方位と斜度が東日本 (冷涼地域) におけるセンチピードグラス (Eremochloa ophiuroides (Munro) Hack.) 被覆速度におよぼす影響

The Influence of Slope Aspect and Slope Angle on the Spread of Centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.) in Eastern Japan (Temperate Climate)

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Abstract

In order to economically and rapidly introduce centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.) to support grazing on abandoned cultivated lands in eastern Japan (temperate climate), we used continuous rather than categorical data to investigate the influence of slope aspect and slope angle on the rate of spread in centipedegrass. We planted centipedegrass in 2003, and the coverage of centipedegrass was investigated in 61 quadrats with varying slope aspects and slope angles between 2003 and 2008. The number of years from the initial appearance to the maximum rate of centipedegrass spread (YMS, years of maximum spread) was calculated. The quadratic surface regression was also calculated to estimate the relationship among YMS, slope angle, and slope aspect. The highest YMS was 1.0–1.5 years in the quadrats that faced south and were relatively flat, whereas the lowest YMS was 3.0–3.5 years in the quadrats that faced north and had a slope angle of 10–20°. Therefore, centipedegrass can be introduced using a lower seeding rate on flat or gentle-sloping lands with southern aspects, even in eastern Japan (temperate climate) that had −4.7°C of daily minimum air temperature in monthly average. Further, quadratic surface regression showed significant effect of slope aspect and slope angle, but its predictability was low, suggesting that plant species shading centipedegrass affected the spread of centipedegrass.

Key words: *Eremochloa ophiuroides*, slope angle, slope aspect, spread rate, turf grass

Introduction

In Japan, abandoned cultivated lands have been increasing because of labor shortages, particularly in mountainous areas[15]. On a relatively flat land, agricultural machinery can facilitate the introduction of highly productive grass species. In contrast, on a steep slope terrain, using agricultural machinery is difficult. Cattle grazing is one of the most suitable and promising options for utilizing such lands[17]. However, Koyama *et al.*[14] reported that if cattle grazing is continued on abandoned cultivated lands, the amount of native plants might reduce, vegetation will decline, and grazing will not be possible. Turf grasses such as *Zoysia japonica* Steud., which is one of the most commonly used grasses in abandoned cultivated lands in Japan[19], are useful in such a situation since they can be

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maintained with little or no fertilizer, conserve soil on the slopes[12], and are tolerant to trampling by cattle[9]. However, it has a lower seed germination rate, and introduction of this grass species by sowing seeds is difficult. Hence, *Z. japonica* seedlings are usually transplanted; however, this requires considerable manpower[4,13].

Recently, centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.), native to south China[5], is increasingly being used as turf grass type plant species[10]. Because centipedegrass has a higher germination rate, it can be introduced by sowing seeds[24]. In Japan, studies have focused on the applicability of centipedegrass in relatively warm southwestern regions[5,8], since this species is a warm-season perennial grass[10]. Increasing the usage of centipedegrass in Japan requires that more information should be obtained regarding its adaptability to temperate climate such as that found in eastern Japan. In our previous study, we used centipedegrass grassland to graze reproductive cows in regions with a temperate climate, and showed the effectiveness of this grass for calf production[6]. Introducing centipedegrass in temperate climate requires information regarding the method to increase the spread of centipedegrass. Higher seeding rate increases the rate of spread in centipedegrass including seed germination, seedling establishment, and leafy stolon elongation[24]. However, centipedegrass seeds are expensive (about 15,000 yen·kg^{-1} in Japan), and increasing the seeding rate is difficult in abandoned cultivated lands. Thus, a method to increase the rate of spread in centipedegrass with lower seeding rate is required.

Slope angle and slope aspect affect the introduction of grasses[23] and grassland vegetation[2]. If topographical features affect the rate of spread in centipedegrass, conditions that increase the spread rate would reduce the seeding rate and thus decrease the cost of introducing centipedegrass. The effect of slope aspect on the rate of spread in centipedegrass has been evaluated in southwestern Japan[7], but not in eastern Japan. The effects of slope angle and slope aspect need to be elucidated because abandoned cultivated lands have varying and continuous slope angles and aspects. However, previous studies on the effect of slope aspect and slope angle on grassland vegetation used categorical data (fixed angles and aspects) rather than continuous data[1,2,7,20,22]. Evaluation of the rate of spread in centipedegrass by using continuous data for slope aspect and slope angle might provide detailed information regarding the rate of seeding required according to topographical features. In this study, we used continuous data on slope aspect and slope angle to investigate the influence of these factors on the spread of centipedegrass in the temperate climate of eastern Japan.

Materials and Methods

Study site

This study was conducted at an experimental pasture called the Fujinita site at the NARO Institute of Livestock and Grassland Science, Tochigi Pref. (36° 55′ N, 139° 58′ E; 330 m elevation) between 2003 and 2008. During the study period, the mean monthly air temperature ranged from 0.1 to 24.7°C, and the monthly rainfall ranged from 8 to 543 mm. The annual mean temperature was 11.7–12.5°C, and the annual total rainfall was 1,483–1,909 mm. The annual minimum and maximum air temperatures ranged from −10.1 to −7.0°C and from 32.3 to 36.1°C, respectively. A 3-ha pasture, including sites with various slope aspects (from 7 to 359°, where north, 0°; east, 90°; south, 180°; and west, 270°) and slope angles (0.5 to 19.1°), was used (Figure 1). Before planting in 2003, the pasture was dominated by *Pleioblastus chino* (Franch. et Savat.) Makino; *Z. japonica*; *Pennisetum alopecuroides* (L.)

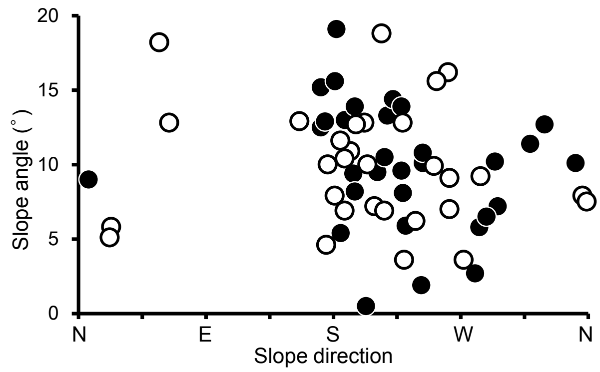

Fig. 1. Distribution of slope aspect and slope angle in the 61 quadrats.
In all, 72 quadrats were planted with centipedegrass in June 2003, but centipedegrass was found in only 61 quadrats in September 2008. ○ , seeded; ● , transplanted.

Spreng.; and *Digitaria adscendens* (H.B.K.) Henr.; this type of vegetation is typically found in abandoned cultivated lands in this region.

Experiments

In this study, to evaluate the rate of spread in centipedegrass, we used two introducing methods with an increased observation point and improved precision. Centipedegrass was seeded or transplanted within the 3-ha area (each plot, 0.5 ha; 3 replicates) between June 4 and 20, 2003. Seeding rate was 10 kg·ha^{-1} as reported previously[24], and the transplanting rate was one pot per meter square with small seedlings (i.e., 2 to 3 leaf stage; height, 3 cm; seedling pot: diameter, 1 cm; depth, 3 cm; individuals per pot, 2 to 3; seedlings, purchased). Each pot was transplanted into a hole dug in the ground (diameter, 2 cm; depth, 3 cm) by using portable electric drills. In all, 72 quadrats of 1 m × 1 m were established to represent various slope aspects and slope angles (Figure 1). Slope angle and slope aspect in each quadrat were measured using a clinometer. Half the quadrats were seeded, and the remaining were transplanted. Coverage of centipedegrass and other plants was measured every May and September from 2003 to 2008. No fertilizer was applied during the experimental period assuming low cost introduction and maintenance in abandoned cultivated lands. The soil at the site is Andosol. The pasture was grazed by reproductive Japanese Black cows from spring (late April or early May) to autumn (mid-October) at stocking rates of 291–439 head·day·ha^{-1}.

Data analysis

Slope aspect was converted into a numerical value from north = 0 and 1° = 1 for east, with north as 0, east as 90, south as 180 and west as 270 with fractional values for angles between the primary aspects. We used centipedegrass coverage data from 61 quadrats between 2003 and 2008. The rate of spread in centipedegrass in each quadrat was analyzed by calculating the years from appearance to the maximum rate of spread in centipedegrass (YMS) by using a quadratic logistic regression (Figure 2). The changes of coverage in centipedegrass in each quadrat from the appearance of centipedegrass seedlings until October 2008 (Figure 2a) were fitted to the quadratic logistic regression equation[25]:

$$y = Y/(1 + ae^{-bt-ct^2})$$

where y is centipedegrass coverage at time t; Y is the final coverage; and a, b, and c were obtained from the data to estimate the relative rate of spread in centipedegrass (Figure 2b). The year of maximum rate of spread in centipedegrass was calculated by differentiating the

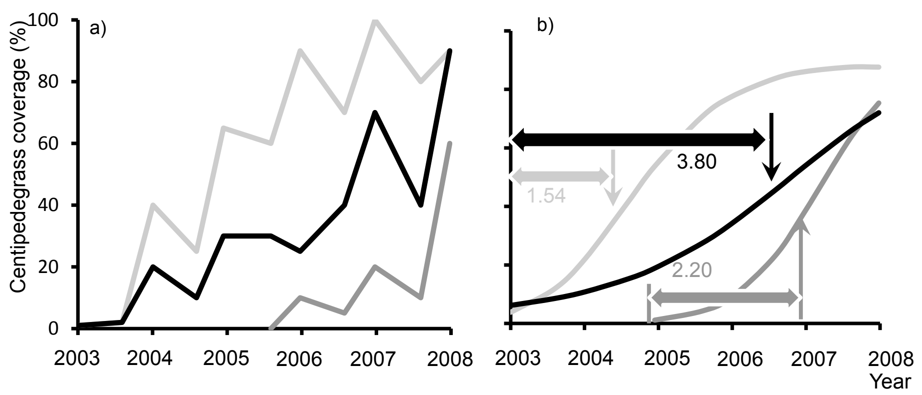

Fig. 2. Concept of the index of the rate of spread in centipedegrass (years from centipedegrass appearance to maximum rate of spread in centipedegrass: YMS) for analysis by using a quadratic logistic regression equation.
Lines of different shades represent data from 3 sample quadrats having different slope aspects and slope angles. (a) Time course of measured centipedegrass coverage. (b) Quadratic logistic regression from fitting actual measured values; the single arrows indicate the time of maximum rate of spread in centipedegrass calculated by differentiating the equation with respect to time; YMS (double-headed arrows) indicates the period of the rate of spread in centipedegrass in each quadrat.

equation with respect to time (*dy/dt*). YMS was calculated from the time of maximum rate of spread in centipedegrass minus the time of appearance in each quadrat. A logistic regressive equation[21] was calculated between YMS of seeding and transplanting.

The relationship between YMS and slope aspect and slope angle was determined by calculating the regression curves by using the following quadratic surface regression:

$$\text{YMS} = a \times \text{SD}^2 + b \times \text{SD} + c \times \text{SA}^2 + d \times \text{SA} + f$$

where a, b, c, d, and f were obtained by fitting this equation to the data to estimate the relative YMS; SD was the slope aspect; and SA was the slope angle. YMS, SD, and SA were standardized when they were regressed using a least-squares method.

The least-squares method of Snedecor and Cochran[18] was used for quadratic logistic regression and quadratic surface regression. Significant differences among these regressions were tested using analysis of variance (ANOVA)[18]. The statistical analyses were conducted using SAS version 9.2 (SAS Institute, Cary, NC, USA). In this research work we used the supercomputer of AFFRIT, MAFF, Japan.

Results

Topographical effects on the growth of centipedegrass

Logistic analysis was used to evaluate the difference in topographical distribution between centipedegrass seeding and transplanting. There were no significant differences between seeding and transplanting (χ^2 = 0.0164, d.f. = 1, P = 0.898). Therefore, we pooled the seeding and transplanting data for the subsequent evaluations to increase the observation point and improve precision.

Changes in centipedegrass coverage over time

In September 2003, centipedegrass seedlings were observed in 57 of the 72 quadrats. In September 2008, centipedegrass was found in 61 of the 72 quadrats, suggesting that centipedegrass had invaded four quadrats from 2003 to 2008. Of the 11 quadrats where centipedegrass perished, 10 were shaded by trees and 1 was dominated by *Pennisetum alopecuroides* (L.) Spreng. and *Trifolium repens* L.

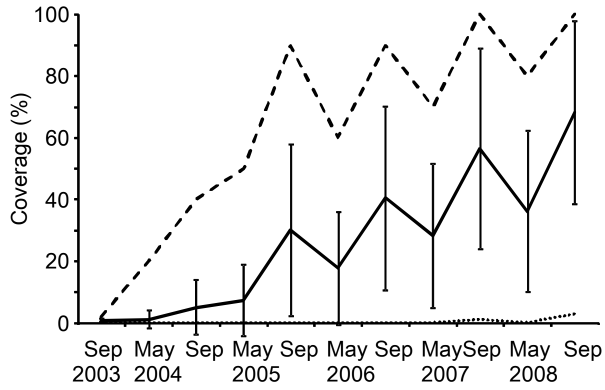

Fig. 3. Coverage of centipedegrass.
Maximum (---), mean (—), and minimum (···) coverage.
Whiskers show coefficient of variation, n = 61.

The average centipedegrass coverage increased from spring to autumn, but not from autumn to spring. It decreased from autumn to spring every year after 2004 (Figure 3). In all quadrats, centipedegrass coverage increased with time, and the rate of increase differed across the quadrats. Average centipedegrass coverage in autumn was 1 % in 2003, 30 % in 2005, and 68 % in 2008; centipedegrass coverage across all the quadrats ranged from 0 to 90% in 2005 and from 3 to 100% in 2008.

Changes in centipedegrass coverage with slope aspect and slope angle

In 2005, the quadrats with higher centipedegrass coverage were located on slopes facing south to west, and those with lower coverage were located on slopes facing north (Figure 4a). Centipedegrass coverage on slopes facing in any aspect was higher in 2008 than in 2005. Slope angle seemed to have a little effect on centipedegrass coverage (Figure 4b). The increase of centipedegrass coverage from 2003 to 2005 and from 2006 to 2008 was evaluated by performing quadratic regression of slope angle and centipedegrass coverage (Table 1). At the locations with a large slope angle, the increase of centipedegrass coverage was small from 2003 to 2005, and it increased from 2006 to 2008. Thus, centipedegrass spread was markedly affected by slope aspect and slightly affected by slope angle.

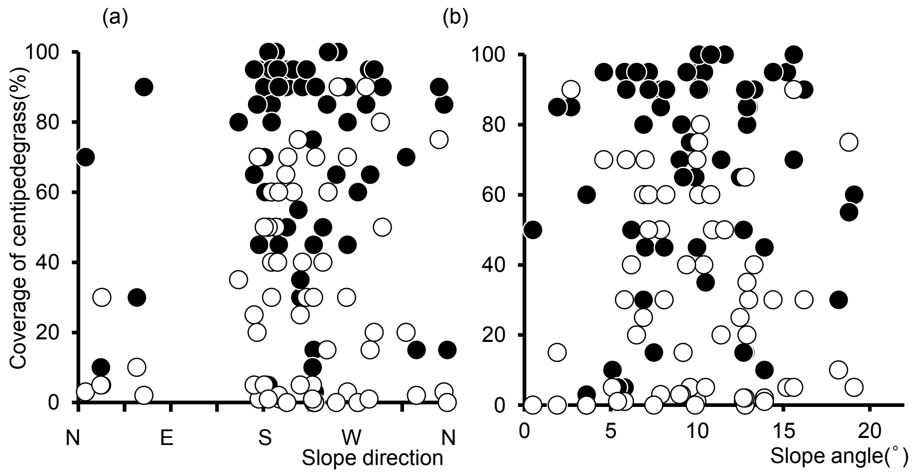

Fig. 4. Centipedegrass coverage in 2005 and 2008 on the quadrats with different (a) slope aspects and (b) slope angles.
○ , 2005; ● , 2008.

Table 1. Slope angle and percentage of spread in centipedegrass

Period	Slope angle				
	0°	5°	10°	15°	20°
The coverage of centipedegrass* (%)					
2003–2005	23	30	32	28	20
2006–2008	16	32	41	42	34
The percentage of spread in centipedegrass (%)					
2003–2005	60	48	44	40	37
2006–2008	40	52	56	60	63

* from quadratic regression of centipedegrass coverage in 2005 and 2008

Changes in the rate of spread in centipedegrass as a function of slope aspect and slope angle

The mean value and standard deviation of YMS were 2.55 and 1.03, respectively. The mean values ranged from 0.62 to 4.69 years.

The relationship of YMS to slope aspect and slope angle was evaluated using a quadratic surface regression (Figure 5):

$$YMS = 0.0000221 \times SD^2 - 0.00806 \times SD - 0.00446 \times SA^2 + 0.163 \times SA + 2.0126$$
$$(n = 61, r^2 = 0.126, P < 0.05).$$

The ANOVA for this regression was significant ($P < 0.05$; Table 2), but it showed low predictability ($r^2 = 0.126$). The highest YMS was 1.0–1.5 years in the 185° aspect on a flat ground. YMS decreased gradually with changes in aspects and slopes. The YMS of 2.0–2.5 years was noted in the

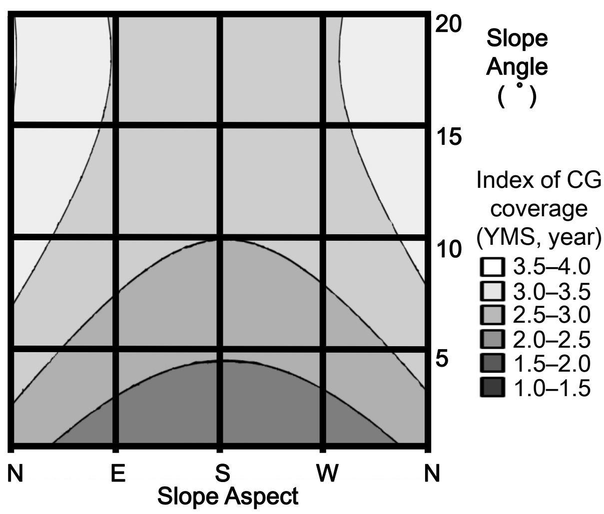

Fig. 5. Distribution of YMS (an index of the rate of spread in centipedegrass) with respect to slope aspect and slope angle.
CG: centipedegrass

Table 2. Analysis of variance of the relationship of years of maximum spread (YMS) with slope aspect and slope angle

Source of variation	S.S.	d.f.	M.S.	F	
Regression	8.8	2	4.4	4.4	*
Deviation	58.1	58	1.0		

* indicates statistical significance at the 5% level.

S.S.: some of square, d.f.: degree of freedom, M.S.: mean square

quadrats located in the western aspect with 5–10° of slope angle and those located in the eastern and western aspects with around 5° of slope angle. At these locations, this finding suggested that the rate of spread in centipedegrass was about 50–60% of that in the locations with the highest YMS. The lowest YMS was 3.0–3.5 years in the quadrats with a northern aspect and 10–20° of slope angle. This suggested that the rate of spread in centipedegrass at these locations was about 33–42% of that in the locations with the highest YMS.

Discussion

Validity of the regression equation

In this study, continuous data were used to evaluate the influence of slope aspect and slope angle on the rate of spread in centipedegrass in eastern Japan (temperate climate; Figure 5). Yamamoto[24] reported that centipedegrass coverage reached 90% by the third year after sowing in a flat agricultural land in eastern Japan. The YMS values for the southern aspect and relatively flat conditions were 1.0–1.5; thus, on such quadrats, 2.0–3.0 years were required from the first appearance of centipedegrass to reach maximum coverage, because YMS is the half time for centipedegrass growth (Figure 2). Therefore, the results from our equation are consistent with those reported by Yamamoto[24] for flat conditions.

Effects of slope angle and aspect on centipedegrass growth

Plant productivity is affected by slope aspect, because of the higher air and soil temperatures and lower soil water content on the south-facing slopes than on the north-facing slopes in regions with temperate[20] and warm climate[22]. In improved pastures, the productivity of warm-season grasses such as bahiagrass (*Paspalum notatum* Flügge) is higher on the south-facing slopes; in contrast, temperate grasses such as orchardgrass (*Dactylis glomerata* L.), Italian ryegrass (*Lolium multiflorum* Lam.), and redtop (*Agrostis alba* L.) grow better on north-facing slopes[1,16,23]. Centipedegrass is ideal for tropical climates; it is classified as a warm-season grass[10]. Our finding that centipedegrass coverage showed a greater increase on the south-facing slopes is consistent with this classification.

Although centipedegrass is a warm-season grass, it can tolerate freezing[10]; hence, winter dieback of some centipedegrass might have slowed the spread of centipedegrass in eastern Japan (annual minimum air temperature ranged from −10.1 to −7.0°C). In this study, centipedegrass coverage decreased from fall to spring (Figure 3). Johnston and Dickens[11] showed that 95% of centipedegrass survived at temperatures above −5.6°C, but the survival rate decreased to less than 20% at −10.1°C. At our study site, the monthly mean value of daily minimum temperature ranged from −4.7 to −2.5°C, which should allow more than 95% of centipedegrass to survive, but the minimum daily annual air temperatures were −10.1°C in 2006, which should allow $<$ 20% of centipedegrass to survive. In addition, lower soil temperature on the north-facing slopes[22] might have reduced the probability of overwintering and summer growth of centipedegrass. Thus, the northern aspect and cold climate in eastern Japan decreased the overwintering survival of centipedegrass. Hirata *et al.*[7] evaluated the effect of aspect on centipedegrass spread in southwestern Japan (monthly mean value of daily minimum temperature in winter was around 0°C) and found no difference between the north- and south-facing slopes. Therefore, the influence of slope aspect on the spread of centipedegrass is an important factor in the temperate region with a monthly mean value of daily minimum temperature of around −4.7°C rather than in relatively warm regions.

With an increase in slope angle, the percentage of centipedegrass spread decreased from 2003 to 2005. Cerdà and García-Fayos[3] indicated that a higher slope angle increases the runoff rate of seeds by rainfall. Thus, the higher slope angle might have caused higher runoff rate of seeds, lower seed germination rate, and lower percentage of centipedegrass spread in 2003–2005. In addition, centipedegrass never spread on a higher slope angle in the upper aspect of the gradient, despite spreading in all aspects on a flat land. These factors might have affected the spread of centipedegrass in areas with a higher slope angle.

Botanical composition as another factor for the introduction of centipedegrass

The spread of centipedegrass introduction was affected by not only slope angle and slope aspect but also another factor, as was evident by the lower r^2 (0.126, $P < 0.05$) for regression of YMS. The botanical composition was thought to be another factor that influenced the spread of centipedegrass. Hirata *et al.*[7] also reported that centipedegrass coverage was lower on slopes with an easterly aspect, because these areas were dominated by bench-type tall fescue (*Festuca arundinacea*) as temperate grass, which is susceptible to both the spread of stoloniferous prostrate species and summer depression, rather than *Paspalum notatum* Flügge and *Z. japonica*, which were dominant on the other aspects. *Z. japonica*, the dominant species at our study site in 2003, was only distributed on slopes with a southern aspect, whereas *P. chino*, *P. alopecuroides*, and *D. adscendens* were distributed on slopes with the remaining aspects (data not shown). The quadrats distributed with *P. chino* were not replaced by centipedegrass, because *P. chino* is a tall grass and is not degraded by grazing, preventing its replacement by centipedegrass. In this study, centipedegrass could not be introduced in 11 quadrats: 10 quadrats were shaded by trees, and one quadrat was dominated by *Pennisetum alopecuroides* (L.) Spreng. and *Trifolium repens* L. These findings suggest that the competitive ability to spread was higher in centipedegrass than in most plant species, but was lower than some plant species that did not degrade during the grazing period and shaded centipedegrass with their tall height. These properties of vegetation and coverage of centipedegrass were also considered to be affected by cattle grazing. Further studies are needed to clarify the effect of botanical composition and cattle behavior on centipedegrass spread.

Practical implications

Centipedegrass can be introduced in abandoned cultivated lands in eastern Japan in regions with a monthly mean value of daily minimum temperature of around −4.7°C. It can be introduced from northern Kanto to more warm areas in southwestern Japan, but the possibility of introduction of centipedegrass in colder regions having low temperatures below −4.7°C in winter such as the mountainous areas, is still unclear. The rate of spread in centipedegrass studied using continuous data for slope aspect and slope angle revealed that the location of the highest spread rate was in the southern aspect having a flat ground (location A). The rate of spread in centipedegrass in locations of the western aspect with 5–10° of slope angle and eastern and western aspects with around 5° of slope angle (location B) were about 50–60% of that in the locations with the highest spread. The locations with the lowest rate of spread in centipedegrass were those in the northern aspect having a 10–20° slope angle (location C); the spread rate in these locations was about 33–42% of that found in the location with the highest spread. For considering different effective strategies to introduce centipedegrass by changing the seeding rate according to topographical features, the rate of spread in centipedegrass for different slope aspects and slope angles is available. Yamamoto[24] indicated that centipedegrass could be introduced at a seeding rate of 5 kg/ha in a flat ground, such as location A in our study. These results suggest that the seeding rate according to the topographical features should be 5 kg/ha in location A, 10 kg/ha in location B because of the 50–60 % decrease in the rate of spread compared with that at location A, and 15 kg/ha in location C because of the 33–42 % decrease in the rate of spread compared with that at location A. Thus, our regression relating the rate of spread in centipedegrass from continues data will facilitate more economical centipedegrass introduction rather than that from categorical data, because our regression equation is more suitable for abandoned cultivated lands with varying and continuous slope angles and slope aspects.

This study also suggested that the spread of centipedegrass was affected by not only slope angle and slope aspect, but also vegetation. Plant species that shade centipedegrass throughout the grazing period might reduce the spread of centipedegrass. Thus, for the successful introduction of centipedegrass, care should be taken that it is not planted under trees and in areas that are subjected to intensive cutting or grazing.

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方位と斜度が東日本（冷涼地域）におけるセンチピードグラス（*Eremochloa ophiuroides*（Munro）Hack.）被覆速度におよぼす影響

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摘　　要

北関東程度の冷涼な気候条件の耕作放棄地放牧において，経済的かつ早期にセンチピードグラス草地を造成するため，斜面方位と斜度がセンチピードグラスの被覆速度に及ぼす影響を評価した。方位と斜度が異なる 61 のコドラートにセンチピードグラスを 2003 年に導入し，2008 年までその被度を調査した。センチピードグラス被覆速度の指標として，センチピードグラスの出現から最も早く広がる速度に達するまでの期間（YMS）を求めた。そして，方位と斜度を独立変数，YMS を従属変数として曲線回帰を行った。その結果，YMS が最も短い地形は南向きの平坦な場所で，その値は 1.0–1.5 年であった。YMS が最も遅い地形は北向きの 10–20˚の斜面で，その値は 3.0–3.5 年であった。このことから，東日本の冷涼な気候（月平均最低気温が−4.7℃程度）の気候条件下でセンチピードグラスを種子により導入する場合，平坦な南側の地形で播種量を少なくすることが実用的と考えられた。一方，曲線回帰は有意であるが r^2 が低く，その要因としてセンチピードグラス導入には前植生の庇蔭の影響も受けていたことが考えられた。

キーワード：センチピードグラス , 斜度 , 方位 , 被覆速度 , シバ型草地