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Growth Efficacy of Sorghum and Rice Amended with Dried Versus Composted Aquatic Vegetation

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Abstract

Aquatic vegetation is a potential source of organic matter and nutrients for crop production and soil sustainability. However, its high water content and presence of toxic compounds have been major deterrents for commercial application. This split-pot study evaluated the application of *Pistia stratiotes* (PS) (water lettuce) and *Lyngbya wollei* (LW) (filamentous cyanobacteria) to grow rice and sorghum. The aquatic vegetation was applied as dried and composted amendments on sandy (<3% organic matter) and muck (>80% organic matter) soils. A completely randomized split-pot design evaluated the effect of the amendments on root dry weight (RDW), shoot dry weight (SDW), and nutrient content of above ground biomass. The application of dried PS and LW on sandy soil produced larger and heavier sorghum shoots than those grown under composted treatments. Soil type was not a determinant factor of plant nutrient content: total Kjeldahl nitrogen, phosphorus, potassium and silicon. Shoot dry weight of rice grown on sandy soils was significantly greater than grown on muck soils using dried LW and composted LW treatments. The allelopathic effects of PS and LW were more pronounced on sandy soil compared to muck soil, indicating the potential application for using aquatic vegetation as a soil amendment on sandy soil in the future.

Keywords: water lettuce, filamentous algae, amendment, aquatic vegetation, allelopathy, composting

1. Introduction

The presence of invasive aquatic vegetation in farm canals can impede drainage and irrigation and is cause for environmental concerns if not controlled properly (Alam et al., 1995; Ndimele et al., 2011). In the Everglades Agricultural Area (EAA) of south Florida, two most common aquatic vegetation species are *Pistia stratiotes* (water lettuce) and *Lyngbya wollei* (filamentous cyanobacteria). While several management approaches including chemical control and mechanical harvesting have been attempted, they may not be cost effective options for growers. However, if aquatic vegetation can be utilized as a soil amendment or bio-fertilizer it has the added advantage of offsetting some of the cost associated with mechanical harvesting, resulting in cleaner canals. Wilkie and Evans (2010) proposed three major concerns that have typically hampered the large-scale utilization projects for invasive aquatic vegetation. These are (i) the high upfront capital costs and complexity of utilization programs relative to operational cost associated with a control program; (ii) the "perceived" low value of products from aquatic plants relative to the expense of handling feedstock that is composed of almost 90% water; (iii) the possibility that any demonstration of value for invasive aquatic vegetation could have the perverse effect of speeding. While all these factors remain as important considerations, ongoing research into the beneficial uses of aquatic vegetation has the potential to reevaluate the current control strategies for many water bodies.

Numerous studies have been successful in showing the benefits of using aquatic plants as organic amendments, whether to control disease (Zhou & Everts, 2004), inhibit algal growth in waterways (Wu et al., 2013), or stimulate seedling growth (Ahn & Chung, 2000; Bhadha et al., 2014). Each of these studies was successful in showing the benefits of secondary metabolites (allelochemicals) produced by aquatic plants. Bhadha et al. (2014)

were able to show that root length of rice significantly increased in response to *Pistia stratiotes* at the end of a two-week period compared to the control, illustrating the fact that *Pistia stratiotes* can be used as a potential bio-fertilizer to stimulate growth of rice. Alternatively, studies have also shown inhibitory effects of allelochemicals on plant growth under controlled laboratory settings. Alliota et al. (1991) isolated potential allelochemicals (α-asarone, steroid derivatives, hydroxyl fatty acids) from *Pistia stratiotes*, while Bagchi et al. (1990) found that *Lyngbya wollei* produced and released secondary metabolites which inhibited growth of other cultured cyanobacteria and algae. The best use of aquatic weeds from an agronomic perspective is to apply a layer of aquatic vegetation to the soil that would help suppress weeds and retain moisture. The application could either be during a fallow period or as mulch for a growing crop. Once decomposition occurs, the residues could be incorporated into the soil to add organic matter and nutrients. However, the environmental conditions and the use of composted rather than dried aquatic plants may influence the allelopathic activity of these compounds when applied to the soil for crop growth (Inderjit, 2005; Kalamdhad & Das, 2011). Riemer and Toth (1971) showed that some aquatic weeds, such as *Myriophyllum heterophyllum* and *Elodea Canadensis* may be composted for agricultural use without the addition of extra nitrogen. Singh (1963) conducted trials to evaluate the effect of five composted aquatic plants (*Pistia sp., Hydrilla sp., Najas sp., Ottelia sp*., and *Eichhornia sp*.) on vegetable yields. Crops of tomatoes and okra were grown on plots to which these composts had been added at the rate of 28 tons ha^{-1}. The study revealed that the yields of tomatoes and okra were increased by all aquatic plant composts except Eichhornia sp. The author concluded that composts derived from aquatic vegetation have the potential for manuring fish ponds or as agricultural fertilizer. Annually, in the United States professional growers alone purchase $250 million per year in compost products (EPA, 1997). This study attempts at preparing composts from a balanced mixture of aquatic plants having the necessary nutrients to grow rice and sorghum crops.

Rice (*Oryza sativa* L.) and sorghum (*Sorghum bicolor* L. Moench) are two common row crops grown in the EAA. Both crops are annual grass plants, which belong to Poaceae family; however, their establishment and adaptation to environmental conditions are different. Rice is adapted to aquatic habitats and can grow in several soil types such as saline, alkaline and acid soils. However, its growth is mostly influenced by the physical properties of the soil that will determine its ability to hold water (OECD, 1999). On the other hand, sorghum can grow in low fertility, moderately acidic and highly alkaline soils, but is best adapted to fertile, well drained soils and clay percentage between 10 and 30% (Dial, 2012).

Bhadha et al. (2014) showed that both, *P. stratiotes* and *L. wollei* had a negative effect on the germination of five different varieties of plant seeds (snap bean, corn, sorghum, common lambsquarters, and rice) that were amended with various rates of dried application. The presence of numerous allelochemicals such as vicenen (apigenin-6,8-di-C-glycopyranoside), isovitexin (apigenin-6-C-glucoside), and lucenin (luteolin-5,8-di-C-glucoside) being released from the aquatic vegetation were identified as the cause of growth defects. This study evaluated the effect of applying *Pistia stratiotes* and *Lyngbya wollei* in dried versus composted form on sandy and muck soils to grow rice and sorghum. In Florida, sugarcane production on sandy soils has increased by nearly 85% in the past 25 years, and identifying a suitable soil enhancer for sandy soils has been gaining global interest due to concerns of soil loss via runoff, desertification and oxidation processes.

2. Method

The experimental design consisted of a split-pot experiment which allowed us to evaluate the root behavior under treatment and control settings. The split-pot was created by vertically dividing in half a 17 L rectangular pot (23 cm long, 23 cm wide, and 33 cm tall) with a PVC sheet (3 mm thick) secured to the inside pot corners and sealed with silicon to prevent lateral movement of water between compartments (Figure 1). The study evaluated four treatments which consisted of dried *P. stratiotes*, dried *L. wollei*, composted *P. stratiotes* and composted *L. wollei* applied to muck or sandy soils. The treatments were applied to one half of the pot while the other half was filled with control soil (either muck or sand). Both half-pot treatment and control were fertilized with a mixture of 37-0-0 slow release fertilizer (2.5 g), di-ammonium phosphate (1.0 g), potassium chloride (2.0 g), Sul-Po-Mag (0.95 g) and micromix (0.25 g). Pots were set up in a randomized complete block design with four replicates for the growth of rice and sorghum.

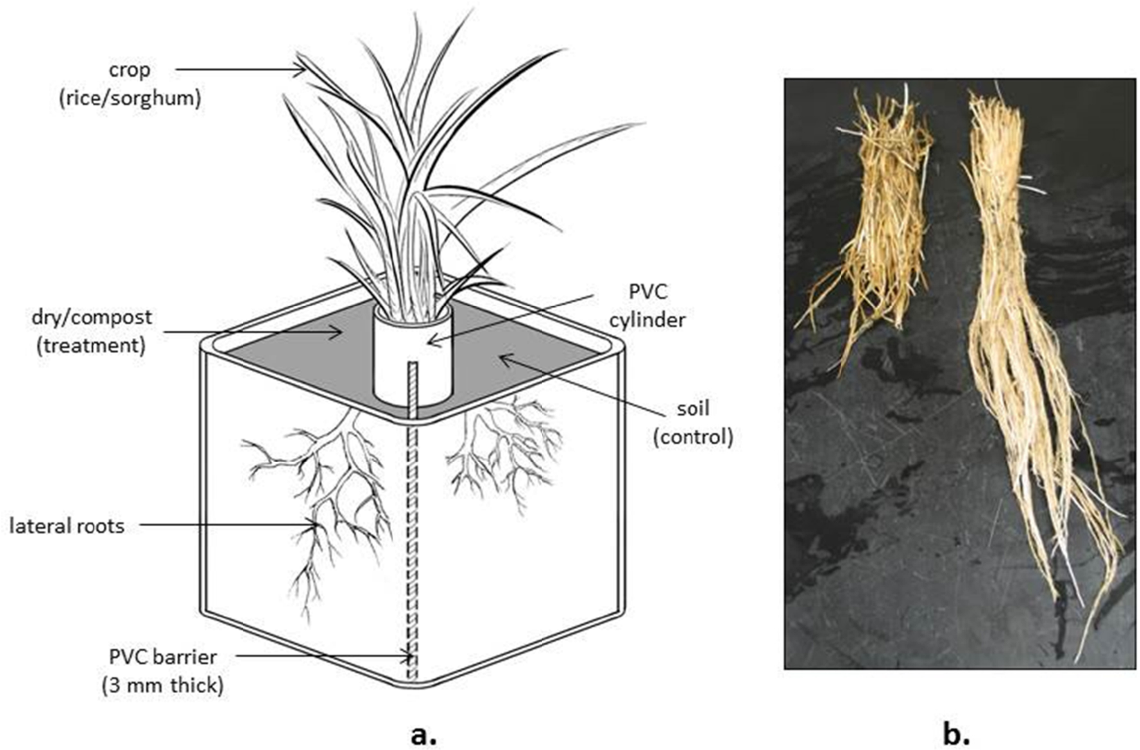

Figure 1. a. Split-pot design used to grow rice and sorghum in sandy and muck soil. b. Rice root evaluation between control and treatment sections

2.1 Soil and Amendment Analyses

For the study, we used Pahokee muck soil (Euic, hyperthermic Lithic Haplosaprist) and Margate sand soil (Siliceous, hyperthermic Mollic Psammaquent). *P. stratiotes* (PS) and *L. wollei* (LW) were collected from local farm canals. For the sorghum experiment, the amendments were sun-dried for seven days, however for the rice experiment, due to weather constraints the amendments were air-dried at 110 °C for two days in a drying room. After drying, the aquatic vegetation was grounded to be used either as dried amendments or converted into compost. Dried aquatic vegetation was composted by adding 10% muck soil and 5% ammonium nitrate (by weight) to the dried material. The batch of mixture was set aside to compost for four weeks. Every three days the batch was turned over (mixed), and temperature recorded. Baseline soil properties including pH, potassium (K), calcium (Ca), magnesium (Mg), and silicon (Si) concentration were measured prior to the experiment. Properties of both soils are presented in Table 1. Dried and composted amendments were analyzed for total Kjeldahl nitrogen (TKN), phosphorus (P), K, and Si. Soil pH was determined using a 1:1 water to soil mixture; elemental K, Ca, Mg, Si, P was determined by ashing the samples at 500 °C in a muffle furnace and performing a 12.1 M hydrochloric acid digestion. An inductively coupled argon plasma (ICP) was used to analyze the filtered digestates (Mylavarapu & Moon, 2002). A sulfuric acid digestion (Mylavarapu & Moon, 2002) was used to determine TKN and the digestate was analyzed on an Astoria 2 segmented flow analyzer (Astoria-Pacific Company, Clackamas, OR). Nutrient analysis of dried and composted aquatic vegetation used as amendments is shown in Table 2.

Table 1. Properties of sand and muck soil used in the study

Soil Type	pH	K, g/kg	Ca, g/kg	Mg, g/kg	Si, g/kg
Sand	8.1	0.030	13.33	0.179	0.047
Muck	7.2	0.161	7.51	1.27	0.038

Table 2. Nutrient concentration of amendments used in the study

Amendment		TKN, g/kg	P, g/kg	K, g/kg	Si, g/kg
Dried	PS	20.99	2.869	13.676	3.390
Dried	LW	27.72	0.438	3.765	0.583
Composted	PS	26.75	1.634	23.645	3.717
Composted	LW	24.96	1.762	3.191	1.625

PS = *Pistia stratiotes*, LW = *Lyngbya wollei*.

2.2 Plant Growth, Harvest and Analysis

Rice was transplanted to the split-pots one week after they germinated in the field and kept under these conditions throughout the experiment. Plants were grown within a small PVC cylinder (7.5 cm diameter) that was placed and filled with the selected soil type in the middle of the vertical barrier (Figure 1). Half-pot treatments contained 2 kg of fertilized muck or 4.5 kg of fertilized sand with composted PS (0.5 kg dry weight), composted LW (0.5 kg dry weight), dried PS (0.2 kg) or dried LW (0.2 kg).

Sorghum seeds were germinated directly in the PVC cylinder (Figure 1) and plants were irrigated manually on each side of the split-pot for adequate plant growth. Half-pot treatments contained 2 kg of fertilized muck or 4.5 kg of fertilized sand with composted PS (0.7 kg dry weight), composted LW (0.7 kg dry weight), dried PS (0.4 kg) or dried LW (0.4 kg).

Plants were harvested from the pots 30 days after planting. Shoot fresh weight was measured and air-dried at 110 °C for three days to obtain their dry weight. Shoots were grounded and tissue was analyzed for TKN, P, K, and Si. Roots from each half-pot were separated from the soil and cleaned. Root samples were air-dried at 110 °C for three days to obtain their dry weight.

2.3 Statistical Analyses

Data results were analyzed to determine the effect of four treatments (dried and composted, PS and LW) on two soil types (muck and sand) on shoot and root dry weights, as well as leaf nutrient content of rice and sorghum. The experiment was carried out as a split-pot technique, where the whole-pot factors were Soil (muck/sand), floating aquatic vegetation - FAV (water lettuce/filamentous algae), and Material (dried/composted), and the split-pot factor was treatment versus control. For each main effect in the model, Tukey multiple pairwise comparisons with letter grouping were displayed. For each model interaction, Tukey multiple comparisons of simple effects was conducted. A three factor linear model was fitted for each response variable using the GLIMIMIX procedure in SAS 9.3.

3. Results

3.1 Sorghum Shoot Dry Weight and Plant Nutrient Content

The application of dried PS and LW on sandy soils produced larger sorghum shoots that weighed significantly ($p < 0.05$) higher than those grown under composted treatments. For sorghum plants, significant two-way interaction between soil and material type indicate that on average, dried amendments increase SDW in sandy soil (Table 3). Shoot dry weight (SDW) of sorghum grown on sandy soils was higher compared to the muck soils under all four treatments (Dried PS, Compost PS, Dried LW, and Compost LW) (Figure 2a). Moreover, separation of means for sorghum showed that the plant had significantly greater SDW when they contained half-pot treatment of dried FAV in sandy soils compared to composted LW in sandy soils, and dried and composted PS in muck soils; however, treatments in muck soils did not present significant differences among them.

Statistical analysis of soil and FAV main effects showed that on average P concentration in the plant was greater in muck soil, and when LW was used as an amendment compared to PS. However, a two-way interaction indicated dependence between soil and material type which shows that in general both half-pot dried and composted treatments increased P content in muck soils but decreased P content in sandy soils, while dried treatments also resulted in decreased P content compared to compost treatments in sandy soils. Moreover, separation of means shows that plants amended with half-pot treatments of dried LW and composted LW in muck soil, as well as composted LW in sandy soil had significantly more P content compared to dried PS and composted PS treatments in sandy soil (Table 3). Potassium content did not indicate significant differences of main effects or factor interaction; however, separation of means showed that K content was significantly higher with the half-pot application of dried LW in muck soil compared to dried LW in sandy soil. There were no differences in K content between treatments in either sandy or muck soil. Analyses of TKN showed no significant differences between treatments.

3.2 Rice Shoot Dry Weight and Plant Nutrient Content

Shoot dry weight of rice grown on sandy soils was significantly ($p < 0.05$) higher than grown on muck soils under dried LW and composted LW treatments (Figure 2b). Rice presented significantly greater SDW when it was grown in sandy soil and with half-pot application of dried amendments. However, a significant interaction between type of soil and FAV indicate that on average LW increased SDW in sandy soils but decreased SDW in muck soils, while LW also significantly increased SDW in sandy soils compared to PS. Moreover, mean separation of the effects of type of soil (sand versus muck), FAV (PS versus LW), and material (dried versus composted) shows that SDW was significantly greater on treatments that contained half-pot dried LW in sandy soils compared to composted PS in sandy soils and composted LW in muck soils; however, treatments in muck soils did not present significant differences among them (Table 4). A high significant interaction was observed between FAV and material type indicating that overall composted material had a positive effect in P content regardless of the FAV type, as well as dried LW in comparison to the application of dried PS; however, the significant interaction between the three factors suggests a dependence on soil type (Table 4). In general, soil type was not a determinant factor on plant nutrient content of TKN, P, K, and Si (Table 4). Mean separation of effects showed significantly higher concentrations of TKN (3.6%) with the application of composted LW in muck soil compared to composted PS in muck soil (3.1%) and dried PS in sandy soil (3.0%); however, there were no differences among treatments applied in sandy soils (Table 4). Both TKN and P content were significantly higher when composted materials and LW vegetation were present. Mean separation of effects showed that significantly greater P concentration was present in plants that received half-pot application of dried LW in muck soil, in comparison to dried LW in sandy soils and dried PS in muck soil, which had the lowest P content of all (0.25%). In addition, treatment application in sandy soils did not present significant differences among them, nor did the application of composted treatments in either soil type (Table 4). Rice plants showed higher K concentration when they received the application of half-pot dried amendments. Mean separation of the effects of soil, FAV and material type showed that plants grown in sandy soil with half-pot treatment of composted PS had statistically lower K concentration compared to dried amendment applications of PS or LW in either soil type. Additionally, there were no differences in K concentration among the treatments applied in muck soils (Table 4). Silicon concentration had no significant differences of main effects of soil, FAV or material type. However, a two-way interaction between soil and FAV type, as well as soil and material type, showed that Si content was significantly greater with half-pot treatments of PS than LW in sandy soils, and with dried FAV rather than composted FAV in sandy soils. A three-way interaction was also observed, which suggests the dependence between the three factors (soil, FAV and material). The results of plant nutrient content are variable with different soil type and half-pot treatments applied as soil amendment; however, all plant nutrient contents were within optimal ranges for rice growth, except for Si which has a critical level of deficiency of <5% (Dobermann and Fairhurst, 2000). It is also important to note that SDW and nutrient content results were influenced by both treatment and control sections of the pot.

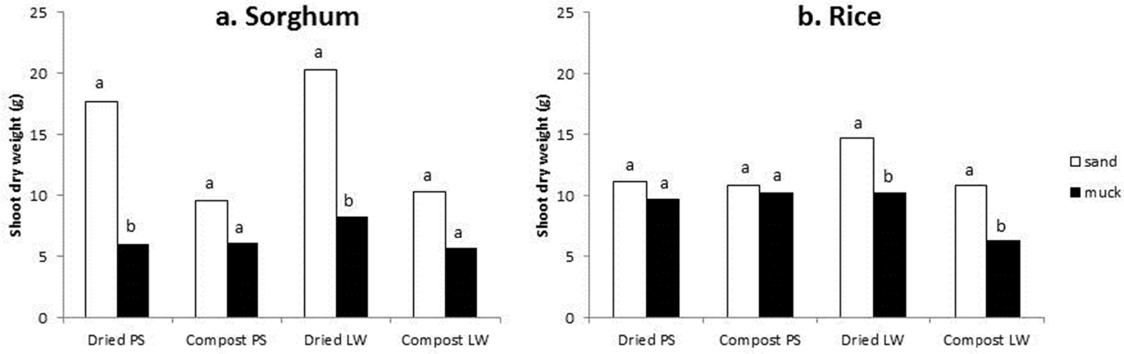

Figure 2. Effect of dried versus composted *Pistia stratiotes* (PS) and *Lyngbya wollei* (LW) on the shoot dry weight (g) of sorghum and rice grown on sandy and muck soils. Different alphabets correspond to significant differences ($p \leq 0.05$) between sand and muck

Table 3. ANOVA and Tukey-Kramer comparisons for mean shoot dry weight (SDW), total Kjeldahl nitrogen (TKN), phosphorus (P), potassium (K), and silicon (Si) content of sorghum plants with the application of four half-pot treatments in sand and muck soil

Material	**FAV**	**SDW**	**TKN**	**P**	**K**	**Si**
Sand		g	-------------------g/kg-------------------			
Dried	PS	17.8 ab	40 a	2.9 b	38 ab	0.39 bc
Dried	LW	20.4 a	40 a	3.1 b	27 b	0.31 c
Composted	PS	9.7 bc	42 a	3.1 b	35 ab	0.36 c
Composted	LW	10.3 c	43 a	4.7 a	33 ab	0.41 abc
Muck						
Dried	PS	6.0 c	43 a	4.4 ab	38 ab	0.53 ab
Dried	LW	8.3 bc	47 a	5.2 a	42 a	0.53 a
Composted	PS	6.0 c	46 a	4.3 ab	35 ab	0.45 abc
Composted	LW	5.6 bc	47 a	5.1 a	34 ab	0.41 abc
ANOVA						
Soil		***	n.s	***	n.s	***
FAV		n.s	n.s	***	n.s	n.s
Material		**	n.s	n.s	n.s	n.s
Soil×FAV		n.s	n.s	n.s	n.s	n.s
FAV×Material		n.s	n.s	n.s	n.s	n.s
Soil×Material		***	n.s	*	n.s	n.s
Soil×FAV×Material		n.s	n.s	n.s	n.s	n.s

Letter grouping indicates significant differences between different Materials.
*, **, *** Indicate significance at p<0.05, 0.01, and 0.001, respectively; n.s. corresponds to not significant.

Table 4. ANOVA and Tukey-Kramer comparisons for mean shoot dry weight (SDW), total Kjeldahl nitrogen (TKN), phosphorus (P), potassium (K), and silicon (Si) content of rice plants with the application of four half-pot treatments in sand and muck soil

Material	**FAV**	**SDW**	**TKN**	**P**	**K**	**Si**
Sand		g	------------------mg/kg-----------------			
Dried	PS	11.2 ab	30 b	2.7 bc	24 a	0.3 a
Dried	LW	14.7 a	31 ab	2.8 b	24 a	0.3 a
Composted	PS	6.9 b	33 ab	3.0 ab	21 b	0.3 a
Composted	LW	10.8 ab	34 ab	3.0 ab	22 ab	0.3 a
Muck						
Dried	PS	9.66 ab	33 ab	2.5 c	24 a	0.3 a
Dried	LW	10.22 ab	34 ab	3.3 a	24 a	0.3 a
Composted	PS	10.26 ab	31 b	3.1 ab	23 ab	0.3 a
Composted	LW	6.27 b	36 a	3.0 ab	23 ab	0.3 a
ANOVA						
Soil		*	n.s.	n.s.	n.s	n.s
FAV		n.s.	**	**	n.s.	n.s.
Material		**	*	**	***	n.s.
Soil×FAV		**	n.s	**	n.s.	*
FAV×Material		n.s	n.s	***	n.s	n.s
Soil×Material		n.s	n.s	n.s	n.s	*
Soil×FAV×Material		n.s	n.s	**	n.s	*

Letter grouping indicates significant differences between different Materials.
*, **, *** Indicate significance at p<0.05, 0.01, and 0.001, respectively; n.s. corresponds to not significant.

3.3 Sorghum Root Dry Weight on Sand and Muck

Overall, sorghum root growth was greater in sandy soils than muck soils (Figures 3a and 3b). Control root dry weight (RDW) presented a significant two way interaction between soil and material type (Table 5). Dried treatments resulted in significantly greater control RDW in comparison to composted treatments when applied in sandy soils. Mean separation showed that the control had significantly greater RDW when dried FAV and composted PS were applied to the adjacent treatment section in sandy soils, compared to composted LW applied in sandy soils, dried FAV applied in muck soil, and composted PS applied in muck soil. Treatment RDW presented significant ($p < 0.05$) two way interactions between soil and FAV type, as well as soil and material type. These interactions indicated that RDW increased as a result of PS addition in sandy soils but decreased

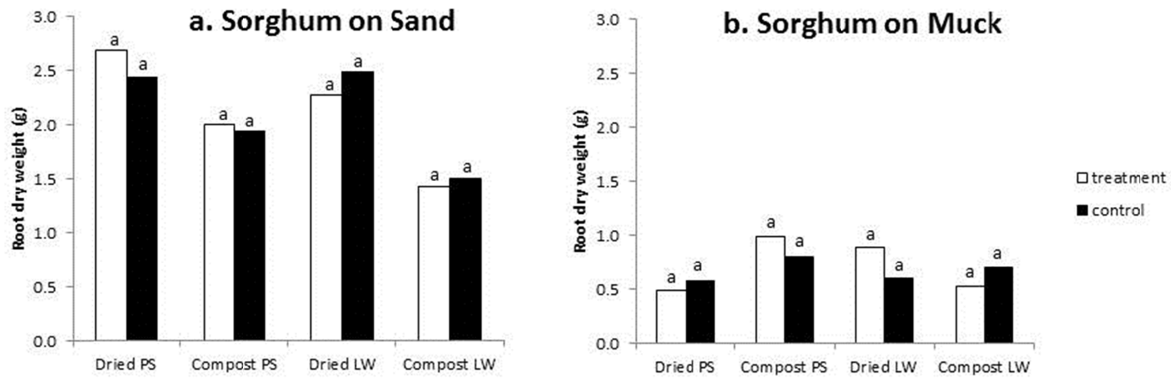

Figure 3. Changes in root dry weight (g) of sorghum under dried and composted *Pistia stratiotes* (PS) and *Lyngbya wollei* (LW) grown on (a) sandy and (b) muck soils. Different alphabets correspond to significant differences ($p \leq 0.05$) between treatment and control

Table 5. ANOVA and Tukey-Kramer comparisons of mean root dry weight (RDW) of half-pot treatments and control sections of sorghum plants grown in sandy and muck soil

Material	FAV	Control	Treatment
Sand		--------------g------------	
Dried	PS	2.45 ab	2.69 a
Dried	LW	2.49 a	2.28 ab
Composted	PS	1.94 ab	1.99 ab
Composted	LW	0.81 cd	0.77 bc
Muck			
Dried	PS	0.32 d	0.27 c
Dried	LW	0.60 cd	0.89 bc
Composted	PS	0.80 cd	0.99 bc
Composted	LW	1.03 bcd	0.92 bc
ANOVA			
Soil		***	***
FAV		n.s.	n.s.
Material		n.s.	n.s.
Soil×FAV		n.s.	*
FAV×Material		n.s.	n.s.
Soil×Material		**	*
Soil×FAV×Material		n.s.	n.s.

Letter grouping indicates significant differences between different Materials.

*, **, *** Indicate significance at $p<0.05$, 0.01, and 0.001, respectively; n.s. corresponds to not significant.

with PS addition on muck soils. Also, dried treatments increased RDW in sandy soils but decreased RDW in muck soils, and dried treatments increased RDW in sandy soils, while composted treatments decreased RDW in sandy soils as well (Figure 3 a and b). Separation of means shows that half-pot treatments with dried PS in sandy soil resulted in greater RDW than the application of dried PS in muck soil. No differences were observed between treatments applied in muck soils; however dried PS applied on muck soils resulted in significantly lower RDW (0.27 g) than dried PS applied on sandy soils (2.69 g).

3.4 Rice Root Dry Weight on Sand and Muck

Main effects of rice root dry weight (RDW) difference between treatment and control areas indicate that greater RDW difference was found in plants grown in sandy soils than in muck soils (Figure 4 a and b). Even though

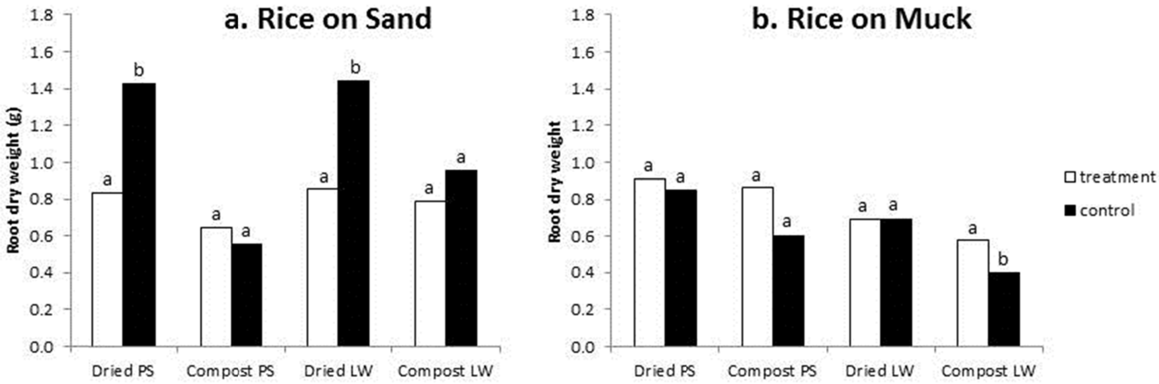

Figure 4. Changes in root dry weight (g) of rice grown on (a) sandy and (b) muck soils under dried and composted *Pistia stratiotes* (PS) and *Lyngbya wollei* (LW). Different alphabets correspond to significant differences (p ≤ 0.05) between treatment and control

Table 6. ANOVA and Tukey-Kramer comparisons of mean root dry weight (RDW) of half-pot treatments and control sections of rice plants grown in sandy and muck soil

Material	FAV	Control	Treatment
Sand		--------------g------------	
Dried	PS	1.43 a	0.84 a
Dried	LW	1.44 a	0.86 a
Composted	PS	0.56 cd	0.65 a
Composted	LW	0.96 b	0.79 a
Muck			
Dried	PS	0.85 bc	0.91 a
Dried	LW	0.70 bc	0.70 a
Composted	PS	0.61cd	0.86 a
Composted	LW	0.40 d	0.58 a
ANOVA			
Soil		***	n.s.
FAV		n.s.	n.s.
Material		***	n.s.
Soil×FAV		**	n.s.
FAV×Material		n.s.	n.s.
Soil×Material		***	n.s.
Soil×FAV×Material		*	n.s.

Letter grouping indicates significant differences between different Materials.
*, **, *** Indicate significance at p<0.05, 0.01, and 0.001, respectively; n.s. corresponds to not significant.

there was no interaction between factors, in this scenario, the separation of means showed that half-pot treatments of composted LW, composted PS and dried PS in muck soils resulted in significantly greater RDW of the treatment area compared to the control area (Table 6). Whereas half-pot treatment of dried LW in sandy soils resulted in greater RDW of the control area compared to the treatment area. Half-pot treatments did not present significant differences among them; therefore, differences in RDW between treatment and control areas were influenced by significant differences of the half-pot control. Mean separation indicated that the control area had significantly greater RDW when dried PS and dried LW was applied to the adjacent treatment sections in sandy soils, compared to any of the other treatments in either soil type.

4. Discussion

Both *P. stratiotes* (PS) and *L. wollei* (LW) have sufficient nutrient and micro-nutrients to be used as potential bio-fertilizers when applied to soils. However, theses aquatic plants can exude allelochemicals that can have both, negative and positive effect on the growth of sorghum and rice plant.

4.1 Sorghum

Silicon content was greater for plants grown in muck soil compared to sandy soils. Separation of means showed that sorghum plants had higher Si contents when half-pot dried LW was applied in muck soils, in comparison to dried FAV and composted PS treatments in sandy soils. According to Balakhnina and Borkowska (2013), plant Si concentrations range from 0.1% to 10%. However, previous research has determined that silicon applied to sorghum crops ensures better growth under environmental drought stresses (Hattori et al., 2005); this is not common for sorghum crop production in Florida during the wet summer months in which the plants were grown. No significant differences on RDW between control and treatments areas of sorghum root growth indicate that root inhibition was not observed with any of the treatments. It is possible that sorghum root exudates compounds, such as sorgoleone, potentially inhibited the allelopathic effect of FAV; or that the allelochemicals were decomposed once the treatments were added to the soil (Dial, 2012; Dayan et al., 2010; Inderjit, 2005).

4.2 Rice

In general, RDW of the control area was greater when rice was grown in sandy soil and when dried FAV was applied in the adjacent treatment section of the pot. Since every pot had a different control area, it is possible to infer that dried LW had a negative allelopathic effect on rice root growth; whereas composted PS, composted LW, and dried PS did not show root inhibition and could potentially be used as soil amendments in muck soils under the flooded environmental conditions of the rice experiment. Nevertheless, rate applications will have to be tested in order to determine to what extent these amendments can have a positive effect in root growth, since no significant differences were observed among treatments. Throughout the rice experiment, an inhibitory effect of dried PS and LW in sandy soils was only evident for RDW and not for SDW or plant nutrient content because the roots were separated by a physical barrier, while the above ground plant was product of the whole-pot which included the control area that also influenced foliar growth. It may also be possible that the negative effect of allelochemicals present in PS and LW only influences the site that had first contact with the allelopathic compounds, which in this case are the roots, and not the shoot of the plant. This happens because the phytotoxicity of the compounds can be different throughout the plant. Hence, it can negatively affect root development but there is a potential for the compounds to detoxify after entering the plant and not affecting the above ground biomass. Moreover, there is also a potential requirement for greater accumulation of phytotoxic levels on the above ground biomass to cause a negative physiological response (Inderjit & Duke, 2003).

4.3 In Summary

The study showed that utilization of the aquatic plants as dried versus composted amendment affects the behavior of sorghum and rice growth. For example, the application of dried PS and LW resulted in nearly twice as much increase in shoot dry weight in sorghum plant grown on sand compared to the composted treatment. Application of dried PS and LW clearly showed a significant negative treatment effect on rice root dry weight when grown on sandy soils compared to the control. Since sorghum root growth was not negatively affected by any treatment and the best RDW and SDW were obtained with the application of dried aquatic vegetation in sandy soils, then it is possible to consider the incorporation of dried FAV as a suitable amendment to enhance sorghum root and shoot growth in sandy soils. In general, the allelopathic effects (negative and positive) of PS and LW were more pronounced on sandy soils compared to muck soils, probably because organic soils have greater carbon molecules that bind the organic allelochemicals exuded by the aquatic vegetation rendering it unavailable for plant uptake. The fact that the application of aquatic vegetation such as *P. stratiotes* and *L. wollei* has a positive effect on crops grown on sandy soils is an interesting observation that warrants further investigation, especially for growers wanting to grow rice or sorghum on sandy soils.

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