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Allelopathic interference of sweet potato with cogongrass and relevant species

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Abstract Cogongrass (*Imperata cylindria*) is an invasive weed and harmful to ecological systems and agricultural production in many countries. It was found that plant extracts and root exudates of sweet potato (*Ipomoea batatas*) exhibit allelopathic potential and inhibit the growth of cogongrass to a greater extent than either barnyardgrass (*Echinochloa crus-galli*), Indian goose-grass (*Eleushine indica*), or lettuce (*Lactuca sativa*) in bioassays. Greenhouse trials indicated that sweet potato soil reduced the emergence of the noxious weed by 50 %, yet exhibited either weaker inhibition or the promotion of barnyardgrass, Bidens (*Bidens pilosa*), and Leucaena (*Leucaena leucocephala*), while the desired growth of upland rice (*Oryza sativa*) was not affected. In cogongrass fields, the incorporation of 1–2 tons aboveground parts and cultivation of sweet potato provided 80–85 % weed control. On the other hand, the reduction of congograss in fields may be offset by the alternate invasion of *B. pilosa* which multiplied its biomass by 2–6 times with sweet potato amended soils. The findings of this study indicate that sweet potato is an effective crop in the biologic management of the invasive cogongrass in agricultural fields, thus the interactive mechanism between sweet potato and the invasive weed demands further investigation. Ecologically, this study highlights the specificity of allelopathic interactions between cogongrass and sweet potato that is helpful to minimize the disturbance from infestation of this invasive weed against native species and crops.

Keywords Allelopathy · Cogongrass · Inhibition · Sweet potato · *Bidens pilosa* · Biological control

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Introduction

Cogongrass is one of the most troublesome and problematic weed species throughout the tropics and subtropics (Holm et al. 1977). Cogongrass spreads mainly by way of seeds and rhizomes (Dozier et al. 1998) and is an invasive weed (Xuan et al. 2009). It has been reported to reduce the production of 35 crop species in 73 countries (Holm et al. 1977; Udensi et al. 1999). Cogongrass is a major impediment to reforestation efforts in southeast Asia, the number one weed in agronomic and vegetable production in many parts of Africa, and is responsible for thousands of hectares of lost native habitat in the southeastern US (MacDonald 2004). It is considered a primary weedy species in tea (*Camillia sinesis* L.), rubber (*Hevea* spp.), pineapple (*Ananas comosus* Merr.), coconut (*Cocos nucifera* L.), oil palm (*Elaeis* spp.), and other perennial plantation crops. It also infests natural habitats, destroying many native plant ecosystems (MacDonald 2004). It thrives in areas of human disturbance and is reportedly established on over 500 million hectare worldwide (Holm et al. 1977; Dozier et al. 1998). Cogongrass invades and persists in moist tropical areas because of its extensive deforestation and fire-based land utilization system (Holm 1969). The mechanical control of this noxious weed is difficult once it is established, primarily due to re-growth from rhizomes (Hartley 1949). Several studies have found that the use of cover crops and selected herbicides can reduce the emergence of cogongrass, suppress the weeding frequency, and increase crop yield (Udensi et al. 1999; Akobundu et al. 2000; Chikoye et al. 2001). Cover crops such as velvet bean [*Mucuna cochinchinensis* (Lour.) A. Chev] and kudzu [*Pueraria phaseoloides* (Roxb.) Benth] combined with both hand weeding and chemical application have been successful controls in cassava production systems in West Africa; however, a similar approach in maize cover crops resulted in a reduction in grain production (Akobundu and Ekeleme 2000; Chikoye et al. 2000, 2001). Yandoc et al. (2005) studied the use of two parasitic fungi of *I. cylindrica*, including *Bipolaris sacchari* (E. J. Butler) Shoemaker and *Drechslera gigantea* (Heald and Wolf) Ito, to suppress the growth of cogongrass, as of now the practical application of this research has not occurred.

Sweet potato (*Ipomoea batatas* L.) is a nutritionally rich food. It is the seventh most important crop worldwide and the fifth most important crop in developing nations (Jung et al. 2011). This plant is adaptable to a wide variety of growing conditions. Furthermore, its roots, leaves, and shoots are excellent sources of nutrients and micronutrients for livestock and humans. This crop is rich in polyphenols, vitamin B, calcium, iron, zinc, and proteins, in addition to being resistant to diseases and pests (Pace et al. 1985; Odake et al. 1994). Sweet potato has been recognized as a very competitive crop against certain weeds (Villamayor and Perez 1983). The allelopathic ability of sweet potato has been reported, such as inhibition against cucumber (*Cucumis sativa* L.) yellow nutsedge (*Cyperus esculentus*), alfalfa (*Medicago sativa* L.), and cow pea (*Vigna unguiculata*) (Taylorson 1967; Harrison and Peterson 1986; Walker and Jenkins 1986; Walker et al. 1989). Chon and Boo (2005) detected that coumarin, trans-cinnamic acid, caffeic acid, and chlorogenic acid are plant growth inhibitors of the crop and that they were available in leaves, stems, and roots.

We found that local Vietnamese farmers in hilly and mountainous areas cultivated sweet potato in fields, which were infested by cogongrass so as to reduce the growth of the weed (laboratory reports). This research was afterward carried out to evaluate allelopathic interactions between sweet potato cogongrass and other plant species. Trials were conducted in the laboratory, greenhouse, and field during the period 2005–2009 to examine the possibility of biologic management of this noxious weed by sweet potato.

Materials and methods

Plants for experiment

The Okinawan purple variety of sweet potato cultivated in the fields of Okinawa, Japan, was used to compare the effects of sweet potato on cogongrass, barnyardgrass (*E. crus-galli*), Indian goose-grass (*E. indica*), Bidens (*B. pilosa*), Leucaena (*L. leucocaphala*), lettuce (*L. sativa*) and upland rice (*O. sativa*), which were used as indicator plants in bioassays and greenhouse trials. *E. crus-galli*, *E. indica*, *B. pilosa*, and *L. leucocaphala* are common plants found in cogongrass fields. *L. sativa* was selected as it is commonly used for bioassays as this plant species is sensitive to allelopathic effects, while upland rice is a crop affected by the infestation of cogongrass in crop fields. Seeds of *E. crus-galli*, *B. pilosa*, and *E. indica* were collected in fields and kept in a freezer (−20 °C) in the dark for 1 year thus breaking dormancy before used, while commercial *L. sativa* seeds were applied. The seeds of these plants were then placed into an oven at 40 °C for 2 days, cooled at room temperature, and rinsed repeatedly with distilled water to remove alien particles. Germination tests of all seeds were then conducted, the germination rate was revealed to be >90 %.

Laboratory experiment

Sweet potato plants grown in fields close to the University of the Ryukyus, Okinawa Campus, Japan, were collected and transferred to the laboratory. The leaves, stems, and stalks were throughly cleaned with tap water and then rinsed with distilled water several times. They were then ground and extracted using distilled water at rate of 1 g/100 ml and were filtered through filter paper. A volume of 10 ml of the supernatant was added to an agar culture medium (0.5 %) of 500 ml. The agar was then deposited in 500 ml glass beakers. Similar stems of the sweet potato at 20 cm length were grown in 500 ml agar culture medium beakers with 2, 4, and 6 plants per beaker. A total of 10 germinated seeds of cogongrass were sown on the surface of the beakers. In addition, the beakers treated with leaf extract were also sown with 10 seeds of each of the following: *E. crus-galli*, *E. indica*, and *L. sativa*. The agar culture medium was used as a control. All samples were transferred to a growth chamber (set at 25 °C, 4,000 lux, humidity of 70 %). After 7 days, the height and root length of the cogongrass and indicator plants were measured.

Greenhouse experiment

The experiments were conducted in a greenhouse of the Faculty of Agriculture, University of the Ryukyus, Okinawa, Japan, in 2007. Plastic pots (diameter: 19.5 cm, height: 40 cm, 3 pots per treatment) filled with commercial soil (Newman company, Okinawa, Japan) to a depth of 25 cm. Cogongrass rhizome were collected, cleaned with tap water, and cut at 20-cm length. A total of 10 rhizomes were placed at 10-cm depth in each plastic pot. Stems of sweet potato were grown in the pots at the same depth and thinned to 1, 3, 5, 10, 15, and 20 plants per pot after 2 weeks. In another trial, soil from fields cultivated with sweet potato (variety: Okinawan purple) for 1 year was used. After removing the roots of sweet potato, the soil was air dried in the greenhouse for 1 week (average temperature: 28–30 °C), ground, and placed into pots similar to those used above. A total of 20 germinated seeds of cogongrasses, *E. crus-galli*, *B. pilosa*, *L. leucocaphala*, or *O. sativa*, were sown in the pots at a depth of 2 cm. All samples were placed in the greenhouse (average temperature: 27–30 °C). Fertilizers were provided by conventional methods and a similar amount of water was added daily. The cogongrass control was grown in commercial soil with no amendments. After 2 months, plant height, number of plants, and dry weight of the cogongrass was measured.

Field experiment

This experiment was conducted between May to September (temperature: 27–35 °C) during 2008–2009 in a field (gray clay soil) at the Experimental Field Center, Faculty of Agriculture, University of the Ryukyus, Okinawa, Japan. The selected field had been abandoned for many years and was greatly over run by cogongrass (98 % cogongrass, 2 % *Bidens pilosa*). The field was divided into 3 × 4 m plots and was plowed to a depth of 20–25 cm. The aboveground part of the cogongrass was removed. Treatments in the fields include (A and B)—incorporation of 1 and 2 tons/ha of sweet potato plant material to soil, respectively. The fresh aboveground parts of the sweet potato were diced into 2-cm pieces before being installed at 5–10-cm depth in the plots. (C)—cultivation of sweet potato in plowed cogongrass. Stems of the sweet potato were planted in rows with a 20-cm space between rows. After 2 weeks, the sweet potato plants were thinned to 10-cm interval between plants. (D)—hand weeding, where the plots were plowed and the above-ground biomass and rhizomes of cogongrass removed by hand. Control plots were untreated with sweet potato. Fertilizers and water for the plots were provided by conventional methods. After 3 months, the presence of cogongrass and *B. pilosa* were recorded in three randomly located 50 × 50 cm areas in each plot.

Statistical analysis

All treatments were arranged in a completely randomized design with three replications. A combined analysis was conducted by one-way balanced ANOVA and Cross Site Analysis of CropStat (Ver. 7.2, 2007). The mean and CV were estimated for each level of the treatment of interest across remaining treatments, sites, and replicates. Means were separated by least significant difference (LSD) at the probability level of $P < 0.05$, followed by Duncan–Waller tests.

Results

Laboratory experiments

All plant parts including root, stems, stalks, and leaves of sweet potato exhibited allelopathic activity although inhibition of indicator plants was species dependent (Table 1). Plant height and root length of cogongrass and lettuce were reduced; however, only root length was significantly inhibited as compared with the controls (df = 12, F = 71.7, $P < 0.001$). The root length of both Indian goose-grass and barnyardgrass was markedly promoted by sweet potato, but the response of plant height was varied. The height of cogongrass was not significantly influenced by extracts of stems, leafstalks, leaves, and the 2–6 plants/beaker treatment, but the effects on root length varied among treatments. For root exudates, inhibitory activity was roughly proportional to the applied densities (Table 1). Of which, the 2 plants/beaker treatment showed inhibition of 16 %, which increased to >40 % at 4 plants/beaker. At 6 plants/beaker, root reduction was not significantly different to that of the 4 plants/pot, yet plant height was stunted (Table 1). It appears that root exudates of sweet potato may contain plant growth inhibitors which suppress the emergence of cogongrass. The leaf extracts exerted >30 % suppression on height of lettuce; however, the effects on cogongrass and barnyardgrass were negligible. The allelopathic activity against cogongrass varied among the parts of sweet potato examined (Table 1) with stem inhibition the greatest and that of leaf tissue the lowest. Suppression of root length was greatest for the sweet potato leaves, followed by stems and then stalks.

Greenhouse trials

The inhibitory effects of sweet potato grown in pots on growth of cogongrass were proportional with density (Table 2). At 1–5 plants/pot, rhizome and aboveground biomass were significantly inhibited (df = 6, $F = 87.7$, $P < 0.001$ and df = 6, $F = 161.4$, $P < 0.01$, respectively). In contrast, the number of seedlings and plant height were reduced, but not markedly than controls. At 10–20 plants/pot, emergence of the noxious weed was reduced by a greater amount. Except for the plant height, which was not significantly affected by any treatment (df = 6, $F = 0.8$, $P = 0.6$), the interplant of sweet potato with cogongrass markedly reduced emergence and size of the harmful weed proportional to sweet potato density (Table 2).

Table 1 Selective effects of sweet potato on emergence of cogongrass and indicator plants in bioassays

Treatments	Plant height (cm)	Root length (cm)
Cogongrass		
Control	3.0bc	9.5cd
2 plants	2.5bc	8.0d
4 plants	2.5bc	5.1e
6 plants	0.9c	5.3e
Stems	1.9bc	2.7f
Leafstalks	2.5bc	3.6ef
Leaves	2.9bc	2.0f
Indian goose-grass		
Control	11.7a	10.0c
Leaves	14.7a	14.4ab
Barnyardgrass		
Control	15.0a	13.5b
Leaves	11.3a	15.9a
Lettuce		
Control	5.0b	13.5b
Leaves	3.1bc	11.7c
F	18.3	71.6
P	<0.001	<0.001

Different letters indicate significant differences among treatments at $P < 0.05$, one-way balanced ANOVA and cross site analysis, followed by Duncan–Waller tests. Control, plants grown in the beakers filled with agar only

Table 2 Effects of sweet potato on emergence and growth of cogongrass in greenhouse trials

Treatments (plant)	Plant number (plant)	Plant height (cm)	Rhizome (g)	Aboveground parts (g)
Control	22.3a	39.6a	14.9a	8.4a
1	16.3ab	38.1a	11.6b	5.7b
3	16.7ab	36.2a	8.6c	5.7b
5	15.7ab	39.7a	4.8d	4.5c
10	12.3bc	37.7a	5.8de	4.2d
15	12.7bc	39.0a	3.4ef	4.7c
20	7.7c	31.2a	2.8f	2.1e
F	4.7	0.8	87.7	161.4
P	0.01	0.6	<0.001	<0.001

Different letters indicate significant differences among treatments at $P < 0.05$, one-way balanced ANOVA and cross-site analysis, followed by Duncan–Waller tests. Control, plants grown in commercial soil only

Table 3 Effects of sweet potato soil on emergence of cogongrass and indicator plants in greenhouse trials

Treatments	Shoot length (cm)	Root length (cm)
Cogongrass control	1.3f	1.5de
Cogongrass	0.6f	0.8f
Barnyardgrass control	4.9c	2.9c
Barnyardgrass	3.4d	4.2b
Bidens control	0.5f	0.7f
Bidens	0.6f	1.1ef
Leucaena control	1.2f	1.8d
Leucaena	2.3e	3.1c
Rice control	7.4a	5.3a
Rice	6.5b	5.8a
F	82.8	73.8
P	<0.001	<0.001

Different letters indicate significant differences among treatments at $P < 0.05$, one-way balanced ANOVA and cross-site analysis, followed by Duncan–Waller tests. Control, plants grown in the beakers filled with agar only

Sweet potato soil exhibited selective effects on growth of cogongrass compared with that of barnyardgrass, *Bidens*, *Leucaena*, and rice (Table 3). Both the shoot and root length of the cogongrass were significantly reduced by about 50 % (df = 9, $F = 82.8$, $P < 0.001$), while the shoot length of other indicator plants was either reduced to a lesser extent or increased. In contrast, root length of barnyardgrass, *Bidens*, LeIucaena, and rice all strongly increased in soil conditioned by sweet potato (df = 9, $F = 73.8$, $P < 0.001$).

Field trials

The incorporation of sweet potato tissue into cogongrass soil significantly reduced the emergence of the weed. However, the inhibitory level between the two applied doses (1 and 2 tons/ha) was not markedly different, except for the number of plants (Table 4). Plots amended with sweet potato had the greatest biomass reduction in cogongrass. Plowing significantly reduced emergence of cogongrass; however, the application of sweet potato tissues or cultivation of the crop in the plowed cogongrass fields provided greater reduction of the noxious weed. Plant height was slightly inhibited (df = 2, $F = 6.5$, $P = 0.02$), the number of plants and dry biomass of cogongrass were markedly reduced relative to controls (df = 2, $F = 49.3$, $P < 0.001$; df = 2, $F = 10.2$, $P = 0.01$, respectively) (Table 4).

Table 4 Effects of application of sweet potato on emergence of cogongrass and *Bidens* in fields

Treatments	Plant number (plant)	Plant height (cm)	Dry biomass (g)
Cogongrass			
Controls	76.3a	68.4a	68.1a
A	17.0c	42.6b	14.1c
B	7.9d	48.7b	13.7c
C	7.7d	42.6b	9.8c
D	19.7b	73.3a	20.9b
F	49.3	6.5	10.2
P	<0.001	0.02	0.01
Bidens			
Controls	6.0c	12.8c	8.2d
A	6.5c	23.9a	18.0b
B	17.5a	20.7ab	22.6a
C	12.5b	24.2a	17.2b
D	8.0c	18.5b	13.3c
F	15.1	12.6	51.6
P	0.001	0.002	<0.001

Different letters indicate significant differences among treatments at $P < 0.05$, one-way balanced ANOVA and cross site analysis, followed by Duncan–Waller tests. Control, plots untreated with sweet potato

A application of 1 ton/ha sweet potato, *B* application of 2 tons/ha sweet potato, *C* cultivation of sweet potato in plowed cogongrass, *D* hand weeding

While sweet potato cultivation or amendment suppressed the emergence of cogongrass, these areas became greatly invaded by *Bidens pilosa*, a problematic invasive species in many countries. Before the study was conducted, the coverage of *B. pilosa* in the fields was <2.0 %; however, the biomass of this weed rapidly increased in volume when growth of cogongrass was controlled by the use of sweet potato. The dry biomass of *B. pilosa* in plots which contained sweet potato increased 2–2.5 times. In the hand weeded plots, *B. pilosa* invaded at a lower magnitude which promoted = 1.5 times of the dried biomass. The density and height of cogongrass was slightly increased (df = 4, $F = 15.1$, $P = 0.001$; df = 4, $F = 12.6$, $P = 0.002$, respectively) than and dry biomass (df = 4, $F = 51.6$, $P < 0.001$) (Table 4). The invasion of *B. pilosa* was proportional to the amount of cogongrass biomass reduction by either the application of sweet potato or hand weeding.

Discussion

This study is the first to observe that sweet potato is a useful crop to control the emergence of cogongrass. This appears to demonstrate that sweet potato is a "natural enemy" of cogongrass, as it markedly reduced the emergence of the noxious weed in trials conducted in the laboratory, greenhouse, and field. The use of either incorporating plant materials into soil or cultivating sweet potato in fields invaded by cogongrass achieved 70–80 % reduction in this noxious weed (Table 4). It is suggested that the cultivation of sweet potato in cogongrass-infested fields may be beneficial to local farmers. The soil used to cultivate sweet potato was inhibitive against cogongrass and other weeds, while the desired growth of upland rice was not affected.

Results in the greenhouse indicate that allelopathic interference of sweet potato on cogongrass, barnyardgrass, *Bidens*, *Leucaena*, and upland rice was selective and species dependent. Barnyardgrass, *Bidens*, Indian goose-grass, and *Leucaena* are commonly found in the fields infested by cogongrass. Of these species, both *Bidens* and *Leucaena* are invasive non-native species, and barnyardgrass and Indian goose-grass are weeds which are problematic for agricultural production. The use of sweet potato appears to be highly effective in biologically controlling emergence of the noxious cogongrass and also contribute to the reduction of *Bidens*, *Leuceana*, barnyardgrass, and Indian goose-grass with no effect on desired crop species (Tables 1, 3).

In the greenhouse trials, sweet potato showed the greatest inhibition of cogongrass, followed by barnyardgrass and upland rice. In contrast, growth of the two upland species *Bidens* and *Leucaena* was strongly promoted (Table 3). Results from sweet potato amendment the field trials were similar, with 70–80 % reduction in growth of cogongrass, but a marked increase in the emergence and growth of the invasive *Bidens*. While the control of cogongrass by sweet potato may be helpful, an alternative invasion of the *Bidens* may be problematic. The interaction between sweet potato and *Leucaena* needs further investigation. This invasive species causes problems in the subtropics and tropics such as Okinawa, Japan, Southeast Asia, and Australia, and possess the toxic non-protein amino acid, mimosine, which is responsible for the strongly invasive nature of this legume (Xuan et al. 2006).

The alternate invasion of *B. pilosa* to fields in which the emergence of *I. cylindrica* was suppressed can be understood by the reciprocal production of allelochemicals by cogongrass. Xuan et al. (2009) detected that cogongrass produces many allelochemicals from rhizomes and root exudates which showed selective inhibition to the growth of *B. pilosa* than other plants that commonly found in *I. cylindrica* fields, such as *L. leucocaphala* (*Leucaena*). The allelochemicals from cogongrass were phenols, phenolic acids, fatty acids, and lactone (Xuan et al. 2009). Since the density of cogongrass in fields was greatly reduced by sweet potato, it is also likely that the amount of these allelochemicals resident in the soil should also be reduced, releasing the allelopathic suppression of *B. pilosa*. As stated above, sweet potato may be a "natural enemy" of cogongrass, vice versa, it may be a "natural friend" of *B. pilosa* as growth promotion was observed in both greenhouse and field trials (Tables 2, 3 4). The mechanism of the interaction between sweet potato and *B. pilosa* should also be studied further. Though the alternative invasion of *B. pilosa* into agricultural systems may cause problems, the control of this invasive species is much easier thorough either mechanical or biologic management as the species lacks the deep rhizome of cogongrass.

As the use of sweet potato was effective in reducing by up to 85 % the emergence of cogongrass in fields, further trials on examining application methods of sweet potato to fields in order to provide greater control of cogongrass and optimum crop yield should be carried out. In this study, the use of both cultivation of sweet potato in rows (20-cm spacing, 10-cm interval between plants) and incorporating 1–2 ton plant materials into plowed soil were tested. However, time of application and different cultivating density of the crop on the cogongrass field need to be elucidated. Furthermore, varietal difference of sweet potato to growth of *I. cylindrica* should be conducted so as to select the candidate with the greatest potential to reduce the noxious weed. The inhibition mechanism of sweet potato on the growth of cogongrass either by chemical or physical pathway should be clarified. The identification of allelochemicals derived from sweet potato, which are involved in the selective inhibition of cogongrass growth, is also needed.

Ecologically, findings of this study specify the allelopathic interaction occurred between congograss and sweet potato and propose the use of this crop may be helpful to minimize the disturbance from infestation of this invasive weed in the ecosystems. One established cogongrass outcompetes native vegetation, forming large monotypic expanses with extremely low species diversity (MacDonald 2004). The application of sweet potato may be useful to increase the biodiversity of plants in cogongrass fields. For instance, *B. pilosa* was <2 %, but the cultivation of this crop promotes its volume to 2–2.5 times (Table 4). In natural systems, multiple species may be involved in reciprocal allelopathic interaction that is one of several factors affecting the ability of a plant to invade and establish in a new ecosystem. On the other hand, reduced reliance on traditional herbicides via the use of allelopathy has been frequently noted as ecologically and environmentally favorable. Since no specific herbicide against cogongrass has been yet approached, the use of sweet potato is environmentally and ecologically safer than either traditional control or common synthetic herbicides at present to reduce the troublesome of this species occurring in agricultural production and ecological system.

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