An Evaluation of the Invasive Potential of Beach Vitex (*Vitex rotundifolia*)

Charles A. Gresham* and Amber Neal

The Belle W. Baruch Institute of Coastal Ecology and Forest Science,

Clemson University

P. O. Box 596, Georgetown, SC 29442

ABSTRACT

This study was conducted to determine if the introduced woody plant Beach Vitex, *Vitex rotundifolia* (Verbenaceae), (BV), has the potential to displace native beach dune species from front dunes. Nine BV communities on front dunes and control dunes without BV in Georgetown County South Carolina were inventoried. BV accounted for 84% of the stems in BV communities; sea oats, *Uniola paniculata* (Poaceae), and beach grass, *Ammophila breviligulata* (Poaceae), contributed 2.8% of the stems. Seaward BV runners grew an average of 188 cm in 2004 and the average 2004 seed crop was estimated to be 10,921 seed / m^2. In greenhouse experiments, sweet corn, *Zea mays* (Poaceae), seed germination and seedling growth were reduced by watering with leachate of a nursery pot containing BV compared to watering with leachate from a pot containing potting media only. BV appears to have the potential to be an aggressive invader and deserves monitoring.

*Corresponding author's email address: cgrshm@clemson.edu

INTRODUCTION

Biological invasions of non-indigenous plant pests, plants, pathogens, and arthropods are serious threats to the rural, urban, and natural ecosystems of the United States (National Research Council 2002) and the Coastal Plain of South Carolina contains several examples. Kudzu, *Pueraria lobata* (Willd.) Ohwi (Fabaceae) was introduced to the United States in 1876 and in the 1930's and 1940's it was widely planted in the Piedmont of Alabama, Georgia and Mississippi for erosion control (Miller and Edwards 1983, Britton et al. 2002). Although most commonly seen in South Carolina's Piedmont, several populations are proliferating in Georgetown County. Common Reed (*Phragmites communis* Trinius) (Poaceae) is an aggressive wetland invasive that is either an European form of the native reed (Swearingen et al. 2002) or a mixture of the two genotypes (Blossey et al. 2002) that is difficult and costly to control (Swearingen et al. 2002). Tallowtree, *Sapium sebiferum* (L.) Roxb. (Euphorbiaceae) was introduced into Charleston SC nearly 200 years ago as an ornamental (Hunt 1947) and was spread along riverbanks and wetlands by birds (Renne et al. 2000). This tree is commonly found in wet upland areas of Georgetown County and could form monospecific stands as it has along the Gulf Coast (Bruce et al. 1995). Unfortunately, another introduced, exotic woody species is proliferating along many Georgetown County beaches and is of concern to natural resource managers (Socha and Roecher, 2004).

Beach Vitex, *Vitex rotundifolia* (L.) fil. (Verbenaceae), [nomenclature, Wagner et al. 1999] (BV), is a widespread strand plant found from China, Taiwan, and Japan south to Malaysia, India, Sri Lanka, Mauritius, Australia, Pacific Islands, and Hawaii (Wagner et al. 1999). It is a prostrate, spreading woody shrub that is considered an excellent beach plant because of its salt tolerance and rapid growth leading to its 'spreading indefinitely' (Dirr 1998). Besides its use as a beach dune stabilizer, Ono et al. (2002) have isolated and described several compounds from the fruits of BV that inhibited the growth of human lung and colon cancer cells.

For any exotic species to successfully invade a new region three processes must occur: propagules must arrive in the new region, the species must become established and it must spread (Liebhold et al. 1995, National Research Council 2002). The arrival of BV was greatly aided by, if not solely caused by, intentional planting on beachfront dunes and residential lots in beach areas. Personal observations of several BV communities indicate that the species is successfully competing with the native vegetation, thus it appears to be established. Finally, recent observations indicate that it is spreading by vegetative growth and is growing in areas not previously planted.

Unfortunately there is little published research on the invasive potential of BV to support these observations. ZhiQuan et al. (1996) reported that BV was a suitable species to form a vegetative belt on the outer fringe of a Chinese coastal forest and that 100 % ground coverage was achieved one year after planting. ChongMin and EulSoo (2001) reported that BV vertical branches grew to 0.46 m tall and horizontal runners were up to 7.6 m long. They found high seed germination rates (71%) in the laboratory, lower rates in sea sand (30%), and no germination rate difference between dry and moist seed stratification.

The purpose of this research was to describe the species composition of BV communities on the Georgetown County South Carolina beaches to determine if BV was displacing native vegetation and to determine how BV competes with native vegetation.

From field measurements and greenhouse experiments we quantified competition for light, nutrients, and water along with four possible allelopathic interactions.

MATERIALS AND METHODS

This research included three investigations; a field description of BV community biotic and abiotic factors, a set of greenhouse experiments to test for allelopathic interactions and laboratory tests of seed germination in the presence of BV-derived aqueous extracts.

BV Community Description

Nine study areas were located on three beaches in Georgetown County, South Carolina (Table 1). The study areas were selected to include homogeneous BV communities on front dunes with adjacent front dunes supporting native dune communities. All study areas were just seaward of an occupied beach house and BV planting dates were obtained from property owners.

At each study area, three sample sites were established in June and July 2004. A sample site was subjectively located near the center of the homogeneous BV community (middle site), one sample site was located in the ecotone between the BV community and front dunes without BV (edge site), and a control site was established on a nearby front dune dominated by native vegetation (control dune). A sampling point was randomly located in each site, and a stem count by species was made in a $1m^2$ subplot centered on the sampling point. Terminology followed Radford et al. 1968. Prostrate BV runners entering the plot but not rooted in the plot were counted also. Spatial cover by species was visually estimated using the following cover classes; <1%, 1 to 5%, 5 to 10%, 10 to 25%, 25 to 50%, 50 to 75% and 75 to 100%. Surface (0-10 cm) soil samples were taken at the middle and control dune sites. Two flowering shoots were selected in each middle site and 2004 length growth and number of leaves were recorded. At each study area, the annual growth of five seaward BV runners was measured. The litter layer was collected from one 1 m^2 circular plot established near the middle site in study areas 1, 4, and 9. Finally a temporary $1m^2$ circular plot was established in the BV community of each study area when the fruits were mature (late July in 2004). All panicles containing one or more fruits in the $1m^2$ circular plot were counted and every fourth panicle was clipped, bagged and returned to the laboratory.

Light measurements were made on the soil surface of the middle sites at study areas 1, 4, and 9. A meter stick was placed on the soil surface and 11 PAR light measurements were recorded at 10-cm intervals. One PAR measurement was made above the BV at each study area.

Soil samples were air dried at room temperature with forced ventilation. All dried samples were tested for hydrophobic properties by releasing drops of tap water just above the soil and measuring the time necessary for the soil to absorb the water (Krammes and DeBano 1965). Timing was stopped at 120 seconds. Samples from the middle and control dune sites of study areas 1, 4, and 9 were sent to Clemson University for soil chemical analysis. Litter samples were weighed at field moisture content and a subsample was taken. Field moisture weights and oven dry weights (60^{o} C, forced air) were determined for the subsamples and the ratio used to determine oven dry weight of the entire litter collection. The number of fruits on each clipped panicle was counted and recorded by study area.

Greenhouse Experiments

The study design of the greenhouse experiments was three replications of five sets of treatment and control procedures applied to three bioassay species. Plastic greenhouse flats (19.4 cm by 19.4 cm by 6 cm deep) were filled with the screened A and E horizon of a forested Lakeland sand soil. Each flat was then sown with 30 seeds of 'Silver Queen' sweet corn, *Zea mays* L. (Poaceae), 'Dixie Lee' cowpeas, *Vigna unguiculata* (L.) Walpers (Fabaceae) or radish, *Raphanus sativus* L. (Brassicaceae). Each flat then received one of the five treatment procedures or associated control procedure and was placed in a fiberglass greenhouse. In experiment 1, the treated flats were periodically watered with a solution made by soaking 100 gm of fresh BV leaves in 870 mL of room temperature water for at least 15 hours. Control flats were periodically watered with untreated water. The treated flats in experiment 2 were filled with surface (0-10 cm) soil from BV communities and watered with tap water; the control flats were filled with surface (0-10 cm) soil from control dunes and watered with tap water. In experiment 3 a BV litter layer was added to the treated flats to mimic the litter layer density measured in the field (473.6 g/m^2). The control flats received a longleaf pine, *Pinus palustris* Miller (Pinaceae) litter layer applied at the same density as the BV litter. Treated and control flats were watered with tap water. Treated flats in experiment 4 were periodically watered with the leachate of nursery pots containing BV plants and control flats were watered with the leachate of nursery pots containing potting media only. The leachates were collected by placing the nursery pots on plastic sheeting and watering the pots until the desired volume percolated through the pots and was collected from the lowest corner of the sheeting. In experiment 5 the treated flats were placed under a tent of two layers of greenhouse shade cloth that approximated the BV shade measured in the field. Control flats were not shaded. After 20 days of treatment the living seedlings were counted and total height measured. The seedlings of each flat were then clipped at ground level and the aboveground biomass bagged. The soil of each flat was screened through fiberglass window screening in running water and the retained root biomass was bagged. The aboveground and root biomass was dried at 60^{o}C in a forced air oven until a constant weight was obtained and the weights recorded.

Laboratory Experiments

The design of this research was two replications of four germination tests with treatment and control solutions repeated with three species of seed. Each test consisted of 12, 10-cm disposable plastic petri dishes each with a disk of coarse filter paper in the lower dish. Twenty seed (of the same lots used in the greenhouse research) were added to each of four dishes for each of the three bioassay species. Two dishes of each species received enough treatment solution to saturate the filter paper and the other two dishes received a similar volume of control solution. Solutions were added periodically to keep the filter paper saturated. The treatment and control solutions for germination test 1 were the same nursery pot leachates used in greenhouse experiment 4. For test 2 the treatment solution was a 1:1 (v/v) 15-hour, room temperature aqueous extract of BV community soil decanted to remove the soil. The control solution was similar, but soil from the control dune was extracted. The treatment and control solutions used in greenhouse experiment 1 were used for germination test 3. For test 4, the treatment solution was a filtered, 15-hour, room temperature aqueous extract of 100 g (oven dry weight) of BV litter in 1 L of water. The control solution was a similar extract of longleaf pine needles.

The petri dishes were then placed on a laboratory bench for seven days. On the seventh day, the number of germinated seed were counted and the dishes (with tops removed) were placed in a 50 ^{o}C bench top oven until the seedlings and filter paper were dry then they were weighed.

Data Analysis

Stem density and cover class data were averaged by species and sample site (middle, edge and control dune) over the nine study areas. The cover class mid-point was used to average the cover class ranges. Shoot growth and fruit density data were averaged over the nine study areas. Soil data were averaged by site (middle and control dune) over the three study areas sampled. Data from the greenhouse and laboratory experiments were averaged by species and treatment within each experiment. Paired student t-tests ($\alpha = 0.05$) were used to detect significant differences in means.

RESULTS

BV communities were strongly dominated by BV (Table 2). Stems of BV accounted for 84% of the stems in plots at the middle sites; sea oats, *Uniola paniculata* L. (Poaceae), and beach grass, *Ammophila breviligulata* L. (Poaceae), contributed 2.8% of the stems. Sea oats and beach grass were inventoried as one species in the field. In the edge sites, BV stems were 73% of the total stem density and sea oats/beach grass stems were 12.4%. Cover values also indicate BV dominance in both middle and edge sites. Although BV cover was 65% in edge sites, 18.7% of the edge site was open. Sea oats/beach grass stems dominated control dunes and marsh pennywort, *Hydrocotyle umbellata* L. (Apiaceae) and cord grass, *Spartina patens* (Aiton) Muhl. (Poaceae) were also present.

The low soil surface light levels in middle sites are consistent with high BV cover in middle sites. Study area 1 had only 2.3% of the incoming light reach the soil surface, study area 4 had 5.6% and study area 9 had 10.7%. These three sites had well-developed BV communities.

BV exhibited rapid vertical and horizontal growth (Table 3). Average 2004 height growth was 33 cm that included the terminal flower panicle. The seaward annual horizontal growth for 2004 averaged 188 cm with a maximum growth of 330 cm.

BV also had large seed crops in 2004. Over the nine study areas, BV produced an average of 2,730 fruits/m^2 of middle site area. There are four cells per fruit and one seed per cell (Wagner et al. 1999). If all four cells produced a viable seed, the BV middle site populations would produce a 2004 seed crop of 10,920 seed/m^2. The most productive area had an estimated 2004 seed crop of 22,325 seed/m^2.

There was no evidence of BV affecting soil chemistry (Table 4). None of the soil chemical parameters measured were significantly different between BV middle sites and control dune sites. However, there was a strong hydrophobic reaction of soil from four of the nine middle sites sampled; only one of the nine control dune sites showed such a reaction. The litter layer on the three middle sites sampled averaged 473.6 oven-dry g/m^2 and ranged from 356 to 623 g/m^2.

The greenhouse experiments indicated allelopathic relationships between BV and the bioassay species, but poor germination and survival confounds data interpretation. In four of the five experiments, radish had establishment rates less than 10% and peas had similar establishment rates in two of the five experiments (Table 5). However in experiment 4, watering corn and pea seeds with leachate from nursery pots containing

BV significantly reduced establishment compared to watering seeds with leachate from pots containing potting media only. Height growth, aboveground (stem) biomass, and root biomass of both species were also reduced in treated flats, although the difference was not significant at $\alpha=0.05$.

In contrast, establishment rates were high in the laboratory tests (85 to 100%) but allelopathic relations were not indicated (Table 6). Dry weights for treatment and control pairs for each species within a test were not significantly different in any test. There was a slight beneficial effect of the BV beach soil extract, BV fresh leaf extract and BV litter extract to radish sprout weight compared to their respective controls.

DISCUSSION

These results support the concern that BV is an aggressive invader that displaces native dune vegetation. The field results indicate that few other species occurred in well-developed BV populations, and that the species found under BV did not have the genetic potential to dominate BV. Marsh pennywort does not attain the height of BV and cord grass does not have the stature to produce detrimental shade. Sea oats/beach grass grows taller than BV but these grasses reproduce poorly from seed (Graetz 1973) thus limiting their ability to invade BV communities from seed.

Field measurements and greenhouse experiments indicate that BV has the potential to become a rapidly spreading invader. The large seed crops measured (up to 22,300 seed/m^2) certainly provide the potential for widespread dispersal if the seed were spread, perhaps by birds. Even if the establishment rate were quite low, the large seed crop would compensate for this. The long (up to 3 m) seaward runners were rooted at several locations along their length. They could be broken off during a storm and washed down shore only to be slightly buried by water moved beach stand. If the sand is moist enough to allow the roots to survive, then a new BV plant is established. Once established, BV successfully competes with native vegetation by greatly reducing the amount of sunlight reaching the soil surface, producing allelopathic compounds in the root system and releasing compounds that create hydrophobic soils. Adams et al. (1970) reported that hydrophobic soils were found under some California desert shrubs and concluded that this was a mechanism to exclude annuals that were found surrounding the hydrophobic soils. A propagule from another species will have to tolerate the deep shade and dry surface soil (because of hydrophobic properties) to become established under BV. If a seedling did become established, it would have to tolerate the allelopathic compounds apparently produced in the root system.

The three criteria for successful invasion (arrival, establishment and spreading; Liebhold et al. 1995, National Research Council 2002) are clearly met by BV. It has been planted on Georgetown County beaches since the early 1990s, and has shown the potential to arrive at other locations by either seed or vegetative propagation. The nine populations studied contained many actively growing plants, indicating that BV is well established. Four of the nine study areas have BV populations that have survived for over 10 years and the oldest population has survived for 14 years. The final criteria for invasion (spreading) is exemplified by the BV population at study area 6 that was not planted in the area studied, but grew in from the lot to the south where it was planted 14 years ago. BV plants have also been found on an undeveloped beach ca 1.6 km from the nearest planted population, indicating the ability to spread.

Interpretation of the results from the greenhouse experiments should be tempered by the fact that a strong, consistent, allelopathic interaction was not demonstrated and that the bioassay species (corn, radish and cowpeas) may be more sensitive to any allelopathic compounds produced than the native dune vegetation. Results from one greenhouse experiment did suggest that something leached from the root system of BV hindered the germination and growth of corn. However sea oats/beach grass or marsh pennywort may be much less sensitive and this mechanism may be ineffective on beaches.

The results of field measurements support observations made by us and others who have been monitoring the species that BV is an aggressive invader.

CONCLUSIONS

1) BV communities are practically monocultures, indicating they have displaced native beach dune species that were probably present when the BV was planted.
2) Well-developed BV populations produce deep shade that invading species must tolerate to become established and survive.
3) BV appears to release allelopathic compounds from the root system that decreased the growth of corn seedlings.
4) Soils below some BV populations were strongly hydrophobic that could prevent the survival of a newly germinated seed of a different species.
5) BV populations had a large seed crop in 2004, and BV produces long seaward runners that could be dislodged and relocated in a storm.

MANAGEMENT RECOMMENDATIONS

Two mutually exclusive recommendations can be made from this research.

If the beachfront property owner desires to have the front dunes populated by native vegetation and not BV, then the BV should be removed entirely. Our data indicates that BV will form a monoculture that is not invaded by native vegetation that can be seen from a distance. A few native species are present, but they are well below the BV canopy. The means of removing BV was not included in this research, but conversations with property owners indicate that pulling it by hand and machinery has worked. Local authorities should be consulted about permitting such activity.

If the beachfront property owners desire a hardy, perennial, rapidly growing species then BV is an excellent species for planting. Conversations with beachfront owners have indicated that planting survival is high and our data document the fact that BV populations provide a dense vegetative cover for sand dunes. However property owners maintaining BV should realize that they are cultivating an aggressive species and should actively contain the species to their property.

LITERATURE CITED

Adams, S., B. R. Strain, and M. S. Adams. 1970. Water-repellent soils, fire, and annual plant cover in a desert shrub community of southeastern California. Ecology 51:696-700.

Blossey, B., M. Schwazländer, P. Häfliger, R. Casagrande, and L. Tewksbury. 2002. Common Reed. p. 131-138. *In:* Van Driesch, R., S. Lyon, B. Blossey, M. Hoddle, and R. Reardon, (Tech. Coords.) Biological Control of Invasive Plants in the Eastern United States. USDA Forest Service Pub. FHTET-2002-04, Bulletin Distribution Center, University of Massachusetts, Amherst, MA.

Britton, K.O., D. Orr, and J. Sun. 2002. Kudzu, p. 325-330 *In:* Van Driesch, R., S. Lyon, B. Blossey, M. Hoddle, and R. Reardon, (Tech. Coords.) Biological Control of Invasive Plants in the Eastern United States. USDA Forest Service Pub. FHTET-2002-04, Bulletin Distribution Center, University of Massachusetts, Amherst, MA.

Bruce, K. A., G.N. Cameron and P.A. Harcombe. 1995. Initiation of a new woodland type on the Texas Coastal Prairie by the Chinese Tallow tree (*Sapium sebiferum* (L.) Roxb.). Bulletin of the Torrey Botanical Club 122: 215-225.

ChongMin, P. and P. Eulsoo. 2001. Growing characteristics and propagation of *Vitex rotundifolia* for development of rehabilitation plant in seaboard area. Korean Journal of Environment and Ecology 15:57-68. (abstract only seen)

Dirr, M.A. 1998. Manual of woody landscape plants: Their identification, ornamental characteristics, culture, propagation, and uses. Stipes Press, Champaign, IL.

Graetz, K.E. 1973. Seacoast plants of the Carolinas for conservation and beautification. USDA, Soil Conservation Service, Raleigh, N.C.

Hunt, K.W. 1947. The Charleston woody flora. American Midland Naturalist 37:670-786.

Liebhold, A.M., W.L. MacDonald, D. Bergdahl and V.C. Mastro. 1995. Invasion by exotic forest pests: a threat to forest ecosystems. Forest Science Monograph 30:1-49.

Krammes, J.S. and L.F. DeBano. 1965. Soil wettability; a neglected factor in watershed management. Water Resources Research 1:283-286.

Miller, J.H. and B. Edwards. 1983. KUDZU: Where did it come from? And how can we stop it? Southern Journal of Applied Forestry 7:165-169.

National Research Council. 2002. Predicting Invasions of Nonindigenous Plants and Plant Pests. National Academy Press, Washington, DC.

Ono, M., T. Yanaka, M. Yamamoto, Y. Ito, and T. Nohara. 2002. New diterpenes and norditerpenes from the fruits of *Vitex rotundifolia*. Journal of Natural Products 65:537-541.

Renne, I.J., S.A. Gauthreaux, Jr. and C.A. Gresham. 2000. Seed dispersal of the Chinese tallow tree (*Sapium sebiferum* (L). Roxb.) by birds in coastal South Carolina. American Midland Naturalist 144:202-215.

Radford, A.E., H.E. Ahles and C.R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. The University of North Carolina Press. Chapel Hill NC.

Socha, T. and R. Roecher. 2004. "Kudzu of the beach" threatens Carolina Dunes. Engineer Update 28 U. S. Army Corps of Engineers, Washington, DC.

Swearington, J., K. Reshetiloff, B. Slattery, and S. Zwicker. 2002. Plant invaders of Mid-Atlantic natural areas. National Park Service and U. S. Fish and Wildlife Service, Washington, D. C.

Wagner, L.W., D.R. Herbst and S.H. Sohmer. 1999. Manual of the Flowering Plants of Hawai'i. Vol II. University of Hawai'i Press, Honolulu, HI.

ZhiQuan, Z., Z. Yi, C. ShouZhu and C. YuanSheng. 1996. Study on planting a grass [vegetative] outer fringe on sandy coast shelter forest in Guangdong Province. Forest Research 9:127-132. (abstract only seen)

Table 1. Location of study areas on Georgetown County South Carolina beaches.

Study Area	Beach	Address	Latitude	Longitude	Date BV Planted
1	N. Litchfield	86 Shore Bird Lp.	33° 29.184’	79° 4.919’	1999-2000
2	Litchfield	873 Norris Dr.	33° 27.543’	79° 6.159’	1990-1991
3	Litchfield	1131 Norris Dr.	33° 27.345’	79° 6.274’	1998
4	Pawleys	566 Myrtle Ave.	33° 24.850’	79° 7.700’	1996-1997
5	Pawleys	612 Spring St.	33° 24.679’	79° 7.898’	2001
6	Pawleys	634 Spring St.	33° 24.586’	79° 7.965’	1990*
7	Pawleys	686 Spring St.	33° 24.355’	79° 8.101’	1998
8	Pawleys	702 Spring St.	33° 24.287’	79° 8.135’	1998
9	Debordieu	61 Cheraw Way	33° 21.509’	79° 9.133’	1991

* Planted on adjacent lot.

Table 2. Average (n=9) species density and cover of BV communities and control front beach dunes in Georgetown County SC.

Species	Parameter	BV Community		Control
		Middle Site	Edge Site	Dune
BV stems	Density (stems/m^2)	51.3	48.7	0.1
	Cover (%)	86.1	65.3	0.05
BV runners	Density (stems/m^2)	7.9	6.6	0.0
Sea oats &	Density (stems/m^2)	2.0	9.4	31.1
Beachgrass	Cover (%)	1.2	11.9	35.8
Marsh	Density (stems/m^2)	5.4	3.2	11.7
pennywort	Cover (%)	1.7	1.0	3.7
Cord grass	Density (stems/m^2)	3.8	7.9	7.1
	Cover (%)	0.8	3.1	8.9
Other	Density (stems/m^2)	0.1	0.0	6.3
	Cover (%)	0.1	0.0	0.6

Table 3. Average, standard deviation, and maximum shoot growth and seed production of nine BV communities on Georgetown County SC beaches.

Parameter	Average	Standard deviation	Maximum
2004 Flowering shoot growth (cm)	32.9	19.6	73
Leaves on 2004 flowering shoot (count)	33.9	25.2	84
Beach front 2004 vegetative shoot growth (cm)	188	60	330
Flower panicles (count/m^2)	172.3	51.5	234
Fruits per panicle (count)	17.0	8.7	34.5
Fruits per m^2 (count)	2730.2	1248.5	5581.1
Seed per m^2 (count)	10920.7	4994.1	22324.6

Table 4. Average soil chemical parameters for samples taken in BV middle sites and control dune sites at study areas 1,4, and 9. Macro- and micro-nutrients are reported in kg/ha, salinity in mmhos/cm, nitrate N in ppm and CEC in meg/100g. Parameters are not significantly different by location.

Location	pH	P	K	Ca	Mg	Zn	Mn	Cu	B	Na	Salinity	NO_3 N	CEC
BV	7.6	247	29	8494	123	1.9	6.4	0.07	0.7	97	0.05	1.3	19.6
Dune	7.8	244	21	7354	122	1.2	6.0	0.04	0.7	118	0.09	2.0	17.1

Table 5. Establishment, height, stem, and root weights of corn, radish, and pea seedlings grown in a greenhouse for 20 days and treated with BV related procedures.

Parameter	Corn		Radish		Peas	
	Treated	Control	Treated	Control	Treated	Control
Experiment 1						
Treatment; Watering with an aqueous extract from fresh BV leaves						
Control; Watering with untreated water						
Establishment (%)	57.8a[1]	36.7a	1.11a	0.00a	0.0	1.1
Height (cm)	13.4a	17.7a	0.47a	0.29a	0.10	1.40
Stem Weight (g)	0.40a	0.36a	0.07a	0.06a	0.10a	1.15b
Root Weight (g)	4.15a	3.12a	0.09a	0.05a	0.07a	0.05a
Experiment 2						
Treatment; Flats filled with soils supporting BV populations						
Control; Flats filled with soils from control dunes						
Establishment (%)	27.8a	37.8a	7.8a	10.0a	54.4a	61.1a
Height (cm)	16.8a	15.7a	3.1a	1.3a	10.8a	12.1a
Stem Weight (g)	2.8a	3.4a	0.35a	0.52a	2.4a	2.8a
Root Weight (g)	3.8a	3.8a	0.12a	0.27a	1.5a	2.3a
Experiment 3						
Treatment; BV litter layer added to flats						
Control; Pine needle litter layer added to flats						
Establishment (%)	58.9a	57.8a	24.4a	51.1a	44.4a	43.3a
Height (cm)	13.0a	10.9a	1.60a	1.37a	5.4a	3.1a

Stem Weight (g)	0.58a	0.46a	0.04a	0.25b	1.16a	1.49a
Root Weight (g)	3.45a	3.02a	0.037a	0.077a	0.43a	0.16a
Experiment 4						
Treatment; Flats watered with a leachate from nursery pots containing BV						
Control; Flats watered with a leachate from nursery pots containing potting media only						
Establishment (%)	35.6a	94.4b	2.22a	5.55a	3.3a	40.0b
Height (cm)	25.3a	29.1a	4.83a	6.67a	4.0a	10.7a
Stem Weight (g)	0.56a	1.94a	0.02a	0.67a	0.41a	1.23a
Root Weight (g)	4.59a	6.00a	0.04a	0.08a	2.09a	2.51a
Experiment 5						
Treatment; Shaded to mimic BV community shade						
Control; Unshaded						
Establishment (%)	0.00	23.3	6.67a	6.67a	15.5a	4.4a
Height (cm)	18.6a	26.6b	0.42	0.50	1.80a	0.33a
Stem Weight (g)	0.42a	0.31a	0.11a	0.11a	0.54a	0.51a
Root Weight (g)	2.73a	3.29a	0.06a	0.06a	0.18a	0.05a

[1]Treated and control values within the same species with the same letter are not significantly different (t-test with P<0.05). Pairs without letters had insufficient data for a t-test.

Table 6. Sprout dry weight by species and treatment solution of petri dish germination experiment. Weights within a species and treatment solution pair are not different.

	Sprout dry weight (g)		
Treatment Solution	Radish	Corn	Peas
Leachate from pot with potting media only	0.175	3.17	2.38
Leachate from pot with BV plant	0.165	3.04	2.47
Leachate from control dune soil	0.115	3.16	2.20
Leachate from BV soil	0.185	3.19	2.47
Tap water	0.140	3.13	2.43
Tap water extract of fresh BV leaves	0.210	2.90	2.27
Tap water extract of pine litter	0.150	3.04	2.49
Tap water extract of BV litter	0.235	3.05	2.49