SOIL DEVELOPMENT AND VEGETATION ESTABLISHMENT ON AMENDED SALINE DREDGED MATERIALS[1]

A.F. Wick[2], W.L. Daniels and C.H. Carter III

Abstract: Crop establishment on saline-source fine textured dredged materials is challenging due to the adverse physical properties of the material (e.g. fine texture and lack of structure) and short-term salinity. Two approaches to improve crop establishment and soil properties on such dredged materials on an upland deposition site in Virginia were tested: (1) a topsoil cap plus fertilizer (approximately 20 cm; TS) and (2) incorporation of 30% sand by volume into the surface plus fertilizer (30%S). Each treatment was compared to a Control where only fertilizer was added based on soil fertility testing. A greenhouse study was initiated prior to the installation of field experimental plots. In the greenhouse study, German millet (*Setaria Italica* L.) yields and average plant height from highest to lowest were Control > TS > 30%S after three months. Large aggregation (250-8000 μm) was highest on the Control (68-70% total soil) followed by the TS (56%) and 30%S (48%) treatments; however, salinity was also higher on the Control treatment vs. the other two. The field experiment was installed in the spring of 2009 with an additional compost treatment added to the plots in splits. Plots were seeded to German millet in May 2009 and no-till drilled to *Triticum aestivum* (winter wheat) in October 2009. Weed control and a second application of N fertilizer in the spring of 2010 were impossible due to extremely wet soil conditions; therefore, only total biomass (wheat+weeds) data are presented for 2010. Millet yields (4382 kg ha^{-1}) and total biomass (4319 kg ha^{-1}) were higher on the 30%S treatments followed by the Control and TS treatments. Large aggregation was higher in the Control (70-80% total soil) than the 30%S (40-60%) and TS (20-30%) treatments in 2009 and 2010. Salinity declined with time across all treatments with suitable levels for crop production attained in the amended plots (30%S and TS). Compost additions stimulated microbial biomass and soil C concentrations, but did not significantly increase crop yields or aggregate formation relative to the non-compost treatment. Overall, yields and soil salinity were significantly improved when 30% sand by volume was incorporated into the dredge sediment, making this a feasible remediation strategy in the short-term, provided it is cost-effective.

Additional Key Words: macroaggregate, microaggregate, organic matter, soil quality

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[2] Abbey F. Wick, Post-doctoral Research Associate, W. Lee Daniels, Professor, Dept of Crop and Soil Environ. Sciences, Va. Poly. Inst. and State University, Blacksburg, VA 24061, Charles H. Carter III, owner, Weanack Land LLLP, Charles City, VA.

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Introduction

The US Army Corps of Engineers maintain over 20,000 km of waterways across the USA, requiring the dredging of almost 300 million cubic meters of material on an annual basis (USACE, 2003). Depending on the properties and contamination levels of the dredged sediments, as well as logistical and economical constraints, the material is either handled via open water disposal, into a confined upland disposal facility, or designated for beneficial use. There are three general categories for beneficial use: (1) engineered uses, (2) agricultural and product use, and (3) environmental enhancement. Some examples of options within each category include; habitat development, aquaculture, beach nourishment, recreation, agriculture, mine reclamation, shoreline stabilization, and industrial use/construction (Brandon and Price, 2007). As the capacities of the confined upland disposal facilities are reached, more material is now being considered for beneficial use, particularly upland placement for agriculture or as soil covers for mines and landfills.

Weanack Land LLLP, located around Shirley Plantation in Charles City VA, has a history of accepting dredge materials for beneficial use (primarily agricultural and mine land reclamation uses). Management issues associated with each dredge material accepted at this facility are increasingly complex, i.e. the first sediments accepted (Woodrow Wilson Bridge Project) were fresh-water in origin and very low in contaminant levels, the second group of sediments accepted (Earle Naval Weapons Station, NJ) were slightly contaminated with organics and came from a saline environment, and the current work is oriented towards accepting and remediating moderately contaminated or acid forming materials (Maryland Port Administration and Appomattox River to name a few). Although crop establishment on the Woodrow Wilson Bridge sediments was achieved within two years (Daniels et al., 2007), crop establishment on the Earle Naval Weapons Station sediments has been more difficult. Challenges result from the soluble salt influences on crop establishment as well as adverse physical properties of the material (e.g. high silt and lack of structure).

There are two "active" approaches feasible to remediate these problems, where use of locally available soil resources is highly desirable. The first is the addition of a topsoil cap (approximately 20 cm) from nearby topsoil stockpiles and berms, providing a growth medium suitable for root development of a cover crop followed by succeeding annual crops or perennial vegetation. The second solution is to utilize stockpiled sand dredged from the nearby James River channel and mix this material with the surface of the Earle dredge material to achieve 30% sand by volume. Salt leaching from the surface of the dredge material and macroporosity would be improved by this approach. A more "passive" approach is tillage of the existing sediments. Additionally, the application of compost could improve both biologic and physical soil properties above that of fertilizer applications. Organic amendments are a feasible way to stimulate microbial communities and to provide organic material which acts as a nucleus for aggregate formation (Six et al., 1998). An active microbial community secretes polysaccharides into the soil facilitating aggregate formation and transforms organic nutrients into inorganic forms more available for plant uptake. Aggregation improves soil physical properties by increasing the ratio of interconnected macro- to micropores for root development, gas exchange and water flow in addition to regulating biotic activity through the slow release of organic matter for microbial utilization via aggregate turnover (Hillel, 1982; Essington, 2004; Coleman et al., 2004). Through time, an aggregated soil rich in soil nutrients capable of supporting row crops should develop.

The objectives of this experiment were: (1) to evaluate the main treatment effects of a topsoil cap over the Earle Basin dredge material vs. sand incorporation into existing Earle Basin dredge material on cover crop establishment followed by annual crops or perennial vegetation, (2) to evaluate the secondary effects of additions of a compost + N + P fertilizer treatment and a standard N + P fertilizer applications to each main treatment via split plot applications on cover crop establishment and succeeding annual crops or perennial vegetation and (3) to identify soil chemical (soluble salts and pH), physical (aggregation and organic matter) and biological (microbial biomass) responses to the soil amendments and vegetation establishment.

Materials and Methods

Shirley Plantation is located on the James River in Charles City County, VA (39 km southwest of Richmond). Around the edges of the main plantation property, Weanack Land LLLP manages dredge sediments from navigational waterways in upland containment basins created from degraded farmland and abandoned gravel mining pits (Fig. 1). In 2004, a clay lined containment basin approximately 25 ha in size was created to hold marine dredge material from Earle Naval Weapons Station. The sediments were derived from marine environment (original sediment:water EC >25 dS m^{-1}). The slurried dredge material was hydraulically pumped using a closed loop system into the basin over a period of six months. Approximately 300,000 m^3 of saline, uncontaminated, non-acid forming materials were pumped into the basin in total. Over a three year time period, the material had gone through extensive dewatering; however, the basin was largely devoid of vegetation due to periodic inundation in saline water. By 2009, the Earle Naval Weapons Basin showed indications of natural invasion of surrounding plant species (mostly weedy). The final management goal for this basin is return to farmland, which will only be possible once the sediments are well drained enough to support large farm equipment and the salinity is reduced in the rooting zone to tolerance levels acceptable for specific crops [i.e. *Zea mays* (corn), *Triticum sp.* (wheat), *Glycine max* (soybeans)].

Image: Google Earth, 2130m

Figure 1. Aerial view of the Shirley Plantation and Weanack land holdings in Charles City, VA. Field study was conducted on the southeast corner of the Earle Naval Weapons Basin. Image from Google Earth at an elevation of 2130 m.

There were two components to this study; a preliminary study conducted in the greenhouse to test the effects of each treatment on German millet (*Seteria Italica* L.) establishment in a controlled setting followed by a fully replicated field experiment. Experimental designs for each will be discussed in detail below.

Greenhouse Experiment

A greenhouse experiment was initiated in March of 2009 to test the effects of three treatments on German millet establishment before field plots were installed. Treatments included: (1) Earle dredge material + N + P + lime (Control), (2) Earle dredge material + 30% sand by volume + N + P + lime (30%S), and (3) Earle dredge material covered with 5 cm of topsoil material (20 cm not added due to the small size of the pots; TS). Treatments were assembled and placed in plastic lined pots (15 cm in diameter) at equal weights. Nitrogen fertilizer was applied to all pots in splits (rate of 25 mg kg^{-1} at initial seeding and 25 mg kg^{-1} after plant establishment) as NH_4NO_3; phosphorus fertilizer (triple superphosphate) was also applied at a rate of 100 mg kg^{-1} prior to seeding. Calcium hydroxide was applied (0.1% dry weight) to increase the pH prior to seeding on all treatments. Each treatment was replicated four times.

Treatments were also placed into two pots lined with paper filters to determine 90% container capacity for watering on a weight basis. Pots were seeded with German millet (0.75 g per pot) and vented plastic wrap was used to cover the pots during germination. Plants were thinned to 10 plants per pot once established (30 days). The pots were monitored and watered on a daily basis. German millet establishment was evaluated weekly on each treatment via plant height and at peak biomass the pots were harvested and the aboveground biomass dried and weighed.

Study Site Installation and Field Sampling

After preliminary sampling to test for differences in dredge sediment properties (EC, pH and fertility), plot locations were flagged in the southeast corner of the Earle Naval Weapons Basin approximately 300 m away from the discharge point to avoid high variability in texture (Fig. 2). Two samples were collected and composited from each plot from the 0-5 and 5-20 cm depths prior to treatment installation in mid-April of 2009 (referred to as "pre-install" in the results section; collected on 4-16-09). Main treatments consisted of: (1) a loamy topsoil cap of 20 cm, tilled (TS), (2) 30% sand by volume tilled into the surface 20 cm of dredge material (30%S) and

(3) the existing dredge sediment surface, tilled (Control). Each main treatment was replicated four times in a completely randomized design with plot sizes 15x15 m. Splits of: (1) compost (78.4 Mg ha^{-1}) and (2) non-compost were randomly assigned within each plot and plots were tilled in an east-west direction to avoid contamination across splits. Soil samples were again collected from the 0-5 and 5-20 cm depths prior to seeding and fertilizing (referred to as "post-install" in the results section; collected on 5/13/09) to better represent microbial and aggregate dynamics at time zero.

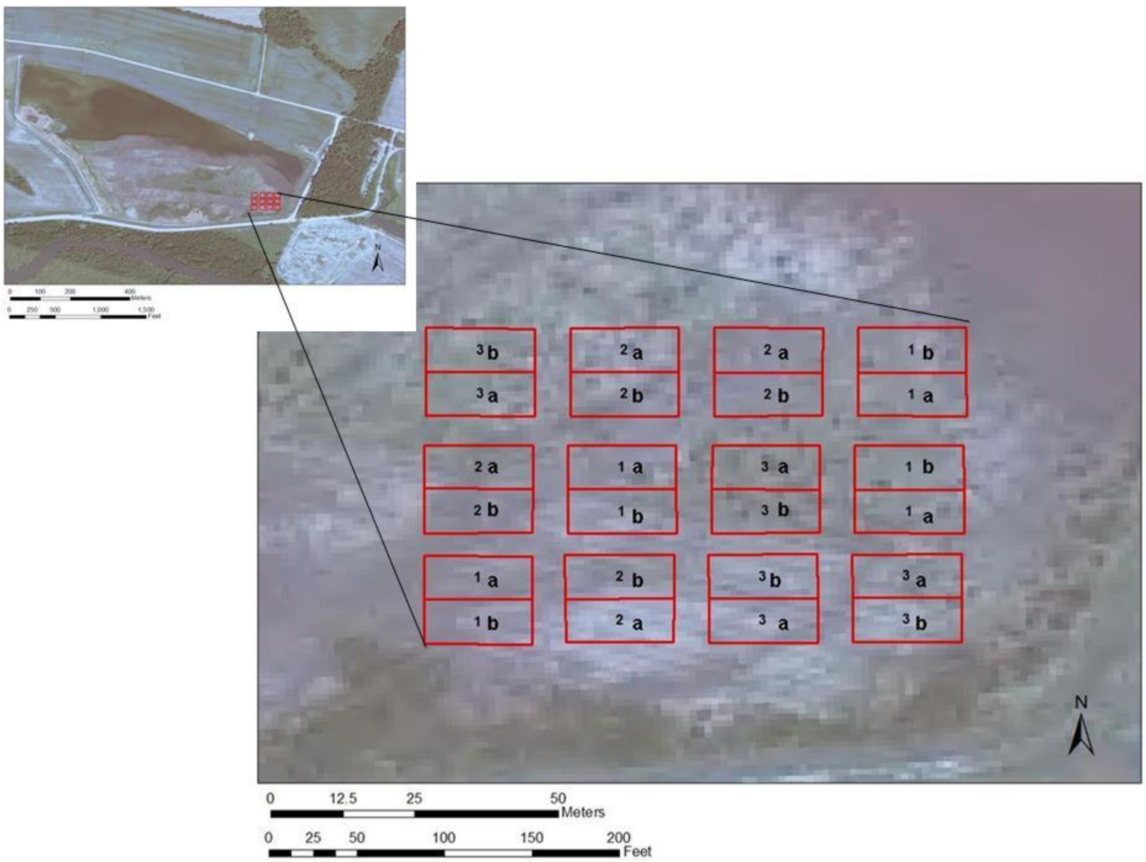

Figure 2. Location and treatments of the experiment on the Earle Naval Weapons Basin on the Shirley Plantation, Charles City, VA. Treatment type indicated by number (1: TS, 2: 30%S, 3: Control). Compost split indicated by letter (a: no compost, b: compost).

Figure 3. Installation of main treatments at the Earle Soil Amendment Crop Plot Experiment, Charles City, VA. Photo taken from southeast corner of plots.

After plot installation and a second soil sampling, the area was hydro-seeded to German millet at a rate of 22.4 kg ha^{-1} with N (40 mg N kg^{-1}) and P (200 mg P kg^{-1}) fertilizer applications (as a combination of di-ammonium phosphate and triple super phosphate) and lime (300 kg ha^{-1}; 0.1% dry rate). Millet yields were determined at peak biomass with three randomly assigned clip plots per split. Within two of the three clip plot locations, soil samples were collected and composited for the 0-5 cm depth and again for the 5-20 cm depth (referred to as “millet” in the results section). Remaining millet on the plots was cut with three passes and raked from the plots. Plots were then no-till drill seeded into winter wheat (*Triticum aestivum)* and fertilized with 45 kg N ha^{-1} and 45 kg P ha^{-1} as a combination of di-ammonium phosphate and triple super phosphate. Due to difficulties in plot access (i.e. an extremely wet winter, making dredge material very soft), the plots did not receive additional N fertilizer applications or weed control as would be necessary for effective management. Total above-ground biomass and soil samples were collected from the plots in June of 2010 using the same method as for the previous year’s sampling (referred to as "wheat" in the results section). Bulk density samples were also collected from the field plots in 2010 using a standard core sampler.

Sample Preparation

Vegetation samples were separated into specific vegetation groups (i.e. millet and "other" in 2009 and "total" in 2010), dried at 55˚C in a force air oven and weighed. Soil samples were split into thirds; one third air dried and sieved to 2 mm for general soil analyses, one third air dried and sieved to 8 mm for aggregate analyses and one third refrigerated and moist sieved to 8 mm for microbial analyses.

Soil Analyses

Soils from both the greenhouse and field experiment were analyzed for saturated paste soluble salt concentrations (electrical conductivity - EC), pH, physical soil properties (via water stable aggregate size distributions - large and small macroaggregates and microaggregates), organic matter (using whole soil and aggregate carbon (C) as a proxy for OM), and microbial activity (using microbial biomass C). Samples from the greenhouse experiment were also analyzed for root biomass and length. An Oakton con 100 series EC probe (Vernon Hills, IL) and a Fisher Scientific Accument Basic pH meter with a glass electrode (Pittsburgh, PA) were used for analyses. Water stable aggregate size distribution of soil was determined using a wet sieving protocol described by Six et al. (1998) on all 8 mm sieved samples. Aggregate sizes were corrected for sand according to Denef et al. (2001) for clarity when comparing across plots of different soil textures. Samples were powder ground (<53 µm) and analyzed for total C (and total N; however total N results will not be presented, only used to determine C:N ratios) via dry combustion (Elementar CNS analyzer, Hannau, Germany). Concentrations for each aggregate sample were calculated on a sand free basis (Elliot et al., 1991) and bulk density values were used to convert concentrations (mg kg^{-1}) into pools (Mg ha^{-1}) for the samples collected in July of 2010. Field moist samples were analyzed for microbial biomass C using a chloroform fumigation-extraction method (Kc = 0.38; Coleman et al., 2004; von Luetzow et al., 2007) followed by analysis using a Sievers 900 total organic C analyzer (Boulder, CO). Root analyses were conducted on volumetric cores collected from the center of each pot in the greenhouse experiment. These cores were slaked overnight and roots were washed and collected on a 2 mm sieve. Root length was then determined using the WinRhizo program. Root samples were then dried in a 55˚C oven and weighed to determine biomass.

Statistical Analyses

One-way analysis of variance was used to determine differences among treatments followed by pair-wise t-tests for separation of means (SigmaPlot, 2008). Statistical analyses were accomplished at $P<0.05$ or $P<0.10$ where specified.

Results

Greenhouse Study

German millet establishment in the greenhouse study was consistent across all treatments. Aboveground biomass production was highest on the Control and TS treatments after three months of growth (Table 1; Fig. 4).

Table 1. Plant height and biomass (at harvest) data for German millet grown on various treatments (Control, 30% sand by volume added (30%S), and topsoil cap (TS)) applied to the Earle Basin dredge materials in a greenhouse experiment. Significant differences are shown across treatments by date with different letters ($P<0.05$).

Treatment	Plant Height				Biomass
	cm				g pot^{-1}
	4/12/2009	5/17/2009	6/18/2009	7/16/2009	7/17/2009
Control	8.61 b	35.1 a	42.7 a	51.1 a	14.9 a
30%S	14.7 a	34.0 a	38.2 a	44.8 a	9.20 b
TS	13.5 a	32.9 a	41.8 a	50.6 a	15.0 a

Electrical conductivity was significantly higher in the TS vs. the Control and 30%S treatments (Table 2). Soil pH was significantly higher in the TS treatment than the Control and 30%S treatments. Large macroaggregate proportions were highest in the Control treatment (0.32 g g^{-1}), while small macroaggregates dominated the 30%S treatment. The TS treatment has a similar distribution of all aggregate size classes (0.21, 0.36, and 0.21 for large- and small macroaggregates and microaggregates, respectively). Root biomass was highest on the TS treatment, followed by the 30%S and Control treatments; however, root length among the treatments was similar.

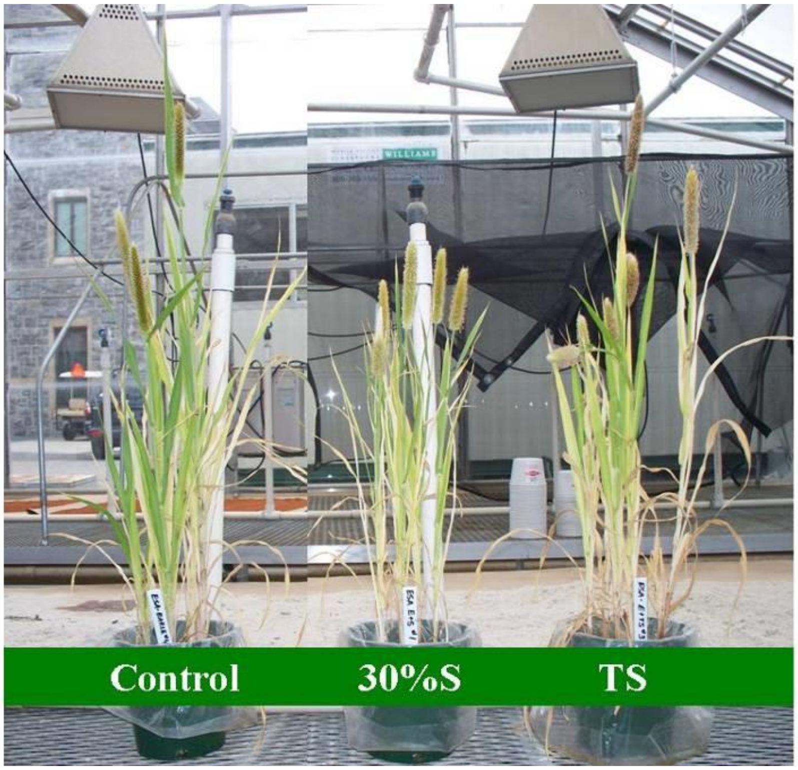

Figure 4. German millet establishment after 3 months on Control, 30% sand (30%S) and topsoil (TS) treatments.

Table 2. Soil electrical conductivity (EC), pH, large macroaggregates (2000-8000 µm), small macroaggregates (250-2000 µm), microaggregates (53-250 µm), microbial biomass carbon (MBC), root biomass and root length for various treatments (Control, 30% sand by volume added (30%S), and topsoil cap (TS)) applied to the Earle Basin dredge materials in a greenhouse experiment. Results presented were from lab analyses conducted following German millet harvest in a greenhouse experiment. Significant differences are shown across treatments with different letters ($P<0.05$).

Treatment	EC	pH	2000-8000 µm	250-2000 µm	53-250 µm	MBC	Root Biomass	Root Length
	dS m^{-1}			g g^{-1}		g kg^{-1}	kg ha^{-1}	cm
Control	9.79 a	6.16 b	0.32 a	0.38 a	0.07 b	18.05 a	198.8 b	355.9 a
30%S	8.87 b	5.94 b	0.21 b	0.26 b	0.05 c	15.44 a	239.7 ab	321.7 a
TS	7.68 c	6.95 a	0.21 b	0.35 a	0.17 a	16.97 a	383.1 a	443.9 a

In general, macroaggregate (250-8000 μm) C concentrations were higher in the Control and 30%S compared to the TS treatment (Fig. 5a), while microaggregate C concentrations were higher in the TS relative to other treatments. Carbon pools (on a Mg ha^{-1} basis) were higher for all aggregate size classes for the TS than other treatments (Fig. 5b).

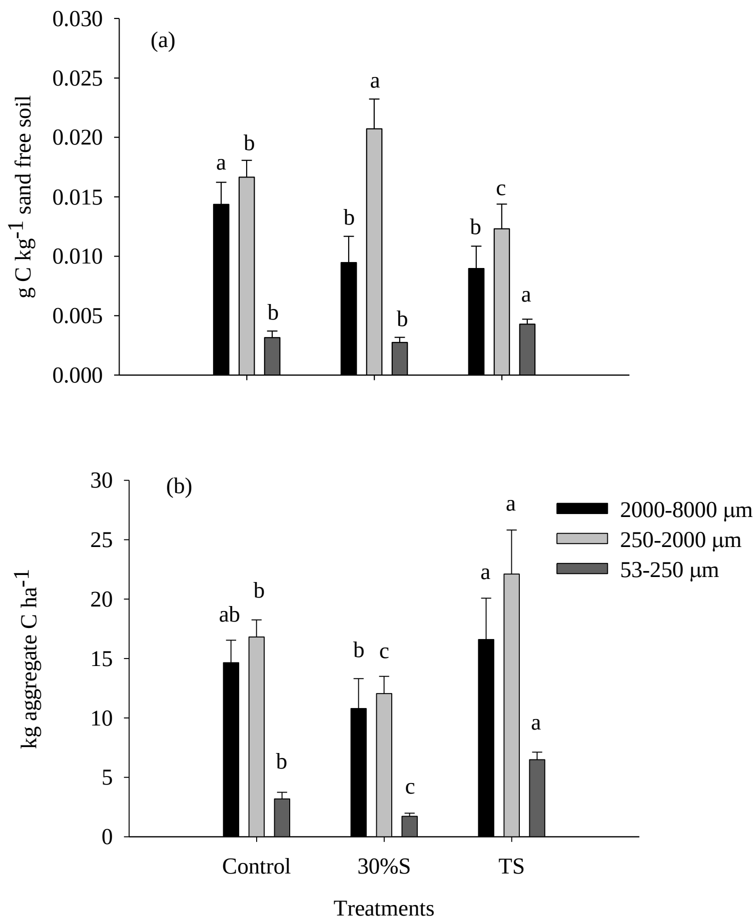

Figure 5. Aggregate carbon (C) concentrations (a) and pool sizes (b) for treatments (Control, 30% sand by volume added (30%S), and topsoil cap (TS)) applied to the Earle Basin dredge materials. Results presented were from lab analyses conducted following German millet harvest in a greenhouse experiment. Significant differences are shown across treatments with different letters ($P<0.05$).

Field Experiment

Standing biomass was similar across all treatments when a compost material was incorporated into the soil (Table 3). Without compost, differences among treatments were apparent. The 30%S treatment had significantly higher biomass production than the TS treatment, with the Control treatment biomass similar to all treatments. Under wheat/mixed vegetation, both the Control and 30%S treatments had higher production than the TS treatment. The addition of compost significantly increased total biomass production in 2010 compared to non-compost plots for the TS treatment. The opposite was observed for the 30%S treatment, where non-compost plots exhibited higher productivity than composted plots within this treatment.

Table 3. Plant biomass for 2009 German millet, other species (invasive) and total as well as 2010 total biomass grown on various treatments (Control, 30% sand by volume added (30%S), and topsoil cap (TS)) applied to the Earle Basin dredge materials in a field experiment. Significant differences are shown across treatments with different letters (P<0.10) and an asterisk indicates significant differences within treatment among compost/non-compost splits.

Treatment	2009			2010
	German millet	Other	Total	Total
	kg ha^{-1}			
	Compost			
Control	3455 a	612.3 a	4067 a	4007 a
30%S	2751 a	893.0 a	3644 a	4302 a
TS	2547 a	828.2 a	3375 a	3897 a*
	Non-compost			
Control	3276 ab	1052 a	4328 ab	4121 a
30%S	4382 a	987.0 a	5369 a*	4319 a
TS	1517 b	1467 a*	2984 b	3364 b

Soil EC was generally lower for the 30%S and TS treatments regardless of compost additions once vegetation was established on the plots (Table 4). There was a consistent decline in EC for all treatments as the plots were seeded to millet and then into wheat; eventually dropping to levels below the threshold for negative yield effects of most agricultural crops (e.g. 4.0 dS m^{-1}; Singer and Munns, 2006; Sparks, 2003). Soil pH was consistently lower on Control and 30%S treatments than the TS in the 5-20 cm depths across all sampling times regardless of compost additions. In the surface soils (0-5 cm), pH did not follow consistent trends with treatment (Table 4). Through time, pH generally increased across all treatments. Compost additions generally did not influence soil pH in either depth of all treatments.

Table 4. Soil electrical conductivity (EC) and pH for treatments (Control, 30% sand by volume added (30%S), and topsoil cap (TS)) applied to the Earle Basin dredge materials in a field experiment. Significant differences are shown across treatments with lower-case letters (P<0.05), upper-case letters indicate a change across dates within treatment and an asterisk indicates significant differences within treatment among compost/non-compost splits.

Treatment/Date	**Compost (0-5 cm)**		**Non-compost (0-5 cm)**	
	EC	pH	EC	pH
	dS m^{-1}		dS m^{-1}	
Pre-Install (4/16/09)				
Control	7.67 a, A	4.59 a, C	4.47 a, A	4.91 a, B
30% S	6.18 a, A	4.31 a, B	6.28 a, A	4.79 a, A
TS	4.73 a, A	4.90 a, C	3.14 a, A	4.89 a, C
Millet (9/7/09)				
Control	3.36 a, B	5.65 b, B	3.24 a, A	5.32 a, B
30% S	1.32 b, B	5.99 ab, A	1.92 b, B	5.50 a, A
TS	1.15 b, A	6.21 a, B	0.846 b, B	6.25 a, B
Wheat (6/22/10)				
Control	2.74 a, B	6.74 ab, A*	2.72 a, A	5.98 b, A
30% S	1.62 b, B	6.60 b, A	2.23 a, B	6.39 b, A
TS	0.995 b, A	7.71 a, A	1.35 b, B	7.24 a, A
	Compost (5-20 cm)		**Non-compost (5-20 cm)**	
Pre-Install (4/16/09)				
Control	6.64 a, A	4.77 a, B	4.23 a, A	5.24 a, A
30% S	5.14 a, A	5.42 a, B	4.15 a, A	5.35 a, A
TS	4.01 a, A	5.79 a, B	3.34 a, A	5.25 a, C
Millet (9/7/09)				
Control	3.28 a, B	5.71 b, A	3.88 a, A	5.17 b, A
30% S	1.75 b, B	5.80 b, B	2.42 a, A	5.36 b, B
TS	0.900 b, B	6.34 a, B	1.73 a, B	6.30 a, B
Wheat (6/22/10)				
Control	3.49 a, B	6.39 b, A	3.22 a, A	5.70 b, A
30% S	2.07 ab, B	6.59 b, A	2.47 a, A	6.55 b, A
TS	1.24 b, B	7.41 a, A	1.08 b, B	7.07 a, A

Soil macroaggregation (250-8000 μm) was consistently higher for the Control treatment than the 30%S and TS treatments, across both depths and regardless of compost additions (Table 5). There was no indication that the addition of compost improved soil aggregation for any treatment. After plot installation, macroaggregation significantly decreased in the 30%S and TS treatments and did not recover to pre-disturbance level. Microaggregates are significantly higher in the TS treatment, due to the difference in soil textures and type of material.

Macroaggregate C was consistently higher for the Control treatment relative to the other two treatments (Table 6). Once wheat was established on the plots, there was a clear separation among all treatments, with- and without compost, for macroaggregate C concentrations. Carbon concentrations for both size classes were similar after compost was added to the plots. Within two years, the effects of the compost additions within the aggregate size classes were diminished by the main treatments (sand and topsoil) to the plots. The only treatment consistently gaining C under the different plantings of millet and wheat was the Control treatment. When comparing the concentrations observed under wheat to the post-installation concentrations, there was a 20 to 45 g C kg^{-1} reduction in concentrations under the 30%S treatment in the macroaggregate fraction in the compost amended splits. The Control and TS treatments both gained C by 2 to 10 g C kg^{-1} soil. In the non-compost plots, both the 30%S and TS treatment concentrations were reduced between plot installation and wheat establishment, while the C in the Control treatment increased in the 0-5 cm depth only. Microaggregate C concentrations increased for all treatments, again when compost was added to the plots, and decreased between plot installation and wheat establishment for the TS treatment only in plots not receiving compost.

Carbon:N ratios can provide insight into the rates at which organic substrates are being utilized by microbial communities in the soil. After compost additions to the plots, C:N ratios were approximately 25:1 to 15:1 in the surface soils of the amended plots (30%S and TS) and were consistently 15:1 in the surface and subsoil of the Control plots pre- and post-compost additions. In non-compost plots, C:N ratios were between 9 and 12:1 across all treatments at all sampling times.

Table 5. Soil aggregation for treatments (Control, 30% sand by volume added (30%S), and topsoil cap (TS)) applied to the Earle Basin dredge materials. Significant differences are shown across treatments with lower-case letters, upper-case letters indicate a change across dates within treatment and an asterisk indicates significant differences within treatment among compost/non-compost splits (P<0.10).

Treatment/Date	**Compost (0-5 cm)**		**Non-compost (0-5 cm)**	
	250-8000 μm	53-250 μm	250-8000 μm	53-250 μm
	g aggregate g^{-1} soil			
Pre-Install (4/16/09)				
Control	0.76 a, AB	0.11 a, A	0.80 a, A	0.09 a, A
30%S	0.73 a, A	0.10 a, A	0.76 a, A	0.10 a, A
TS	0.76 a, AB	0.08 a, C	0.77 a, A	0.11 a, C
Post-Install (5/13/09)				
Control	0.79 a, A	0.06 b, B	0.83 a, A	0.04 b, B
30%S	0.49 b, B	0.05 b, C	0.58 b, B	0.03 b, B
TS	0.29 c, B	0.33 a, A	0.22 c, B	0.43 a, A
Millet (9/7/09)				
Control	0.69 a, B	0.07 b, B*	0.72 a, B	0.05 b, B
30%S	0.48 b, B	0.06 b, BC	0.48 b, B	0.06 b, A
TS	0.27 c, B	0.32 a, A	0.23 c, B	0.37 a, B
Wheat (6/22/10)				
Control	0.77 a, A	0.07 b, B	0.81 a, A*	0.06 b, AB
30%S	0.47 b, B	0.07 b, B	0.51 b, B	0.06 b, A
TS	0.32 c, B*	0.23 a, B	0.22 c, B	0.43 a, A
	Compost (5-20 cm)		**Non-compost (5-20 cm)**	
Pre-Install (4/16/09)				
Control	0.81 a, A	0.07 a, A	0.77 a, A	0.04 a, BC
30%S	0.74 a, A	0.04 a, A	0.76 a, A	0.05 a, A
TS	0.75 a, A	0.06 a, C	0.78 a, A	0.04 a, BC
Post-Install (5/13/09)				
Control	0.78 a, A	0.04 b, A	0.80 a, A	0.02 b, C
30%S	0.53 b, B	0.01 b, A	0.57 b, B	0.02 b, A
TS	0.29 c, B	0.34 a, A	0.23 c, B	0.38 a, A
Millet (9/7/09)				
Control	0.63 a, A	0.06 b, A	0.64 a, B	0.06 b, B
30%S	0.39 b, B	0.11 b, A	0.47 b, C	0.06 b, A
TS	0.22 c, C	0.36 a, A	0.26 c, B	0.32 a, A
Wheat (6/22/10)				
Control	0.76 a, A	0.07 b, A	0.74 a, A	0.08 b, A
30%S	0.49 b, B	0.07 b, A	0.48 b, BC	0.07 b, A
TS	0.34 c, B*	0.19 a, B	0.18 c, B	0.27 a, A*

Table 6. Soil aggregate carbon for treatments (Control, 30% sand by volume added (30%S), and topsoil cap (TS)) applied to the Earle Basin dredge materials. Significant differences are shown across treatments with lower-case letters, upper-case letters indicate a change across dates within treatment and an asterisk indicates significant differences within treatment among compost/non-compost splits (P<0.10).

Treatment/Date	**Compost (0-5 cm)**		**Non-compost (0-5 cm)**	
	250-8000 μm	53-250 μm	250-8000 μm	53-250 μm
	g C kg^{-1} soil			
Pre-Install (4/16/09)				
Control	35.3 a, B	5.02 a, A	39.9 a, BC	4.33 a, A
30%S	33.4 a, A	4.40 a, AB	35.2 a, A	4.61 a, A
TS	35.7 a, A	3.78 a, C	37.3 a, A	5.21 a, A
Post-Install (5/13/09)				
Control	68.1 a, A*	4.70 a, A*	40.8 a, B	2.01 b, C
30%S	89.9 a, A*	3.08 a, BC*	23.6 b, B	0.760 c , C
TS	32.9 a, A*	4.58 a, BC	9.62 c, B	3.92 a, B
Millet (9/7/09)				
Control	65.0 a, A*	5.47 a, A*	47.0 a, A	2.42 b, BC
30%S	44.0 b, A*	2.78 b, C	22.9 b, B	2.34 b, B
TS	32.2 b, A	5.34 a, AB	14.5 b, B	4.20 a, B
Wheat (6/22/10)				
Control	70.2 a, A*	6.88 a, A*	36.4 a, C	3.53 a, AB
30%S	45.2 b, A*	4.65 a, A*	21.7 b, B	2.73 a, B
TS	29.4 c, A*	5.83 a, A*	7.64 c, B	2.66 a, C
	Compost (5-20 cm)		**Non-compost (5-20 cm)**	
Pre-Install (4/16/09)				
Control	36.2 a, B	2.90 a, B	33.5 a, BC	1.65 a, C
30%S	32.9 a, B	1.54 a, C	34.8 a, A	1.95 a, A
TS	33.7 a, A	2.42 a, B	36.0 a, A	1.93 a, B
Post-Install (5/13/09)				
Control	64.2 a, A*	2.91 ab, B*	39.6 a, A	1.11 b, C
30%S	61.7 a, A*	2.40 b, B*	22.9 b, B	0.704 b, A
TS	26.4 b, B*	4.55 a, B	7.45 c, BC	3.55 a, A
Millet (9/7/09)				
Control	45.9 a, B*	4.22 ab, B*	30.9 a, C	2.62 b, B
30%S	31.5 ab, B	3.27 b, AB	23.8 b, B	2.36 b, A
TS	19.7 b, C*	4.60 a, B*	10.8 c, B	3.60 a, A
Wheat (6/22/10)				
Control	66.4 a, A*	6.11 a, A*	37.0 a, AB	4.02 a, A
30%S	39.7 b, AB*	3.51 b, A*	17.6 b, C	2.15 b, A
TS	34.4 b, A*	5.95 a, A*	3.97 c, C	2.33 b, B

When converting soil C concentrations to pool sizes using bulk density values, there was a clear difference in the treatment effects (Fig. 6). The Control treatment contained the most C followed by the 30%S treatment and then the TS treatment. The effects of compost additions to the plots were evident after two years of vegetation growth, especially in the 5-20 cm depth. The effects of compost additions were also observed in the microbial community (microbial biomass C) when the plots were seeded to wheat, by increasing C concentrations in this pool by 20 g C kg^{-1} soil (data not shown); however, there were no differences among treatments for microbial biomass.

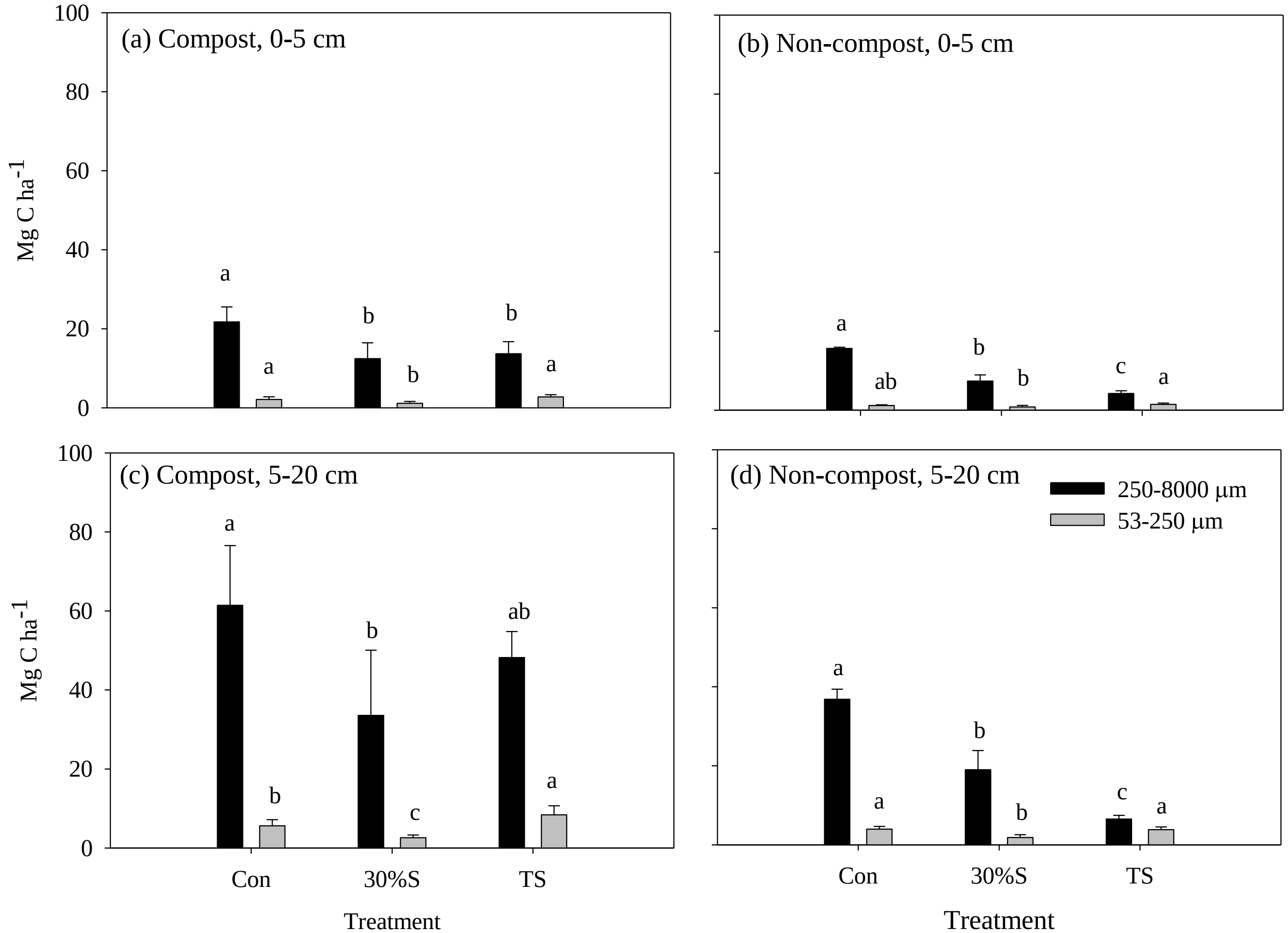

Figure 6. Carbon pool sizes under wheat/mix crop (6/22/10) for treatments (Control, 30% sand by volume added (30%S), and topsoil cap (TS)) applied to the Earle Basin dredge materials. Significant differences are shown across each treatment with lower-case letters ($P<0.10$). Error bars indicate standard deviations.

Discussion

Conversion of saline dredge materials in an upland containment basin into crop production is a challenging process because of: (1) adverse chemical properties (salinity), (2) lack of physical soil structure to provide paths for roots and habitat for microbes, as well as (3) a deficit of fresh, labile organic material in the dredge sediments to drive nutrient cycling and associated beneficial processes. Assessment, manipulation, management and monitoring of these soil properties to improve conditions for crop production are necessary for a complete understanding of this dynamic system. Although there are many instances where dredge material has been beneficially reused (Lee, 2001; Darmody and Marlin, 2002; Darmody et al., 2004; Daniels et al., 2007).amending marine dredge material for agricultural production with continued monitoring and research is quite unique. For the greenhouse component of this study, millet aboveground biomass was higher on the Control and TS treatments than the 30%S treatment, while belowground root biomass was highest on the TS treatment, followed by the 30%S and then the Control treatments. In evaluation of just the vegetation in the greenhouse experiment, the TS treatment would appear to be the most beneficial amendment for the establishment of a cover crop. In the field, millet biomass was highest on the 30%S plots relative to the other two treatments, with the TS treatment having the lowest millet and wheat production. As for soil properties, macroaggregation and C concentrations were higher on the Control than the amended soils for both the greenhouse and field experiments, but EC was also high on the Control treatment relative to the other two treatments. A high level of soluble salts affects the ability of plants to obtain water from the soil (Sparks, 2003) and would negatively impact the establishment of crops less tolerant to saline/sodic soils than millet (i.e. the EC threshold where corn yields are reduced is ~ 1.7 dS m^{-1}; Sparks, 2003). Though high aggregation and C indicate desirable soil properties for soil development and crop establishment (Jastrow and Miller, 1998; Six et al., 1998), the limitation due to salinity outweigh the benefits of aggregation and OM.

One of the goals with the incorporation of sand into the surface of the dredge material was to enhance salt leaching from the surface to zones below the rooting zone via creation of macropores. This goal was successfully attained, although at the cost of loss of aggregation and OM accumulation. A major sand component in soils can reduce the stability of aggregates, making them more dependent upon the tensile strength of fungal hyphae (Degens et al., 1996) than other electrostatic forces and microbial polysaccharides. The addition of a topsoil cap was also successful for creating a "low salt" rooting zone, but again, the physical soil properties and C concentrations were reduced relative to the Control treatment. The TS cap also brought in weedy species (i.e. *Sorghum halepense*, i.e. Johnson grass), exhibited surface crusting early in the experiment and was highly compacted by the equipment during plot construction. Biologically, the amended and Control treatments were similar; however, the composition of these communities could differ greatly based on the salinity of the soils as well as the microbial habitats created by soil aggregates (Coleman et al., 2004).

It also appears as if aggregation in these soils (amended or un-amended) relies upon cation bridging as a primary mechanism of aggregate formation and OM stabilization. An abundance of exchangeable calcium in this material (data not reported) greatly enhanced the aggregation in the Control plots, while dilution or reduction/leaching of these cations in amended soils led to lower aggregation (Six et al., 2004). The addition of compost material did not enhance aggregation in the short-term by serving as a nucleus for microbial activity and thus aggregate formation. However, effects of organic amendments on calcium dominated soils have been observed in the long-term (Baldock et al., 1994). Other than the slight increase in microbial activity and some differences observed in vegetation production, the cost associated with hauling compost to the site did not prove to be beneficial in the short-term. Over the longer term, this relationship might change.

At this point, it is difficult to identify the ideal treatment, especially since a "weed-free", adequately fertilized (i.e. with N, based on soil fertility testing) crop has not been successfully established on these plots. These results point out that management issues associated with crop establishment on dredge sediments (Daniels et al., 2007), especially those of marine origin, are just as important as the optimization of soil properties. For example, the inability to access the plots for fertilizer applications or weed control because of rising water within the fully contained basin over the winter months influenced the wheat production and low load bearing strength of dredge materials. The rising water within the basin also brought salts into the rooting zone, again reducing crop establishment and production. Thus, there are several dynamics that need to be considered when converting dredge material into agricultural production. Optimization of management strategies and soil properties are two approaches for successful agricultural production on these marginal soils.

Conclusions

The short-term results presented in this study point towards the incorporation of sand into this material as being a feasible method for crop establishment and salinity reduction if sand is available on site (reducing the cost for addition of this amendment). It is possible that the addition of less sand would create a balance between aggregate formation, C accumulation and controlling salinity issues, while still producing high vegetation yields. The effects of the compost additions also might be realized in the long-term. It is clear that an additional year of management and a successful crop yield would assist in our selection of a best management practice for this specific type of dredge material.

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