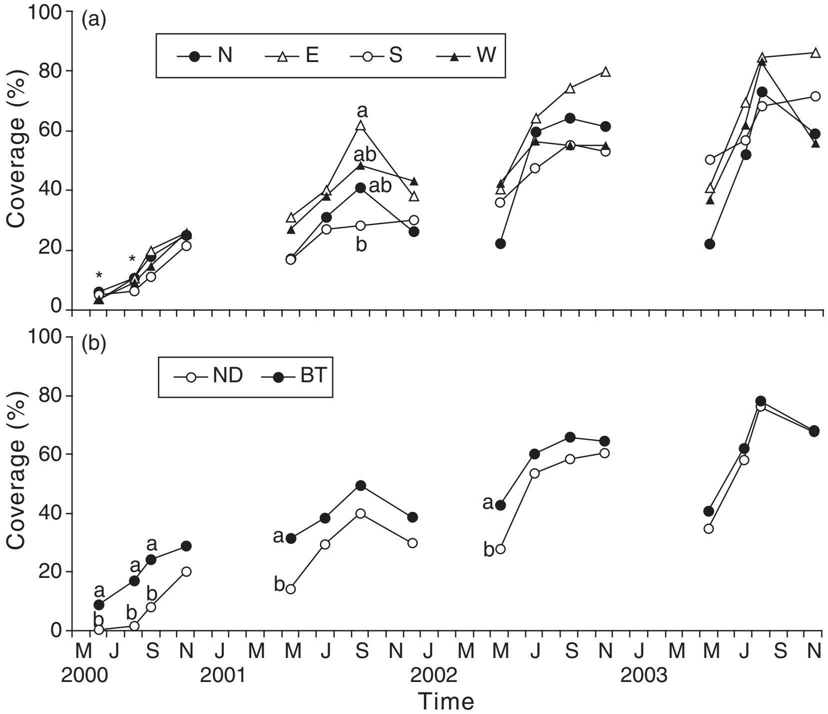

Figure 5. Changes in coverage of centipede grass after sowing as affected by: (a) slope aspect (north, east, south and west); and (b) seedbed preparation method (ND, no disturbance; BT, band tillage) (Experiment 4). Means with different letters within each measurement date are significantly different at P<0.05. For 2 occasions with asterisks in 2000, separation of means across N, E, S and W is, respectively: a, c, ab and bc in June; a, a, b and ab in August.

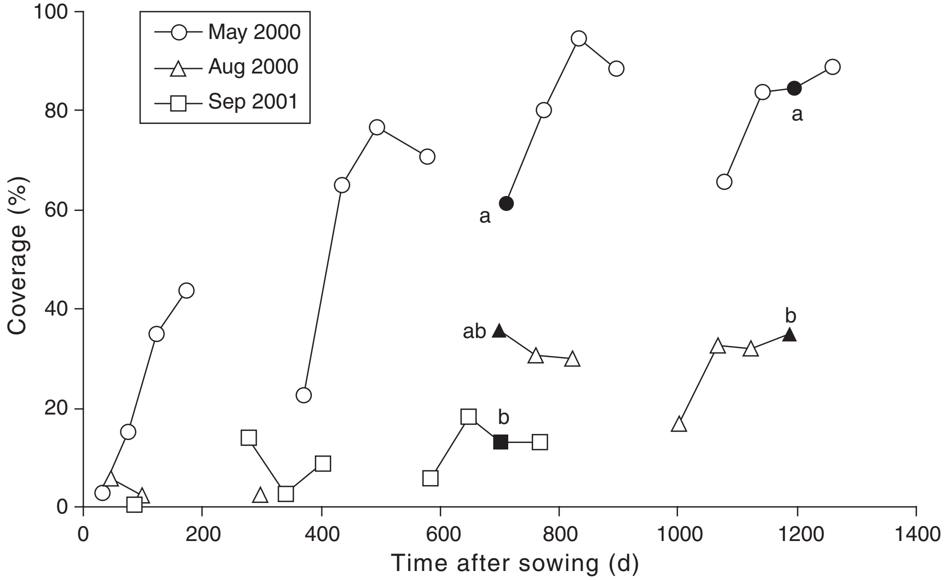

Figure 6. Changes in coverage of centipede grass after sowing, as affected by sowing time (Experiment 5). Means with different letters within each of the 2 measurement dates indicated by closed symbols are significantly different at P<0.05.

tended to show lower coverages. These data suggest that seeding rate for centipede grass pasture establishment may be reduced to levels similar to or lower than those for lawn establishment (12–24 kg/ha; Higgins 1998; Landry and Murphy 2002), if sufficient time is allowed for the grass to become dominant in the pasture, *i.e.*, to 5 kg/ha in the absence of strong competitors and with an establishment period of 1.5 years, and to 10 kg/ha where strong competitors are present and establishment time is extended to 4 years. The present results are useful in determining optimal seeding rates to achieve target coverage levels of centipede grass in a given period, making allowance for the condition of the original vegetation and the high seed cost of centipede grass. It is of note that, even at a seeding rate of 100 kg/ha, centipede grass failed to achieve >50% coverage before 1.5 years, when there was strong competition.

Vegetative planting (13 and 26 sprigs/m^2) resulted in slower expansion of centipede grass than seeding, *i.e.*, 48–57% *vs* 73–89% coverage at the end of the second year. This was attributable primarily to the much lower planting density with sprigging than with seeding (620 and 550 seeds/m^2 for Common and TifBlair, respectively, even at the lowest seeding rate of 5 kg/ha; estimated from the 1000-seed weights of 0.806 and 0.904 g). The possibility of reducing seeding rate to 5–10 kg/ha, described earlier, makes seeding much more attractive than vegetative planting, especially when time and labour for preparing vegetative material are considered (Beard 1973; Higgins 1998; Landry and Murphy 2002). The reason for the consistently non-significant effect of planting density on the development of vegetatively planted centipede grass is unclear from results of the present study; future studies should follow the fate (survival or mortality) of individual sprigs after planting to clarify the situation.

Nitrogen fertiliser

The slow development of centipede grass sown into a cultivated bahia grass pasture at high N fertiliser levels may be a function of strong competition from bahia grass responding to high N fertiliser levels in the seeding year. This effect was carried over to subsequent years. Thus, for rapid centipede grass establishment, nitrogen fertiliser levels should be minimised, at least in the seeding year, although the grass requires adequate nitrogen (<100 kg/ha/yr; Johnson and Carrow 1988) once established.

Cultivar

Development of the 2 centipede grass cultivars did not differ significantly, although seed numbers of TifBlair sown were 11% lower than for Common (based on the 1000-seed weights of 0.904 and 0.806 g). However, since there was little response in coverage to seeding rate in individual species, *i.e.*, the mean coverage difference between the highest (50 kg/ha) and lowest (5 kg/ha; 90% less than the highest rate) seeding rate was only 24%, there was no indication that TifBlair could germinate or establish better than Common.

Slope aspect

Slope aspect has a considerable influence on edaphic and biotic characteristics of a hilly pasture, mainly through variation in soil temperature caused by differences in solar radiation received (Lambert and Roberts 1978; Nikki *et al.* 1980; Sugimoto *et al.* 1985, 1987). In the Northern Hemisphere, the northern slope shows lower soil temperature and higher soil moisture than the southern slope due to lower incident solar radiation, with greater aspect differences in winter than in summer. Reflecting these aspect differences, hilly pastures in the mid-altitude region of Kyushu are often dominated by cool-season grasses on the northern aspect and by warm-season grasses on the southern aspect (Nikki *et al.* 1980; Sugimoto *et al.* 1987). In fact, there were clear aspect differences in the dominant species within the original vegetation in Experiment 4, *i.e.*, Japanese lawn grass on the northern aspect, tall fescue on the eastern aspect, and bahia grass on the southern and western aspects.

In contrast, centipede grass spread on all aspects, becoming dominant in summer–autumn in the fourth year, with best spread on the eastern aspect. We consider this reflects the ability of centipede grass to tolerate and grow well under both high and low temperatures (Islam and Hirata 2005). Furthermore, centipede grass demonstrated a high ability to compete with the original vegetation. A possible explanation for the superior growth of centipede grass on the eastern aspect is that tall fescue, the original dominant grass, is a bunch-type, cool-season grass, which is susceptible to both the spread of stoloniferous, prostrate species and summer depression.

Despite the satisfactory development on all aspects, growth of centipede grass plateaued or declined during the winter–spring periods. In particular, coverage in May after overwintering was as low as about 20% on the northern aspect even 2 and 3 years after sowing, indicating the severity of the winter conditions (*i.e.*, low temperature) on this shady slope. Since the aspect differences in microclimate (*e.g.* solar radiation, temperature) increase with increasing slope gradient, centipede grass may not be able to overwinter successfully on the northern aspect in south-western Japan, when the slope is steeper than that in Experiment 4 (about 25°).

Seedbed preparation method

The superior coverage of centipede grass on BT than on the ND treatment during the first 3 years after sowing is a reflection of the concentration of centipede grass seeds in cultivated areas in contact with soil, and the avoidance of competition from the original vegetation for some time after germination by spatial separation. On an actual sown area (*i.e.*, band area) basis, the seeding rate in BT was as high as 222 kg/ha, because the cultivated bands accounted for 45% of land area. However, in the field observation, seedlings were so dense in the bands after germination that mortality was high, indicating excessive seeding. With the BT method, it is possible to reduce seeding rate on the total area by sowing an optimal rate on the cultivated area, which represents an advantage of BT over ND.

However, in the fourth year after sowing, coverage of centipede grass was similar for the 2 seedbed preparation methods, showing that the ND method was satisfactory for the long-term development of centipede grass. This may be true even at lower seeding rates (*i.e.*, <100 kg/ha) because of the successful expansion of centipede grass at all seeding rates in Experiments 1 and 2, though the time required for ND to achieve the same coverage as BT may be longer. Therefore, with the costs of seedbed preparation (expenses, labour, time) and the risk of soil erosion with BT, ND with no tillage/soil disturbance may be preferable to BT. However, lower seed cost with BT must be considered in deciding on the desirable establishment method. In making a decision between BT and ND, characteristics of bands created (*e.g.* proportion of band area, width and interval of bands, depth of tilling) and natural conditions of the planting site (*e.g.* gradient of slope, type of original vegetation, soil type, rainfall) must be taken into consideration (Livestock Industry Bureau, MAFF of Japan 1988). With the complexity of factors involved, further experiments and analyses are needed to fully evaluate the 2 seedbed preparation methods. In particular, it is necessary to investigate not only centipede grass development but also the establishment costs (tilling and seed) and the environmental impact (soil loss) with the 2 methods as related to seeding rates, band characteristics and natural conditions of the planting site.

Sowing time

Centipede grass sown in August or September showed considerably slower development than that sown in May even at a high seeding rate of 100 kg/ha. This indicates that sowing before midsummer is desirable for satisfactory centipede grass pasture establishment, because of the steep decline in temperature after August. The finding confirms the experience with lawn establishment that late spring–early summer is the best time to plant centipede grass, with later plantings being more prone to winter injury (Higgins 1998; Landry and Murphy 2002).

In Experiment 5, centipede grass planted on exposed subsoil after severe erosion of topsoil, with relatively small amounts of fertiliser (24–36 kg N + 24–37 kg K/ha/yr), showed good development and establishment, provided the seeding time was early (May sowing). This highlights the adaptation of centipede grass to infertile soils (Hanna and Liu 2003; Islam and Hirata 2005), though growth may be depressed without application of nitrogen (Johnson and Carrow 1988).

Implications for regions with similar temperatures

Compared with other sites in the world (*e.g.* Australia, USA) with similar mean annual air temperatures (17.3–17.5 and 13.6–13.8°C at Sumiyoshi and Kagamiyama, respectively), the 2 experimental sites have colder winters (monthly mean minimum = 1.2–4.3 and –0.9 to 2.1°C) and warmer summers (monthly mean maximum = 28.4–30.9 and 25.8–28.2°C). Even in such harsh conditions, centipede grass established and developed successfully. The success of centipede grass at Kagamiyama indicates that this grass may be introduced into regions where sowing of a tropical grass has never been considered, as the climate was considered too cool for most tropical grasses (*e.g.* mean annual temperature = 13–14°C), if other conditions (*e.g.* rainfall) suffice. The ability of centipede grass to grow in a much broader temperature range than most other warm-season grasses is a key adaptational feature of this grass (Hanna and Liu 2003; Islam and Hirata 2005).

Conclusions

This series of experiments provides evidence for successful establishment of centipede grass pastures in south-western Japan with specific outcomes: (a) centipede grass is well adapted to both cool winters and warm summers; (b) seeding rate may be reduced to 5–10 kg/ha when sufficient time is allowed for full coverage; (c) nitrogen fertiliser should be minimised at least in the initial year; (d) the grass is well adapted to all slope aspects; (e) both BT and ND methods result in satisfactory establishment of the grass in the long term; and (f) late spring is the best sowing time for centipede grass. However, further studies are warranted to examine: the fate of individual sprigs after planting; establishment costs with the different methods of establishment; and soil loss with the different methods.

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