Physiological and Ecological Characteristics, and Control of The Perennial Weed Torpedograss (*Panicum repens* L.) in Crop Field and Turf in Ryukyu Islands, Japan

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Key words: perennial weed biology, plant growth response to edaphic factors, rhizomatous weed control, usages of torpedograss, weed-crop interaction.

Introduction

Studies on the physiology, biology and ecology of a plant species are very important for understanding its management practices and possible usages. Rhizomatous weeds are the most difficult to control due to their vegetative reproduction by underground propagules. Rhizomes and/or tubers of a plant species remain dormant in different soil layers for several years, which is one of the factors for survival of the species. The plants adapting to variable climatic and edaphic factors are difficult to control because they modify their morphological characteristics with the environments, and they are resistant to herbicides. Torpedograss (*Panicum repens* L.), a rhizomatous perennial plant, grows in tropical and subtropical regions (lat 35°S to 43°N) around the world. It is found in lowland coastal areas as well as local inland areas to elevations of 1500 to 2000 m. Torpedograss is a serious weed in various crop fields, orchards and golf courses and reduces plant yield up to 80%. It also invades ditches, drains, watercourses, fishponds, and floating mats of vegetation from banks and

adjacent areas. No crop field or golf course in the Ryukyu Islands (Okinawa, Japan) is free from torpedograss infestation, and sugarcane, the main crop in Okinawa covering 50% of cultivable lands, is severely infested with this weed. No comprehensive control strategy of torpedograss has yet been developed. This paper presents physiological and ecological characteristics, and control strategies of torpedograss in crop (sugarcane) field and turf in the Ryukyu Islands. In addition, possible usages of torpedograss are discussed based on biological and ecological aspects of this plant.

Results and discussion

Germination and emergence response of torpedograss to climatic and edaphic factors

Torpedograss is regenerated mainly by rhizomes and to some extent by stems, but not by seeds. Torpedograss produces infertile seed all year round. Germination of the rhizome buds of torpedograss was 100% at temperatures of 20 to 35°C, but germination was not observed at extremely low and high temperatures (<5°C and >45°C). Torpedograss shoots emerged well in soil with a pH range of 4 to 10. Torpedograss shoots emerged from the rhizomes at up to 50 cm depth in dark-red soil (Fig. 1). About 95% of the emerged shoots of torpedograss were recorded 60 days after land preparation, and 91% emergence was obtained from the upper 20 cm soil layer. Reduction of moisture in torpedograss

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Fig. 1 Effect of burial depth on emergence of torpedograss. Bars with the same letters are not significantly different at the 5% level, as determined by LSD test.

rhizome from 66% to 7% resulted in 0% bud sprouting (Table 1).

Growth characteristics of torpedograss as influenced by climatic and edaphic factors, and fertilizer application

Above-ground shoots of torpedograss grew slowly until 50 days after planting (DAP); thereafter, they increased rapidly with time (Fig. 3). The main rhizomes developed at around 50 DAP. Primary branches of rhizomes developed at around 70 DAP, and secondary ones at 110 DAP (Fig. 4). Growth and development of rhizomes were always faster than that of above-ground shoots. Rhizomes and roots made a loose mat-like structure into soil up to 50 cm deep. One plant from a single rhizome-bud produced

24,000 rhizome buds and covered 9 m² in a year. Total biomass production increased with time in spite of decreased temperature (Figs. 2, 5). Three growth phases were identified: establishment growth phase (up to 70 DAP), moderate growth phase (70 to 110 DAP) and

Fig. 2 Mean monthly ambient temperature in the experimental region during 1993-2001.

Fig. 3 Changes in number of torpedograss tillers over time. Data are means $\pm$ SD of five replications. Data were taken from August 1993 to January 1994.

Table 1. Rhizome bud sprouting of torpedograss as influenced by water content in rhizome.

Water content in rhizome (%)	Duration of drying (hours)	*Water recovery in rhizome (%)	Rhizome bud sprouting (%) [#]
54-66 (fresh rhizome)	0	54-66	100
42-53 (dry rhizome)	24	52-61	64-100
32-41 (dry rhizome)	48	47-60	56-90
11-20 (dry rhizome)	72	45-55	27-31
6-9 (dry rhizome)	96	41-51	10-13
5-7 (dry rhizome)	120	41-50	0

* Rhizomes were soaked with water for 16 hours.

[#] Data were taken from 161-192 buds (creeping and ginger-like rhizomes) for each treatment.

Fig. 4 Changes in rhizome branches of torpedograss over time. Data are means $\pm$ SD of five replications. Data were taken from September 1993 to January 1994.

Fig. 5 Biomass production of torpedograss with time. Data are means $\pm$ SD of five replications. Data were taken from August 1993 to January 1994.

fast growth phase (110 DAP to last harvest). Torpedograss shoots elongated up to 150 cm in field conditions, but can elongate up to 250 cm when optimum moisture, temperature and nutrients are available.

Creeping rhizomes and ginger-like rhizomes were found in torpedograss. The creeping rhizomes had internodes with a hollow medullary cavity, and each node had a single bud. The ginger-like rhizomes were solid, swollen, knotty, and ginger rhizome-like in shape. Every ginger-like rhizome had one or more buds depending on size and age (Fig. 6). Ginger-like rhizomes developed from the shoot base, and creeping rhizomes developed from the ginger-like rhizomes. Creeping rhizomes elongated more than 6 m, and the tip of the creeping rhizome

Fig. 6 Torpedograss plant showing shoots and rhizomes. A: a 180-day old torpedograss with 3 m long rhizome; B: ginger-like rhizome; C: rhizomes and roots showing a loose mat-like structure.

was needle-like, thereby enabling this rhizome to penetrate easily into deeper soil. Rhizome distribution in soil depended on the soil type and compactness. Rhizomes were distributed up to 15 cm in depth in golf courses and most rhizomes remained just below the turfgrass root-zone. In contrast, rhizomes were distributed up to 50 cm in cultivated fields, and most rhizomes remained within the upper 30 cm soil layer. The rhizome-internode length was 0.2 to 2.5 cm in golf courses due to soil compactness and walking and mowing effects, but was 3 to 6 cm in cultivated and fallow land. Some rhizomes were found to be rotten in golf courses and wasteland that had been infested for several years, but this was not found in cultivated fields infested for two or three years. Shoots were regularly mowed in golf courses, and, as a result, new shoots developed from the stem nodes and ginger-like rhizomes developed from this new shoot base. This characteristic was not found when torpedograss grew in cultivated fields. Each

ginger-like rhizome was 2 to 30 g (Fig. 6), and remained dormant for several years.

Shoot and rhizome biomass of torpedograss increased rapidly when temperatures of 22 to 29°C prevailed. The plant required higher temperature for proper growth and development during the moderate and fast growth phases. Gray (pH 7.0 to 8.2) soil produced the highest biomass of torpedograss, followed by reddish soil (pH 5.5 to 6.8). Torpedograss also grew well in red soil (pH 4.0 to 5.0) and sand of seashore areas where most grass species failed. Most grass vegetation was damaged by typhoons and saline water, and none recovered except torpedograss.

Root crown developed from the submerged stem-nodes of torpedograss grown in standing water (12 cm deep). Spike-like tillers and sheath-like leaf blades were observed in water-treated plants. Higher shoot biomass and lower rhizome biomass were obtained from standing-water-treated plants than from untreated plants (Fig. 7). Standing water plus shoot removal of torpedograss caused rhizome death. Torpedograss survived well in standing water when the shoots remained above the water surface. Fresh rhizomes of torpedograss contained 54 to 66% water, and dried rhizomes regained up to 50% of their water when water supply was available.

Torpedograss grown for 90 days obtained a

Fig. 7 Effect of standing water on biomass production of torpedograss. Bars with the different letters are significantly different at the 5% level, as determined by LSD test for total biomass.

Fig. 8 Biomass production of torpedograss as a pasture plant. The plant was harvested on April 15 (1st), May 30 (2nd), July 15 (3rd), August 30 (4th), October 15 (5th), November 30 (6th) and January 15 (7th). Bars with the same letter are not significantly different at the 5% level, as determined by LSD test.

significantly higher biomass with 200 to 400 kg ai/ha N than obtained with the fertilizer was applied at a lower rate. The agronomic efficiency of N application decreased to 5 to 38 with the increase in N application to 400 kg ai/ha, which was less than half of the agronomic efficiency with the 200 kg ai/ha N. The agronomic efficiency of N was very low (5 to 22) during 60 DAP. Nitrogen application at a rate of 200 kg ai/ha was the most effective for torpedograss growth. Torpedograss was harvested six to seven times with a yield of 6 to 10 ton/ha each harvest per year by applying N fertilizer at 100 kg ai/ha after each harvest (Fig. 8).

Mechanical and manual control strategies of torpedograss in sugarcane

Moldboard plowing up to 50 cm depth followed by two cross-passes with a rototiller at a 40-day interval before sugarcane plantation damaged weed seedlings and rhizomes, and reduced torpedograss infestation. Burying deeper than 30 cm by deep plowing might effectively reduce emergence of this weed.

Torpedograss reduced sugarcane yields by 65 to 80%, and sugarcane reduced weed biomass by 25 to 56%. In an artificially infested plant sugarcane (first season) field, no regrowth of

torpedograss (TG) was observed when weeding was done 45 DAP; regrowth was observed, however, in the fields weeded at 60 DAP or later (Table 2). Decreasing yields of sugarcane were noted as weeding was delayed; this decreased rate was recorded as 0.9 to 1.5 % per day during 45 to 90 DAP. In the ratoon sugarcane period, no regrowth of TG was observed in the fields weeded at 45 DAP, and these fields achieved a significantly higher yield than did the later weeded fields. Around 10 times greater TG biomass was recorded from the 60 DAP weeded fields in the ratoon sugarcane period than that in the plant sugarcane period. Ratoon sugarcane yield of 60 DAP or later weeded fields was half that of the weed-free or 45 DAP weeded field (Table 2). Torpedograss should be controlled within 45 DAP in the plant sugarcane period to achieve lower weed infestation and to obtain a higher yield in both plant and ratoon sugarcane. Proper weed control in the first sugarcane season could result in increased ratoon yield for several seasons.

Table 2. Effects of weeding time on torpedograss control and sugarcane yield in plant sugarcane and ratoon sugarcane fields.

Weeding time (DAP)	Weed biomasss (gm ⁻²)		Sugarcane yield (gm ⁻²)	
	Plant sugarcane	Ratoon sugarcane	Plant sugarcane	Ratoon sugarcane
T	2257a	3220a	5787a	8267a
S				
W(45)	3d	—	5148a	9719a
W(60)	130c	1242bc	3993b	4977b
W(90)	300bc	1159c	2952bc	4048b
W(120)	512b	1321bc	2624c	4825b
NW(0)	570b	1840b	2347c	4116b

DAP, days after planting; T, only torpedograss; S, only sugarcane; W(45), weeding at 45 DAP; W(60), weeding at 60 DAP; W(90), weeding at 90 DAP; W(120), weeding at 120 DAP; NW(0), no weeding; -, torpedograss not found. Means with the same letter(s) within each column are not significantly different at the 5% level, as determined by LSD test.

Table 3. Efficacy of different herbicides on torpedograss shoot and rhizome.*

Herbicide	Rate (kg ai ha ⁻¹)	Shoot control (%) [#]	Rhizome control (%) [#]
Asulam	2.0–4.0	60–87	90–95
Bialaphos	1.5–3.0	57–67	25–72
Glufosinate	1.5–3.0	80–90	49–100
Glyphosate	1.5–3.0	40–67	40–92
Hexazinon	5.0–10.0	47–60	48–100

* Data of the most effective herbicides among 27 were presented in this table.
[#] 0 = no effect~100 = complete killing.

Chemical control strategies of torpedograss in sugarcane

Twenty-seven different herbicides were tested to evaluate their herbicidal efficiency on torpedograss in a field. Among the tested herbicides, single applications of asulam (2.0 to 4.0 kg ai/ha), bialaphos (1.5 to 3.0 kg ai/ha), glufosinate (1.5 to 3.0 kg ai/ha), glyphosate (1.5 to 3.0 kg ai/ha), and hexazinon (5.0 to 10.0 kg ai/ha) effectively controlled torpedograss shoots and rhizomes (Table 3).

Asulam at 2 to 4 kg ai/ha applied 20, 40, 60 or 80 DAP controlled 100% of torpedograss shoots in sugarcane (Table 4). Regrowth of torpedograss was not observed in pot experiments when asulam was applied within 40 DAP because no new rhizomes developed during this period. However, regrowth levels of <25 and >75% were found in pot experiments when asulam was applied at 60 and 80 DAP because mature rhizome buds survived in a larger number than younger rhizome buds (Table 4). In a naturally infested field, asulam applied 20, 40, 60 or 80 DAP resulted in regrowth levels of >75, 51 to 75, 1 to 25 or 26 to 50% (Table 4). Regrowth levels were the highest in the fields with asulam applied at 20 DAP because most of the existing rhizomes had not emerged from the soil during this period and were therefore not affected by the herbicide. Regrowth levels were the lowest in the fields with asulam applied

Table 4. Effects of asulam application timing and rates on torpedograss control and sugarcane yield in pot and field experiments.

Application timing (DAP)	Rates (kg ai ha ⁻¹)	Torpedograss control (%) [#]		Regrowth (%) [†]		Sugarcane yield	
		Pot	Field	Pot	Field	Pot (g plant ⁻¹)	Field (g m ⁻²)
20	2.0	100	100	Rnf	>75	1573a	1141a
	3.0	100	100	Rnf	>75	973bcde	1086a
	4.0	100	—	Rnf	—	487f	—
40	2.0	100	100	Rnf	51–75	1043bcd	1175a
	3.0	100	100	Rnf	51–75	1062bc	1257a
	4.0	100	—	Rnf	—	988bcde	—
60	2.0	100	100	<25	<25	957bcde	1048a
	3.0	100	100	<25	<25	953bcde	1003ab
	4.0	100	—	<25	—	937cde	—
80	2.0	100	100	>75	26–50	832e	753c
	3.0	100	100	>75	26–50	853de	765bc
	4.0	100	—	>75	—	837e	—
S (check)			—		—	1104b	—
S+T (check)	Hna	0	—	100	—	621f	—

S, only sugarcane; S+T, sugarcane and torpedograss; #, 0 = no effect ~ 100 = complete killing; †, regrowth (%) = (Number of shoots emerging after herbicide application / Number of shoots at time of herbicide application) X 100; DAP, days after planting; Hna, herbicide not applied; —, experiment not conducted; Rnf, regrowth not found. Values with the same letter(s) within each column are not significantly different at the 5% level, as determined by LSD test.

60 DAP because most of the existing rhizomes completed emergence during this period and were killed by the herbicide. Furthermore, regrowth was higher in 80 DAP-applied fields than in 60-DAP applied fields because more new rhizomes developing within 80 DAP survived after asulam application.

Asulam at 4 kg ai/ha applied 20 DAP severely impacted growth and yield of sugarcane, while 2, 3 and 4 kg ai/ha of asulam applied 40 DAP or later had no injurious effects (Table 4). The herbicide applied at 2 to 3 kg ai/ha within 60 DAP resulted in a remarkably higher sugarcane yield than that applied 80 DAP (Table 4).

Torpedograss could not be completely controlled with a single application of asulam in a naturally infested field. Asulam application (3 kg ai/ha) at a 70-day or more interval completely controlled above-ground shoots but not regrowth from rhizomes. Asulam at 3 kg ai/ha applied three times at 40-day intervals starting 40 days after land preparation provided excellent control of torpedograss in sugarcane fields (Fig. 9).

Fig. 9 Effect of application interval of asulam on dry weight production of torpedograss shoots. Bars with the same letter are not significantly different at the 5% level, as determined by LSD test.

Torpedograss control in Turf

Asulam at 4.00 kg ai/ha, flazasulfuron at 0.25 kg ai/ha, asulam at 4.00 kg ai/ha plus flazasulfuron at 0.25 kg ai/ha, asulam at 4.00 kg ai/ha plus flazasulfuron at 0.10 kg ai/ha, asulam at 2.00 kg ai/ha plus flazasulfuron at 0.25 kg ai/ha, and asulam at 2.00 kg ai/ha plus flazasulfuron at 0.10 kg ai/ha were evaluated for torpedograss control in manilagrass (*Zoysia*

matrella (L.) Merr.) turf (Table 5). Asulam and asulam plus flazasulfuron exhibited statistically similar efficacy in control of torpedograss shoots (100%) and rhizome-buds (72-89%). However, asulam plus flazasulfuron showed up to 15% higher efficacy in rhizome control than asulam applied alone. Asulam plus flazasulfuron combinations controlled torpedograss shoots seven days earlier, and resulted in a non-significant lower regrowth up to 33% compared to asulam alone. A slight yellowish injury (5.7-8.3%) appeared on turfgrass for a few days, but it disappeared rapidly and the turfgrass became greener when asulam or asulam plus flazasulfuron was applied. All combinations of asulam plus flazasulfuron exhibited similar weed control efficacy. The lowest rate of asulam at 2 kg ai/ha plus flazasulfuron at 0.1 kg ai/ha resulted in the lowest turf injury (5.7%) (Table 5).

Lengths of stem internodes of torpedograss-shoots from soil surface to turfgrass surface were 0.2 to 2.5 cm, and one stem had 5 to 10 internodes, so the herbicide had to pass many nodes. It was assumed that herbicide could not reach each rhizome bud, which resulted in higher rhizome survival and regrowth in golf courses. However, rhizome internodes were longer in crop fields and herbicides had to pass fewer nodes. As a result, herbicide could reach

the end of rhizomes, and there was very little regrowth.

Rhizomes of torpedograss were aged and had many ginger-like rhizomes in golf courses, and these were not completely affected by herbicides. Rhizomes remained undisturbed in golf courses, which probably resulted in lower control rates of rhizome than in crop fields. In addition, stem-rhizomes and creeping-rhizomes developed many ginger-like rhizomes, which were established individually. As a result, herbicides did not pass to rhizomes that did not develop shoots. Around 28% rhizome-buds (200 buds per m²) survived after herbicide application and further infested the golf course severely.

A single application of asulam at 2 kg ai/ha plus flazasulfuron at 0.1 kg ai/ha could not control torpedograss rhizomes completely in golf courses. Sequential applications of the herbicide at around a 45-day interval should be required until torpedograss regrowth is found in golf course. Herbicides should be applied at least in the 4- to 5-leaf stage (around 30 days after turf mowing) of torpedograss, and turfgrass should be mowed at least 15 days after herbicide application for effective control. Herbicides should be applied before 10 a.m. for better control of torpedograss. Rainfall within five hours after herbicide application reduces

Table 5. Effects of asulam, flazasulfuron or asulam plus flazasulfuron on torpedograss control and turfgrass.

Herbicide treatment	Rate (kg ai/ha)	Shoot control (%) [#]		Rhizome control (%) [#]		Torpedograss regrowth (%) [†]	Turf injury (%) [‡]
		28DAT	35DAT	CR	GR		
Asulam	4.00	92±2b	100±0a	72±4a	73±4a	9±2a	8.3±2.4a
Flazasulfuron	0.25	0±0c	0±0b	—	—	—	—
Asulam+ flazasulfuron	4.00+0.25	100±0a	100±0a	83±7a	80±3a	6±2a	6.7±2.4a
Asulam+ flazasulfuron	4.00+0.10	100±0a	100±0a	79±5a	78±5a	7±2a	6.7±2.4a
Asulam+ flazasulfuron	2.00+0.25	100±0a	100±0a	76±4a	76±1a	7±2a	6.7±2.4a
Asulam+ flazasulfuron	2.00+0.10	100±0a	100±0a	81±3a	81±3a	6±2a	5.7±2.4a

#, 0 = no effect~100 = complete killing; †, regrowth (%)=(Number of shoots emerging after herbicide application/Number of shoots at time of herbicide application) X 100; ‡, injury level is expressed as percent shoot discoloration compared with the untreated check. DAT, days after treatment; CR, creeping rhizome; GR, ginger-like rhizome; —, data not recorded. Values with the same letter within each column are not significantly different at the 5% level, as determined by LSD test.

herbicidal efficacy.

Possible uses

Pasture: Torpedograss could provide a good pasturage because it grows throughout the year and it is palatable for horses, cattle, and goats. Torpedograss is the best grass species for sandy soil, acidic soil, alkaline soil, infertile soil, wet conditions, and standing water conditions, where most grasses fail. This grass can be harvested six to seven times with a yield of 6 to 10 ton/ha each harvest in a year (Fig. 8).

Soil erosion control: Torpedograss could be the best natural resource for soil erosion control because it maintains high shoot densities throughout the year, which protects soil from rainfall and strong winds. Huge rhizomes and roots make (fresh, 2 to 5 kg/m²) a loose mat-like structure up to 50 cm deep and hold the soil compactly. Root and rhizome systems can prevent pond and dam edges from eroding (Fig. 6).

Evergreen vegetation: Torpedograss has an extraordinary ability to withstand highly adverse climatic and edaphic conditions. Torpedograss damaged by typhoons and saline water re-established normal vegetation within one month. Torpedograss could be used as a cover crop in forests and orchards because it grows in shade. This plant uptakes water from 150 cm soil layer and rhizomes hold water, so it can be grown in arid, semiarid and desert areas where rainfall is scarce.

Extraordinary gene resource: Torpedograss can grow with a high soil pH range of 4 to 10 and a wide temperature range of 15 to 50°C. It grows on seashores and in mountain areas, and it is resistant to drought, standing water and high salt concentrations.

Conclusion

Torpedograss grows well from seashore to elevations of 2000 m in diverse climatic

and edaphic conditions such as high salt concentration, shallow standing water, drought, shade, sunny condition, sandy soil, clay soil, acidic soil and alkaline soil. Torpedograss is very important for protecting soil erosion, maintaining green vegetation and providing pasture. Above-ground shoots and rhizomes of torpedograss increase slowly until 50 days after planting (DAP), thereafter, they increase geometrically over time. Three growth phases were identified: establishment phase (up to 70 DAP), moderate growth phase (70 to 110 DAP) and fast growth phase (110 DAP to last harvest). Rhizome has been classified as creeping rhizome and ginger-like rhizome. Asulam at 2.0 to 3.0 kg ai/ha should be applied at 45-day intervals starting 45 days after sugarcane planting for better control of torpedograss. Asulam at 2.0 kg ai/ha plus flazasulfuron at 0.10 kg ai/ha should be applied at 45-day intervals until the regrowth of torpedograss is found in manilagrass turf.

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