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Development of mechanical methods for cell-tray propagation and field transplanting of dwarf napiergrass (*Pennisetum purpureum* Schumach.)

Renny Fatmyah Utamy[a], Yasuyuki Ishii[b,*], Sachiko Idota[b], Lizah Khairani[c], Kiichi Fukuyama[b]

[a]*Interdisciplinary Graduate School of Agriculture and Engineering, University of Miyazaki, Miyazaki, Japan*
[b]*Faculty of Agriculture, University of Miyazaki, Japan*
[c]*Graduate School of Agriculture, University of Miyazaki, Miyazaki, Japan*
(present: Faculty of Animal Husbandry, University of Padjadjaran, Indonesia)

Abstract

Since dwarf napiergrass (*Pennisetum purpureum* Schumach.) must be propagated vegetatively due to lack of viable seeds, root splitting and stem cuttings are generally used to obtain true-to-type plant populations. These ordinary methods are laborious and costly, and are the greatest barriers for expanding the cultivation area of this crop. The objectives of this research were to develop nursery production of dwarf napiergrass in cell trays and to compare the efficiency of mechanical versus manual methods for cell-tray propagation and field transplanting. After defoliation of herbage either by a sickle (manually) or hand-mowing machine, every potential aerial tiller bud was cut to a single one for transplanting into cell trays as stem cuttings and placed in a glasshouse over winter. The following June, nursery plants were trimmed to a 25–cm length and transplanted in an experimental field (sandy soil) with 20,000 plants ha^{-1} either by shovel (manually) or Welsh onion planter. Labour time was recorded for each process. The manual defoliation of plants required 44 % more labour time for preparing the stem cuttings (0.73 person-min. stem-cutting^{-1}) compared to using hand-mowing machinery (0.51 person-min. stem-cutting^{-1}). In contrast, labour time for transplanting required an extra 0.30 person-min. m^{-2} (14 %) using the machinery compared to manual transplanting, possibly due to the limited plot size for machinery operation. The transplanting method had no significant effect on plant establishment or plant growth, except for herbage yield 110 days after planting. Defoliation of herbage by machinery, production using a cell-tray nursery and mechanical transplanting reduced the labour intensity of dwarf napiergrass propagation.

Keywords: establishment, labour time, mechanical transplanting, nursery production, vegetative propagation

1 Introduction

Dwarf napiergrass (*Pennisetum purpureum* Schumach.) of a late-heading type (dwarf late, DL), which was bred in Florida, USA (Hanna *et al.*, 1993) and brought to the Thai Dairy Promotion Organization (DPO) in Thailand, was introduced to Japan in 1996 (Ishii *et al.*, 1998). The plant's features are quite similar to 'Mott' dwarf napiergrass (Sollenberger *et al.*, 1988) and it has the potential to spread in southern Kyushu (Ishii *et al.*, 1998). This grass can be perennial in the low-altitude areas of Kyushu Island (Mukhtar *et al.*, 2003; Ishii *et al.*, 2005, 2008; Wadi *et al.*, 2008), if the lowest minimum temperature is maintained above –6.2°C in winter (Ishii *et al.*, 2008, 2013).

* Corresponding author
Faculty of Agriculture, University of Miyazaki,
Miyazaki 889-2192, Japan
Email: yishii@cc.miyazaki-u.ac.jp
Phone: 8+81-985-58-7251; Fax: +81-985-58-2884

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In 2007, this dwarf napiergrass was spread to 12 extension sites including isolated islands in the Miyazaki, Kumamoto and Kagoshima prefectures of southern Kyushu (Utamy *et al.*, 2011), where the current area under cultivation is more than 10 ha. Dwarf napiergrass can yield sufficient dry matter (DM) at 13 Mg ha^{-1} of a superior herbage quality (Khairani *et al.*, 2013) compared to ordinary tropical grasses under an additional fertiliser application of at least 100 kg N ha^{-1} $year^{-1}$ after establishment (Utamy *et al.*, 2011). This grass has been examined for responses to cutting frequency and plant density (Mukhtar *et al.*, 2003; Wadi *et al.*, 2004), chemical fertiliser and manure application (Hasyim *et al.*, 2008, 2010), rotational grazing management (Ishii *et al.*, 2005, 2009) and weed control at the establishment and early growth stage (Utamy *et al.*, 2012) in southern Kyushu.

However, there remained an agronomic problem to be solved for establishing napiergrass. Napiergrass should be propagated vegetatively by root splitting, stem cuttings or shoot tips due to lack of viable seeds (Burton, 1989). However, it is very laborious to prepare nursery plants and transplant them by hand (manually), and manual methods seem to be inefficient compared with systems using machinery. Although vegetative propagation efficiency was improved by the shoot-cutting method (Kang *et al.*, 2011), mechanical planting is a well-known method for the establishment of rice (Sharma & Singh, 2008), Job's tears (*Coix lacryma-jobi* L. var. *mayuen* (Romman.) Stapf) (Inoue *et al.*, 1984), and fruits and vegetables (Choon, 1999; Sarif *et al.*, 1996). A prototype semi-automated napiergrass planter, on which a worker must ride to set out nursery plants, has been developed (Sollenberger *et al.*, 1987). Transplanting of pangolagrass (*Digitaria eriantha* Steud.) cv. Transvala was developed using a hand transplanter in Okinawa Prefecture (Okinawa Prefectural Livestock Experiment Station, 2005), but it is not available for napiergrass due to over-sizing of nursery plants. An automated mechanical transplanting method was applied to guineagrass (*Panicum maximum* Jacq.) by Nakahara *et al.* (2001) and bahiagrass (*Paspalum notatum* Flügge) by the Kumamoto National Livestock Breeding Center (2006). However, nursery plant production of dwarf napiergrass using cell trays as applied for vegetables, has not yet been tested for napiergrass, and a mechanical planter for vegetables has not been applied yet for nursery plants of this grass species.

Therefore, our objectives were to develop a method for nursery plant production of dwarf napiergrass using cell trays and to compare the efficiency of mechanical versus manual methods for preparing single-nodal stem pieces for cell-tray propagation and in-field transplanting.

2 Materials and methods

2.1 Grass species and site description

The grass species used was dwarf napiergrass of the late-heading type (dwarf late, DL). This grass grows to a height of 1.3–2.0 m (depending on the growing conditions) with an average internode length < 5 cm. This research was composed of two experiments, one for the preparation of stem cuttings and nursery production in a glasshouse (Experiment 1), and another for transplanting nursery plants to the field and establishment of the plants (Experiment 2). Experiment 1 was conducted first at Sumiyoshi Livestock Science Station (SLSS), University of Miyazaki (31° 59´ N, 131° 27´ E, 10 m above sea level) for the preparation of stem cuttings and then at Kibana Agricultural Science Station (KASS), University of Miyazaki (31° 50´ N, 131° 25´ E, 31 m above sea level) for nursery production in the glasshouse from November 2008 to May 2009. Experiment 2 was conducted at SLSS for the transplanting and establishment of nursery plants from June 2009 to October 2009. The soil at SLSS is sandy Regosols up to at least a 1-m depth with a pH (H_2O) of 6 and electrical conductivity of 10.4 mS m^{-1} for the topsoil (0–15 cm; Wadi *et al.*, 2008).

2.2 Nursery production (Experiment 1)

In November 2008, nursery production was conducted to record the labour time at SLSS for both manual and mechanical treatments, with four and three replications, respectively. In each manual treatment, 40 stalks of dwarf napiergrass were defoliated by sickle, engaging three persons. In each machinery treatment, 120 stalks were first defoliated by a hand-mowing machine (Model, Makita Co. Ltd.) operated by gasoline, engaging two persons. The number of labourers was reduced from three to two in the machinery treatment because there was no need to cut stalks manually. After gathering the cut herbage, every tiller bud positioned on an aerial node was cut by scissors to a single-nodal stem cutting, which consists of an internode, stem and axillary bud (Moser & Jennings, 2007), engaging 6.0 persons on average in manual treatments and 4.8 persons in machinery treatments, and the labour time was recorded. The labourers for both manual and machinery treatments were randomly chosen from a total of ten available. Stem cuttings were transported to KASS and transplanted to cell-tray beds (sized 3.0 cm × 3.0 cm × 4.5 cm deep per cell) filled with peat moss (Sakae Transportation Service Ltd., Mimata, Miyazaki), engaging 1.8 persons on average in manual and 6.8 people in machinery treatments, with labour time recorded. The cell trays were placed in a glasshouse and watered once or twice a day (depending on growth conditions) by one person to record labour time from November 2008 to May 2009. The surviving percentage of plants showing regrowth from stem cuttings, judged by the presence of green leaves on plants, was measured at monthly intervals from early January to early May in 2009. Air temperature was monitored by thermometer (Thermo Leaf, Taisei E & L Co. Ltd., Tokyo, Japan) from 3 February to 12 May 2009. The temperature in the glasshouse averaged 17.1, 17.7, 23.0 and 25.4 °C, respectively, for February, March, April and May.

2.3 *Transplanting, establishment and field management (Experiment 2)*

In June 2009, 2000 tillers, which formed 4–5 leaves each and had a basal diameter around 2–3 cm, were prepared as nursery plants of dwarf napiergrass. For the manual treatments, 600 nursery plants were prepared, and for the machinery treatments, 1,200 plants were prepared (for a total of 1,800 plants), engaging 2.0 persons for both plots to record the labour time. Then, green tops and roots below the cell trays were removed by scissors to a fixed 25-cm length, engaging 2.0 persons for both treatments to record labour time. Adjusting the plants to this length was necessary in order to use a Welsh onion planter (Negi-Nira Ishokuki, PNF–3, Katakura-kiki Co. Ltd., Nagano, Japan) in this research. The device is a self-moving planting machine, which must be held by a walking operator, and the capacity of the machine is 580 m hr^{-1} at low-speed operation and 1,210 m hr^{-1} at high-speed operation. In the manual treatment, a shovel was used for transplanting. The field was cultivated by rotary tilling once and no basal fertiliser was supplied before transplanting. The fields were divided into plots 10 m × 10 m for manual treatments and 10 m × 20 m for machinery treatments, each with 3 replications. The inter- and intra-row spacing was 1.0 and 0.5 m, respectively, to maintain a density of 2 plants m^{-2} for both treatments. Plants were transplanted on 5 June 2009 by 4 persons in the manual and on 9 June 2009 by 3 persons in the machinery treatment, and the labour time was recorded.

Plants were transplanted just at the start of the rainy season, before the hot summer season in this area; no irrigation was conducted. Based on data from Miyazaki Meteorological Observatory (Japan Meteorological Agency, 2010), the number of rainy days in the total period, the total (and daily mean) precipitation and the daily mean temperature from transplanting to the observed date for establishment were respectively 17 out of 25 days, 231.0 mm (9.2 mm day^{-1}) and 24.0 °C in the manual plot, and 14 out of 21 days, 230.5 mm (11.0 mm day^{-1}) and 24.3 °C in the machinery plot. These conditions of precipitation and temperature for 3 weeks after transplanting were enough to determine the establishment of this grass. Weeding was conducted on 1 July 2009 by cutting the inter-row space with a hand-mowing machine. Fertiliser was supplied by 3 split applications on 19 June (10–14 days after planting), 11 July (5 weeks after planting) and 3 October 2009 (end of the first defoliation) at 5 g m^{-2} each for N, P_2O_5 and K_2O per application by a compound fertiliser.

2.4 *Determination of plant growth characters and dry matter yield*

The percentage of established plants was determined 3 weeks after transplanting on 1 July 2009 when new leaf growth appeared to suggest the onset of rooting. After this date, no dead plants were observed in any plot. About 110 days after planting, on 26 September 2009, plant height and tiller number were measured for 10 plants per replicated plot (total of 30 plants per treatment) by the line transect method and the herbage was cut at 10 cm above the ground for 2 plants per replicated plot (total of 6 plants per treatment) by the line transect method to measure fresh weight, and about 400 g of subsample was dried at 70 °C for 4 days in an air-forced oven to determine percentage of dry matter, following Ishii *et al.* (2005).

2.5 *Statistical analysis*

The mean values of each variable affecting required labour time for cell-tray stem cuttings in two cutting methods, growth characters (plant height, tiller density, and percentage of leaf blade to whole plant weight) and herbage mass in two transplanting methods of dwarf napiergrass were compared by Student's t-test at the 5 % significance level (SPSS for Windows ver. 16.0, Chicago, IL, USA). The means in the percentage of plants surviving from stem cuttings in the glasshouse and the percentage of plants established in the field were analysed by t-test at the 5 % level after arcsine transformation (McDonald, 2009).

3 Results

3.1 Labour time for nursery production in Experiment 1

In dwarf napiergrass, 160 stalks produced 10,286 stem cuttings, averaging 64.3 stem cuttings stalk^{-1} (Table 1). Required labour for gathering napiergrass stalks was significantly less using machinery (0.06 person-min stem-cutting^{-1}) than manually (0.23 person-min stem-cutting^{-1}). However, the labour time for preparing stem cuttings (averaging 0.30 person-min stem-cutting^{-1}) and for planting stem cuttings into cell trays (averaging 0.16 person-min stem-cutting^{-1}) did not differ significantly between treatments (Table 1). Mechanical harvest of leafage and stubble (the aboveground stem part left after cutting leafage) in dwarf napiergrass was effective in reducing labour time when preparing stubble for production of stem cuttings. The number of stem cuttings produced per stalk was 45.4 manually and 70.6 for the machinery treatment.

3.2 Labour time for watering and surviving percentage of plants showing regrowth from stem cuttings in the glasshouse

Nursery plants of dwarf napiergrass, watered in glasshouse, required labour time at 10.7 person-min application^{-1}. For both treatments (manual and machinery), the surviving percentage of plants showing regrowth tended to increase marginally from early January, reaching a peak in early February at 93.0 and 91.5 % for manual and machinery treatment, respectively, followed by a slight decline through early May to 90.3 and 83.9 %, while significant differences between treatments were not detected on either date.

3.3 Labour time for transplanting nursery plants in Experiment 2

The number of nursery plants transplanted successfully using machinery was 398 (99.5 %) per replication (Table 2). Labour time required for manually preparing nursery plants was 0.03 person-min m^{-2} (2 %) greater than for the machinery treatment, while labour time for manually transplanting in the field was by 0.34 person-min m^{-2} (41 %) lower than for mechanical transplanting (Table 2). Therefore, the entire transplanting process was significantly shorter for the manual operation than for the mechanical operation by 0.30 person-min m^{-2} (12 %), as shown in Table 2. In the present study, manually transplanting 200 nursery plants to the pasture site required 2.20 person-min m^{-2} (367 person-hr ha^{-1}), and machinery transplanting required 2.50 person-min m^{-2} (416 person-hr ha^{-1}).

3.4 Plant survival in the field, growth characters and herbage yield

The percentage of established plants 3 weeks after planting on 1 July 2009 were 99.7 % and 99.5 % in the manual and machinery treatments, respectively, showing no statistical difference (Table 3). The growth characters and herbage yield of dwarf napiergrass were determined on 26 September 2009; plant height reached 114–116 cm, tiller density 53–67 m^{-2} and percentage of leaf blade 61–63 %, with no statistical differences between the methods, except for herbage yield, which was significantly lower for mechanical than for manual transplanting, by 2,880 kg DM ha^{-1} (37 %).

Table 1: *Required labour time for two methods for preparing cell-tray stem cuttings of dwarf napiergrass (Experiment 1).*

Method	*Replications*	*Stalks* (no.)	*Total stem cuttings* (no.)	*Required labour time* (person-min. stem-cutting^{-1})			
				Cut and gather herbage, cut stubble and collect tillers	*Prepare stem cuttings*	*Transplant stem cuttings into cell trays*	*Total*
Manual	4	40	1816	0.226* ± 0.023 (3.0, 3.0–3.0)‡	0.319^{ns} ± 0.037 (6.0, 5.0–7.0)‡	0.185^{ns} ± 0.027 (1.8, 1.0–2.0)‡	0.730* ± 0.038
Machinery	3	120	8470	0.055 ± 0.012 (0.009 ± 0.002†) (2.0, 2.0–2.0)‡	0.297 ± 0.063 (4.8, 4.0–6.0)‡	0.154 ± 0.027 (6.8, 5.0–8.0)‡	0.506 ± 0.047

Data are presented as means ± standard deviation.
* $P < 0.05$; ^{ns}, $P > 0.05$ within each activity by Student's t-test.
† Only for cutting and gathering herbage by machinery.
‡ Mean and range of number of persons engaged.

Table 2: *Required labour time for two methods of transplanting dwarf napiergrass (Experiment 2).*

Method	*Replications*	*Nursery plants* (no.)	*Plot area* (m^2)	*Required labour time* (person-min. m^{-2})		
				Prepare nursery plants	*Transplant nursery plants*	*Total time*
Manual	3	200	100	1.717* ± 0.0058 (2.0, 2.0–2.0)‡	0.480* ± 0.1058 (4.0, 4.0–4.0)‡	2.198* ± 0.1097
Machinery	3	398†	200	1.683 ± 0.0000 (2.0, 2.0–2.0)‡	0.815 ± 0.0624 (3.0, 3.0–3.0)‡	2.498 ± 0.0624

Data are presented as means ± standard deviation.
* $P < 0.05$ within each time by Student's t-test.
† Two plants lacked in transplanting on average.
‡ Mean and range of number of persons engaged.

Table 3: *Percentage of established dwarf napiergrass plants 3 weeks after planting, and growth characters and yield 3.5 months after planting.*

Method	*Replications*	*Character*				
		Percentage of established plants	*Plant height* (cm)	*Tiller density* (No. m^{-2})	*Percentage of leaf blade*	*Herbage mass* (g DM m^{-2})
Manual	3	99.7 ns ± 0.58	116.0 ns ± 2.31	67.3 ns ± 21.9	60.6 ns ± 4.87	783.0* ± 238.0
Machinery	3	99.5 ± 0.00	114.0 ± 3.00	53.0 ± 19.1	63.0 ± 2.65	495.0 ± 103.0

Data are presented as mean ± standard deviation.
* $P < 0.05$ within each character, ns, $P > 0.05$ by Student's t-test.

4 Discussion

4.1 *Labour time for nursery production, plant maintenance and transplanting*

Yokoyama (1996) revealed that a mechanical system reduced labour time for transplanting Welsh onion with a minimum failure of transplanting (<5 %) using the same machinery used in the present study. Mechanical transplanting of guineagrass (*Panicum maximum*) required less labour time as compared to manual transplanting, about 92 % (368 person-hr ha^{-1}) by using the transplanter for paddy rice (Seibyou Pot Transplanter, I. Co. Ltd.) (Nakahara *et al.*, 2001). A 49 % (63.3 person-hr ha^{-1}) reduction in labour time was recorded for mechanically transplanting *Brachiaria brizantha* cv. MG_5 by the Okinawa Prefectural Animal Husbandry Research Center (2010) and a 28 % reduction was recorded for mechanically transplanted rice (Sharma & Singh, 2008). The machinery system reduced labour intensity, with no need for a labourer to stoop when transplanting pangolagrass (*Digitaria eriantha*) cv. Transvala using a hand transplanter (Okinawa Prefectural Livestock Experiment Station, 2005), which was the same situation as in the present study. Boonman (1993) transplanted 20,000 root splits of napiergrass manually into 1 ha of pasture, which required 445 person-hr ha^{-1}. This result was slightly higher than obtained in the present study (367 person-hr ha^{-1}) using the manual method.

The power required to drive the applied transplanting machinery must be considered, because it should be suitable for the target crop species, cultivation system and soil properties. The machinery currently used for Welsh onion, usually operated on Andosols under ridge cultivation, could not operate on the sandy Regosols in this study without establishing ridges due to lack of adequate power of the machinery, resulting in an increase in labour time. The number of people engaged in machine transplanting was three people in the present study, while it could be reduced from three to two people. In the present study, holding the machine, picking up individual nursery plants from the basket and setting the plants on a conveyer were carried out by different people, but if a two-person operation could be established by combining the latter two processes under one person's operation, the labour time at transplanting could be reduced to 0.54 person-min m^{-2}, which nearly corresponds with that in the present manual transplanting. In addition, this machine should be more effective and efficient when used over a wider area, because the time loss when changing direction at the end of each row could be reduced a great deal with longer rows under cultivation.

4.2 *Plant survival in the field, growth characters and yield*

Kipnis & Bnei-Moshe (1988) determined the established plant density of napiergrass (N23) and a napiergrass × pearl millet hybrid by mechanical transplanting at 5.8 plants m^{-2} 3 weeks after establishment. This planting density was almost 3 times higher than the density of the present study (2 plants m^{-2}), however, the present 2 plants m^{-2} was determined as the optimum density to achieve the highest range of herbage yield in the year of establishment (Mukhtar *et al.*, 2003; Ishii *et al.*, 2005).

Regarding the growth characters and yield of dwarf napiergrass determined 3.5 months after planting, the lower herbage yield in the machinery treatment may be due to a shallower planting depth using this low-powered machinery (rated output of 1.6 kilowatts) than the manual treatment. It is expected that using a high-powered transplanter could plant dwarf napiergrass deeper than in the current study. The examined site had sandy Regosols, where drought stress severe enough to suppress plant growth happened frequently, especially hampering the development of shallower planted stem cuttings.

4.3 *Further application of the present nursery production and transplanting methods of napiergrass*

Cultivation of napiergrass at a low-altitude site of Kyushu Island has several merits due to its perennial property (Ishii *et al.*, 2005, 2008; Wadi *et al.*, 2008), high biomass yield with high-quality leafy herbage (Ito *et al.*, 1988; Sunusi *et al.*, 1999), which results in high digestibility and palatability to livestock (Tudsri & Ishii, 2007; Ishii *et al.*, 2009) and dual use as a bioenergy crop (Rengsirikul *et al.*, 2011, 2012, 2013; Khairani *et al.*, 2013) and a biodigester crop (Hasyim *et al.*, 2014). Especially, dwarf napiergrass is suitable for the nutrition of small-holder beef cows in the area, since it can overwinter in the low-altitude areas of Kyushu Island (Ishii *et al.*, 2008, 2013) and it can be fit to the rotational grazing even in abandoned orchard fields (Utamy *et al.*, 2014). Therefore, the present nursery propagation and transplanting practices has a potential to apply to the establishment of napiergrass for a multipurpose use as forage, biodigester and biofuel resource.

5 Conclusion

In the present study, entire processes for nursery production and establishment of dwarf napiergrass were completed, from preparation of stem cuttings based on aerial tiller buds, to cell-tray nursery culture in a glasshouse over winter, to mechanical transplanting by a Welsh onion planter. Even though the manual planting of the stem cutting of dwarf napiergrass needed less labour time per unit area, achieving higher yield after establishment, the entire mechanical processes could be beneficial to reduce labour intensity at transplanting and to expand the cultivation area of this grass species. Considering the actual situation in Japanese agriculture, in which the average age of producers is 65.8 years (MAFF, 2010), this planting machine could be very useful in reducing farmers' work load, and can be maintained for at least 7 years with depreciation costs of less than 100,000-yen yr^{-1} (Agri Business, 2000). Even though farmers have additional costs in mechanical transplantation, it should be a key issue to expand the cultivation area for this plant species. At the moment, plant propagation by the farmers themselves is not so popular, therefore, nursery selling by cell-tray propagation is a next step to expand the production of dwarf napiergrass in the region.

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References

Agri Business (2000). Welsh onion. URL `http://agri-biz.jp/item/detail/1582?page=7`, (last accessed: 28 April 2015).

Boonman, J. G. (1993). *East Africa's Grasses and Fodders: Their Ecology and Husbandry*. Kluwer Academic Publishers, London.

Burton, G. W. (1989). Registration of 'Merkeron' napiergrass. *Crop Science*, 29 (5), 1327.

Choon, Y. K. (1999). Mechanization in chili cultivation. National Engineering Conference on Smart Farming for the Next Millennium, University Putra Malaysia, Serdang, Malaysia, 14–16 March 1999. URL `http://eng.upm.edu.my/msae/machinery.htm`, (last accessed: 9 June 2009).

Hanna, W. W., Monson, W. G. & Hill, G. M. (1993). Evaluation of dwarf napiergrass. *In:* Proc. 17th Intern. Grassl. Congr., Palmerston North, New Zealand. pp. 402–403.

Hasyim, H., Ishii, Y., Wadi, A. & Idota, S. (2014). Effect of digested effluent of manure on soil nutrient content and production of dwarf napier grass in southern Kyushu, Japan. *Journal of Agronomy*, 13, 1–11.

Hasyim, H., Ishii, Y., Wadi, A., Idota, S. & Sugimoto, Y. (2010). Growth response of dwarf napiergrass to manure application originated from digested effluent. *Journal of Warm Regional Society of Animal Science, Japan*, 53, 115–126.

Hasyim, H., Ishii, Y., Wadi, A., Utamy, R. F., Wang, Y., Idota, S. & Fukuyama, K. (2008). Effect of digested effluent of manure on the growth and yield of dwarf napiergrass in southern Kyushu, Japan. *In:* Organizing Committee of 2008 IGC/IRC Congress (ed.), *Multifunctional Grasslands in a Changing World*. Vol. II, ch. Grasslands/Rangelands Production Systems – Integration of Crops, Forage and Forest Systems, p. 228, Guangdong People's Publishing House, China.

Inoue, T., Izawa, T., Nakajima, Y., Kutsuna, Y., Kato, Y. & Taniguchi, M. (1984). Studies on the mechanical cultivation of Job's tears (*Coix lacryma-jobi* L.). – Nursery period, transplanting density and time. *Research Bulletin of the Aichi ken Agricultural Research Center*, 16, 69–72.

Ishii, Y., Fukuyama, K., Iwakiri, T., Wadi, A. & Idota, S. (2009). Establishment of rotational grazing system on dwarf napiergrass pasture oversown with Italian ryegrass by smallholder farmers of Japanese-Black breeding beef cows in southern Kyushu, Japan. *In:* New Paradigm for Diversity of forage Production in the East Asian Region – Proceedings of the 3rd Korea-China-Japan Joint Symposium on Grassland Agriculture and Livestock Production. pp. 218–219.

Ishii, Y., Hamano, K., Kang, D., Rengsirikul, K., Idota, S., Fukuyama, K. & Nishiwaki, A. (2013). C_4-Napier grass cultivation for cadmium phytoremediation activity and organic livestock farming in Kyushu, Japan. *Journal of Agricultural Science and Technology*, A3, 321–330.

Ishii, Y., Mukhtar, M., Idota, S. & Fukuyama, K. (2005). Rotational grazing system for beef cows on dwarf napiergrass pasture oversown with Italian ryegrass for 2 years after establishment. *Grassland Science*, 51 (3), 223–234.

Ishii, Y., Tudsri, S. & Ito, K. (1998). Potentiality of dry matter production and overwintering ability in dwarf napiergrass introduced from Thailand. *Bulletin of the Faculty of Agriculture - Miyazaki University*, 45, 1–10.

Ishii, Y., Wadi, A., Utamy, R. F., Wang, Y., Fukagawa, S., Idota, S. & Fukuyama, K. (2008). Adaptability of dwarf napiergrass to small holders of beef cows in southern Kyushu, Japan. *In:* Organizing Committee of 2008 IGC/IRC Congress (ed.), *Multifunctional Grasslands in a Changing World*. Vol. II, ch. Grasslands/Rangelands Production Systems – Integration of Crops, Forage and Forest Systems, p. 230, Guangdong People's Publishing House, China.

Ito, K., Murata, Y., Inanaga, S., Ohkubo, T., Takeda, T., Numaguchi, H., Miyagi, E. & Hoshino, M. (1988). Studies on the dry matter production of napiergrass II. Dry matter productivities at six sites in southern area of Japan. *Japanese Journal of Crop Science*, 57 (3), 424–430.

Japan Meteorological Agency (2010). Previous climatic data. URL `http://www.data.jma.go.jp/obd/stats/etrn/index.php`, (last accessed: 28 December 2010).

Kang, D.-J., Ishii, Y. & Nishiwaki, A. (2011). Effects of the shoot-cutting method on field propagation in napiergrass (*Pennisetum purpureum* Schum.). *Journal of Crop Science and Biotechnology*, 14 (2), 139—142.

Khairani, L., Ishii, Y., Idota, S., Utamy, R. F. & Nishiwaki, A. (2013). Variation in growth attributes, dry matter yield and quality among 6 genotypes of napiergrass used for biomass in year of establishment in southern Kyushu, Japan. *Asian Journal of Agricultural Research*, 7, 15–25.

Kipnis, T. & Bnei-Moshe, S. (1988). Improved vegetative propagation of napiergrass and pearl millet × napiergrass interspecific hybrids. *Tropical Agriculture (Trinidad)*, 65, 158–160.

Kumamoto National Livestock Breeding Center (2006). Transplanting of bahiagrass. Kumamoto. URL `http://www.nlbc.go.jp/kumamoto`, (last accessed: 18 February 2010).

MAFF (2010). Census of Agriculture, Forestry and Fisheries in 2010. Department of Statistics, Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan. URL `http://www.maff.go.jp/j/tokei/sokuhou/census10_zantei/index.html`, (last accessed: 22 October 2010).

McDonald, J. H. (2009). *Handbook of Biological Statistics (2nd edition)*. Sparky House Publishing, Baltimore, Maryland. URL `http://udel.edu/~mcdonald/`, (last accessed: 2 November 2010).

Moser, L. E. & Jennings, J. A. (2007). Grass and legume structure and morphology. *In:* Barnes, R. F., Nelson, C. J., Moore, K. J. & Collins, M. (eds.), *Forages Volume II (6th edition)*. pp. 15–35, Blackwell Publishing, Iowa, USA.

Mukhtar, M., Ishii, Y., Tudsri, S., Idota, S. & Sonoda, T. (2003). Dry matter productivity and overwintering ability of the dwarf and normal napiergrasses as affected by the planting density and cutting frequency. *Plant Production Science*, 6 (1), 65–73. doi: 10.1626/pps.6.65.

Nakahara, Y., Kobashi, K. & Matsuoka, H. (2001). Development of seed harvesting system of guineagrass cv. Natsukomaki. *Bull. Kyushu Branch Japan. Grassl. Sci.*, 31 (1), 54–56.

Okinawa Prefectural Animal Husbandry Research Center (2010). Vegetative reproduction of tropical grass, *Brachiaria brizantha* cv. MG_5 by cell-tray nursery plant. Okinawa. URL `http://www.affrc.go.jp/research/seika/data_kyusyu/h19`, (last accessed: 18 February 2010).

Okinawa Prefectural Livestock Experiment Station (2005). Transplanting method of pangolagrass cv. transvala. Okinawa Green Grass, 2: 1-4.

Rengsirikul, K., Ishii, Y., Kangvansaichol, K., Pripanapong, P., Sripichitt, P., Punsuvon, V., Vaithanomsat, P., Nakamanee, G. & Tudsri, S. (2011). Effects of inter-cutting interval on biomass yield, growth components and chemical composition of napiergrass (*Pennisetum purpureum* Schumach) cultivars as bioenergy crops in Thailand. *Grassland Science*, 57 (3), 135—141.

Rengsirikul, K., Ishii, Y., Kangvansaichol, K., Sripichitt, P., Punsuvon, V., Vaithanomsat, P., Nakamanee, G. & Tudsri, S. (2013). Biomass yield, chemical composition and potential ethanol yields of 8 cultivars of napiergrass (*Pennisetum purpureum* Schumach.) harvested 3-monthly in central Thailand. *Journal of Sustainable Bioenergy Systems*, 3, 107–112.

Rengsirikul, K., Tudsri, S., Sugimoto, Y., Idota, S. & Ishii, Y. (2012). Dry matter production and energy efficiency of dwarf napiergrass (*Pennisetum purpureum* Schumach) under supply of animal manures, legume clippings and chemical fertilizer. *Bulletin of the Faculty of Agriculture, Miyazaki University*, 58, 69–77.

Sarif, H. S. H., Kassim, B. & Mohd, S. I. S. (1996). The future of mechanized high density fruit cultivation in Malaysia. Smart Farming 99, Malaysia. URL `http://eng.upm.edu.my/msae/machinery.htm`, (last accessed: 9 June 2009).

Sharma, S. C. & Singh, T. P. (2008). Development and performance evaluation of a mat type nursery raising device. *AMA, Agricultural Mechanization in Asia, Africa and Latin America*, 39 (2), 64–70.

Sollenberger, L. E., Prine, G. M., Ocumpaugh, W. R., Hanna, W. W., Jones Jr., C. S., Schank, S. C. & Kalmbacher, R. S. (1988). 'Mott' Dwarf Elephantgrass: A high quality forage for the subtropics and tropics. Circular S-356, Agricultural Experiment Station, Institute of Food and Agricultural Sciences, University of Florida, Gainsville, Florida, 1-18.

Sollenberger, L. E., Prine, G. M., Ocumpaugh, W. R., Schank, S. C., Kalmbacher, R. S. & Jones Jr., C. S. (1987). Dwarf napiergrass: A high quality forage with potential in Florida and the tropics. *Proceedings - Soil & Crop Science Society of Florida*, 46, 42–46.

Sunusi, A. A., Ito, K., Ishii, Y. & Ueno, M. (1999). Effect of the level of fertilizer input on dry matter productivity of two varieties of napiergrass (*Pennisetum purpureum* Schumach). *Grassland Science*, 45, 35–41.

Tudsri, S. & Ishii, Y. (2007). Improvement of pasture production and sustainability under smallholder condition in Thailand. *Bulletin of the Faculty of Agriculture, Miyazaki University*, 53, 1–10.

Utamy, R. F., Ishii, Y., Idota, S., Harada, N. & Fukuyama, K. (2011). Adaptability of dwarf napiergrass under cut-and carry and grazing systems for smallholder beef farmers in southern Kyushu, Japan. *Journal of Warm Regional Society of Animal Science, Japan*, 54, 87—98.

Utamy, R. F., Ishii, Y., Idota, S. & Khairani, L. (2012). Effect of weed control management on herbage yield, quality and wintering ability in the established dwarf napiergrass (*Pennisetum purpureum* Schumach). *Journal of Warm Regional Society of Animal Science, Japan*, 55, 17–26.

Utamy, R. F., Ishii, Y., Iwamura, K. & Idota, S. (2014). Effect of weed control on etablishment and herbage production in dwarf napiergrass. *Journal of Life Sciences*, 8, 46–50.

Wadi, A., Ishii, Y., Hasyim, H., Utamy, R. F., Idota, S. & Fukuyama, K. (2008). Rotational grazing effects of dairy cows on yield and consumption in dwarf napiergrass at a paddok scale for 3 years from establishment in southern Kyushu, Japan. *In:* Organizing Committee of 2008 IGC/IRC Congress (ed.), *Multifunctional Grasslands in a Changing World II*. p. 135, Guangdong People's Publishing House, China.

Wadi, A., Ishii, Y. & Idota, S. (2004). Effects of cutting interval and cutting height on dry matter yield and overwintering ability at the established year in Pennisetum species. *Plant Production Science*, 7, 88–96. doi:10.1626/pps.7.88.

Yokoyama, M. (1996). Development of machine-assisted transplantation technique utilizing seedlings that are grown in a special-arranged cell system. *Bulletin of the Shizuoka Agricultural Experiment Station*, 41, 13–23.