UNDERGRADUATE RESEARCH PROJECT

Submitted to:

Department of Geology

Submitted by:

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Changes in Spectral Slope due to the Effect of Grain Size and Moisture in Beach Sand of Western Puerto Rico

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Abstract:

A GER-1500 spectroradiometer was used to collected reflectance measurements in several laboratory experiments using sand from five beaches of western Puerto Rico. Sand samples were analyzed and the spectral slope was calculated to determine its changes due to different grain size and composition. Results indicate that all the studied parameters of sand (grain size, composition and humidity) affect the magnitude of the reflectance and the spectral slope. The reflectance curve showed the major change between 450 and 550 nanometers in all the five beaches. Higher magnitude in the slope correlates with fine grain size and carbonates composition material and lower magnitudes in the slope with bigger grain size and higher composition of dark minerals. It was also found that the spectral are reduced with an increase in the water content. The statistical analyses of the spectral slope show that they have significance difference between the different grain sizes.

Keywords: GER-1500 spectroradiometer, spectral slope, reflectance, sand, grain size, water content

Introduction and Statement of the Problem:

A GER 1500 spectroradiometer was used to collect reflectance measurements in several laboratory experiments with sand from different beaches of the West and Southwest of Puerto Rico. A previous study investigated the “Spectral Analyses and Sedimentation of the West Coast of Puerto Rico” (Cameron, 2003) and correlated the reflectance from the GER 1500 with the sediments characteristics such as grain size, sand composition and mineralogy along the west coast of Puerto Rico. Another study presented the “Spectral Characterization of Sandy Beaches in Western Portion of Puerto Rico” (Chiques, 2005). Chiques (2005) research was focused on the development of a database of the reflectance curves for several types of the sandy beaches for the west coast of Puerto Rico and to determine how texture and composition affects the shape and magnitude of the reflectance curve of beach sand. These two investigations have helped to understand the spectral response of sandy beaches in Puerto Rico. Most recently an undergraduate research project in five beaches of the West and Southwest of Puerto Rico (El Faro, El Mani, Guanajibo, Crashboat and Tamarindo West) analyzed sand samples with sieving and XRD to characterize the grain size and composition (Garcia, 2006). In that study a Thetaprobe ML2x sensor was also used to take moisture measurements in the sand and evaluates changes in magnitude of the reflectance when the sand is dry or wet. The results indicated that all studied aspects of grain size, composition and humidity affect the magnitude of the sand reflectance. High magnitude of the reflectance correlated with fine grain size, higher composition of lighter minerals and carbonates material. Lower magnitude of the reflectance correlated with bigger grain size and high composition of dark minerals like magnetite and ferromagnesian minerals. The experiments of water content showed that the magnitude of the reflectance curves is affected by humidity in all the study beaches. The experiments showed that the dry sand reflects more light than the wet sand producing a significance change in the curves magnitude, which has a relation with the composition, grain size and humidity in the sand (Figure 1). The reflectance curves show a major change in the slope between 450 to 550 nm in all the beaches. These results motivated the current study, which focuses on further analyses of the spectral slope in order to better understand its relationship with the characteristics of the sand. Most minerals in the sand have particular reflectance peaks in the infrared region of the spectrum. However, current remote sensor cannot detect those peaks. Therefore, an innovative procedure to study sand using the visible range is needed. Since the spectral slope is the major signal in the visible range of the spectrum, a protocol to correlate it with sand parameters could provide a cost effective way to apply remote sensor to study sandy beaches.

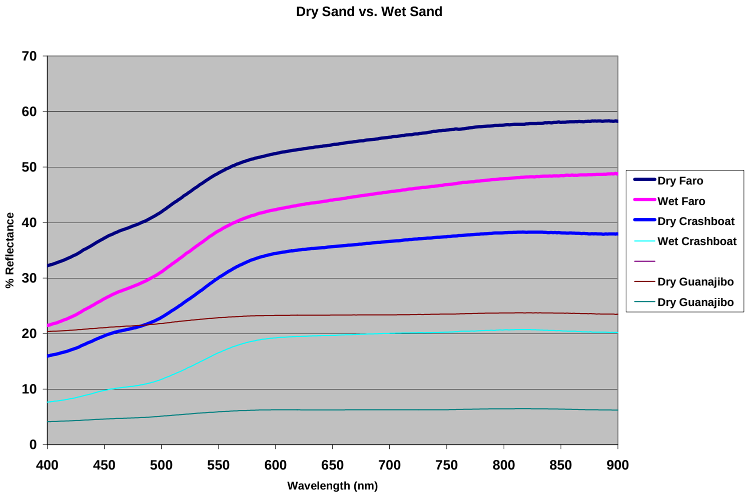


Figure 1: Dry sand vs. Wet sand

In this research the spectral slope is analyzed in the three beaches more representatives of the reflectance variability based on my previous work. The beaches are: El Faro, Crashboat and Guanajibo (Figure 2). The Faro beach have the higher magnitude in the reflectance curve because have a lot of light minerals and quartz. The Guanajibo beach show the lowest reflectance because have a lot of dark minerals, Crashboat is the beach that show the composition of the sand between the Faro and Guanajibo beaches.

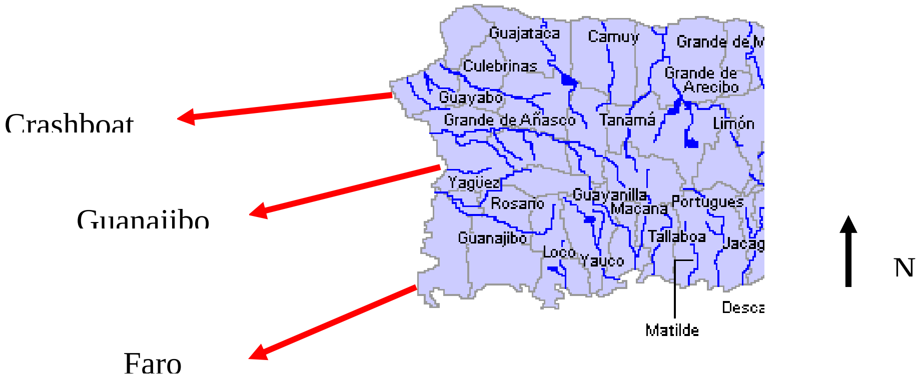


Figure 2: Study Area Map

Geology of the Study Area:

This research considered beaches from the West Coast of Puerto Rico. The coastal areas in Puerto Rico show different sand composition and grain size. In 1978 Morelock described the beaches around Puerto Rico. In the west coast the mountains dominated the coast from Aguadilla to Cabo Rojo, the coast is dominated by the effect of structural mountain ridges separated by broad alluvial valleys. The ridges from a rocky coast and sandy beaches occupy the shoreline bordering the alluvial valley (Morelock, 1978). The geology of the west coast is composed of rocks and sediments from the Post-Eocene, sediments and igneous rocks from the Eocene, rocks from the Cretacic, and Serpentinite, Chert, Amphibolites and Alkaline Rocks (Figure 3).

Aguadilla – Crashboat beach is isolated bounded by rocky shoreline. The beach sediments are composed of approximately equal parts of carbonate shell material, quartz and light minerals, and igneous rock fragments.

Guanajibo – Mayaguez bay is composed of igneous fragments, magnetite, other dark mineral grains, and minor amounts of light minerals grains.

Cabo Rojo – El Faro beach is composed of carbonates and quartz. It has a unique circulation patterns in the bay.

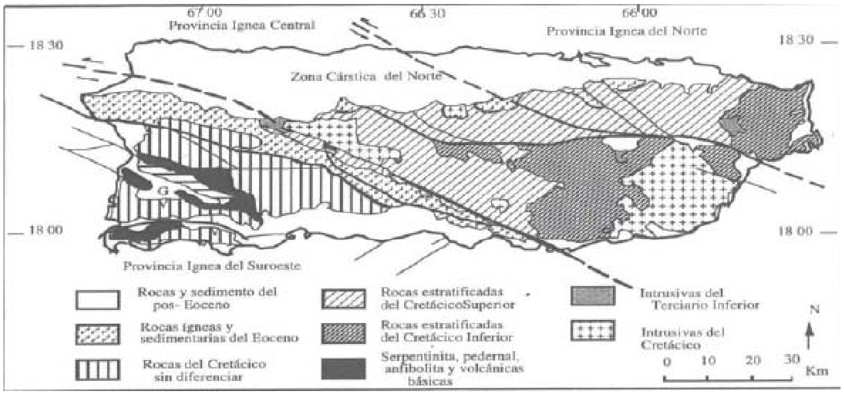


Figure 3: Geologic Map of Puerto Rico

Previous work:

Cameron et al. (2003) presented the spectral analysis and sedimentation of the west coast of Puerto Rico. In that research he used remote sensing technique to correlate spectral measurements as the reflectance with the sediments characteristics such as grain size, sand composition and mineralogy along the west coast of Puerto Rico. The samples were taken in Punta Algarrobo, Punta Güanajibo, Punta Ensenada and Playa Azul. The sediments characteristics were tested using the sieving method, XRD and percentage of carbonates. His field data indicated that reflectance intensity changes during variations of carbonate material.

Chiques et al. (2005) presented the spectral characterization of sandy beaches in the western portion of Puerto Rico. In that research she collected reflectance measurements in 15 sandy beaches in western Puerto Rico with a spectroradiometer. The samples of the beaches were analyzed in the laboratory to determine the composition of the sand sediments. The results indicated a change in magnitude in the reflectance curve compared with the composition. Higher magnitude correlated with more carbonate material concentration in the sand and lower magnitude correlated with higher concentration of dark mineral. The reflectance curve showed a change in the slope of the reflectance curve between 450 to 550 nanometers that were present in all 15 beaches.

Garcia et al. (2006) collected reflectance measurements during several laboratory experiments with sand from five beaches of the western part of Puerto Rico. Sand samples were analyzed with sieving and XRD to characterize the grain size and composition. A Thetaprobe ML2x sensor was used to take moisture measurements in the sand and evaluate changes in magnitude of the reflectance when the sand is dry or wet. Results indicated that all the studied parameters of sand (grain size, composition and humidity) affect the magnitude of the reflectance. Higher magnitude correlated with fine grain size and carbonate composition material and lower magnitudes with bigger grain size and higher composition of dark minerals. During the same experiments it was shown that the reflectance is reduced with high water content. The reflectance showed a major change in the magnitude between 700 to 800 nanometers that is present in all five studied beaches.

Methodology:

Field Work: Samples were collected and analyze samples from three beaches of the Western part of Puerto Rico: El Faro, Crashboat and Guanajibo. Two sets of three samples at different places from each beach were collected at random. One set of sample came from the dry zone and the other from the foreshore or surf zone. Reflectance from each zone was measured using the GER 1500 spectroradiometer (Figure 4). The specific locations were registered in each beach using a GPS (Table 1). The GER-1500 Spectroradiometer was used to collected reflectance measurements of every sample. The instrument has 512 channels with a spectral range from 350 to 1050 nm (visible to near infrared). It measures the radiance, a measurement of the light reflected by the surface of the object. The equation used to convert from radiance to reflectance was:

$$\%R = \frac{L(sand)}{L(s\tan dard)2} x100$$

Where the standard used was a gray card that reflects 50% of the incoming light.

Figure 4: GER 1500 spectroradiometer

Table 1: Latitude and Longitude of Sand Sampling Stations

Beach	Latitude (N)	Longitude (W)
Faro	17° 56’ 06.8”	67° 11’ 26.2”
Crashboat	18° 27’ 35.6”	67° 09’ 54.4”
Guanajibo	18° 10’ 07.5”	67° 10’ 48.4”

Statistical Analyses: Data collected during last semester experiments were analyzed using analyses of variance and correlations. Also, the spectral slope was calculated. These analyses will help future work with satellite images.

The equation to calculate the spectral slope is:

$$y = mx + b$$

Where: y = y axis (Reflectance %), m = slope value, x = x axis (Wavelength (nm)) and b = intercept in y

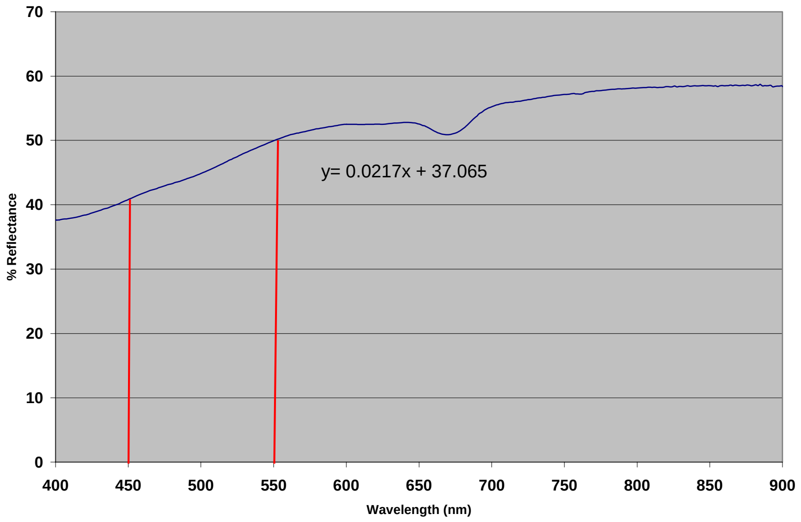


Figure 5: Spectral range used to calculate the spectral slope

The spectral slope was calculate between 450 to 550 nm wavelength range using the excel program. This range was used because it showed the most significant change in the reflectance curve (Figure 5).

The analysis of variance (ANOVA) was performed by the Statistical Consulter Laboratory in the Mathematics Department of the University of Puerto Rico at Mayaguez. This resource was used because I have not taken any statistical course and I do not have the knowledge to do it. Professor Pedro Torres Saavedra provided the help for the statistical analyses presented here. He took the spectral slopes and performed the requested ANOVA. He used the Statistical Analysis Software (SAS) to evaluate the variability shown by the spectral slope at different grain size and wet conditions. The SAS is design for all statistical analysis and it is used by research in all fields. The change in the spectral slope was also studied using graphs with the changes in the slope.

Results:

Field measurements from the studied beaches indicated that the dry sand have higher magnitude in the reflectance than the wet sand. This trend was the same in all the beaches. El Faro beach had the highest reflectance measurements than the other two beaches. This beach is composed of light minerals and a lot of quartz. The previous work (undergraduate research in last semester) indicated that one important characteristic in the reflectance is the sand composition, because the lights minerals in the sand reflects more light. Guanajibo beach had the lowest reflectance because this beach is composed of dark minerals like magnetite, igneous material and ferromagnesian minerals. The crashboat beach had a reflectance between the other two beaches. Crashboat beach have a sorted composition because is composed of light minerals like quartz and carbonates and dark minerals like magnetite and igneous material. Figure 6 shows the reflectance in the studied beaches and the differences between dry and wet sand.

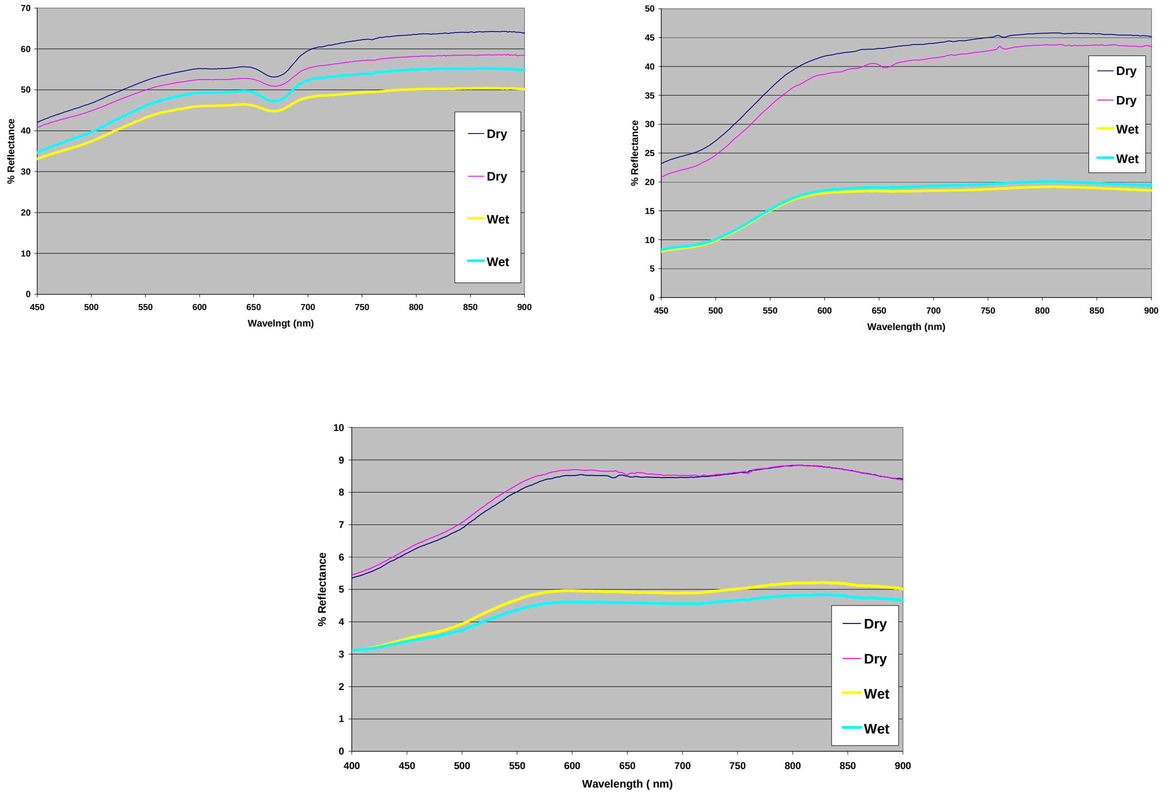


Figure 6: Reflectance Curves in Faro, Guanajibo and Crashboat Beaches

The different graphs show how the shape of the reflectance curve is almost the same. However, it is also clearly shown that the magnitude of the spectral slope between 450 and 550 nanometers is different. A further analysis shows that the steep slope correlates with high concentration of carbonates and quartz and gentle slope correlates with high dark mineral content (Figure 7). Crashboat beach showed the highest spectral slope because it has a lot of carbonates and quartz. The slope of dry sand was 0.03 and in the wet sand was 0.01. El Faro beach is composed of quartz and had a slope of 0.03 in dry sand and 0.02 in wet sand. The Guanajibo beach had the lowest spectral slope because it is composed of a lot of dark minerals, magnetite and igneous material. Its dry sand showed a slope is 0.03 and the wet sand 0.02. In order to better understand these results the differences of the slope between the dry and wet sand was calculated for 450nm, 550nm and 700nm. The results are in table two.

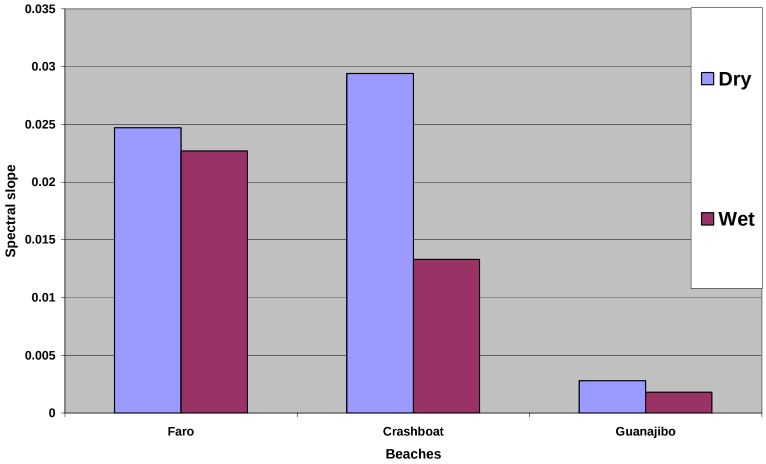


Figure 7: Spectral slope of dry sand vs. wet sand

Table 2: Difference percent in the spectral slope of dry and wet sand. These differences were calculated using the data shown in Figure 7.

Beaches	450 nm	550 nm	700 nm
Crashboat	14%	19%	22%
Faro	11%	11%	13%
Guanajibo	4%	5%	5%

The spectral slope to different grain size and humidity was calculated for all the beaches. The results show that in most cases the dry sand has the highest spectral slope than the wet sand (Figure 8). El Faro beach had the highest slope compared with the other four beaches. The 2.0 phi grain size in El Faro had the highest spectral slope and the 0.5 phi the lowest. In Guanica beach the dry sand had the highest slope and the wet sand the lowest, except for 1.0 phi, because in this grain size the wet sand with 4ml of water had the highest spectral slope. The Crashboat and the Mani beaches had the same behavior than El Faro beach because the dry sand had a high spectral slope and the wet sand the lowest slope. Guanajibo showed the lowest spectral slope.

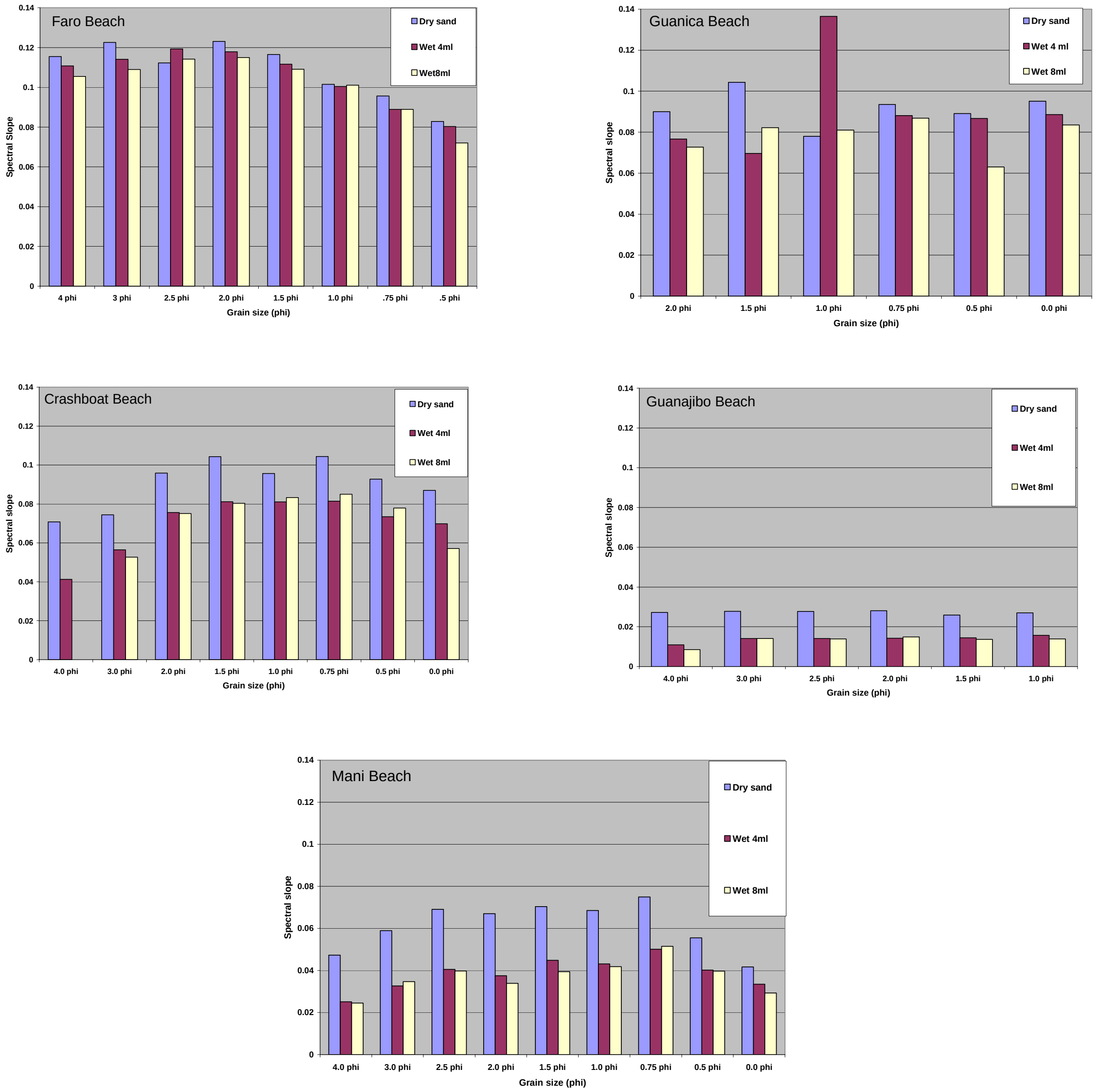
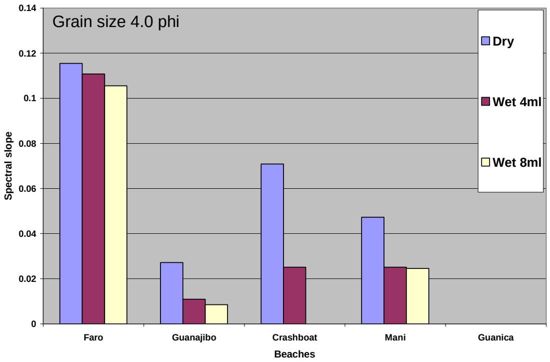
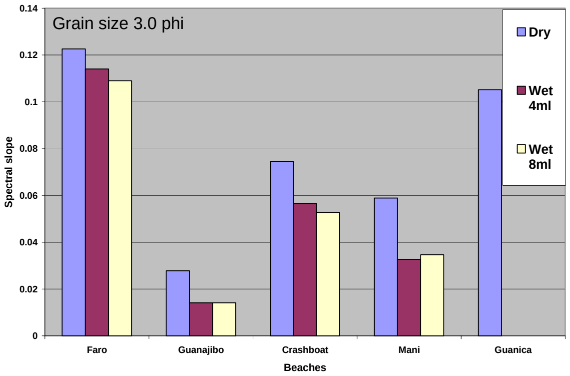


Figure 8: Spectral slope to different grain size and humidity

Figure 9 shows the differences in all beaches for different grain size between dry and wet sand. The 4.0, 3.0, 2.5, 2.0 and 1.5 phi showed the same trend, where El Faro beach had the highest spectral slope and the Guanajibo the lowest slope. The other grain size had different trends in the slope, in the 1.0 phi the wet sand of Guanica beach had the highest spectral slope, 0.75 and 0.5 phi of the dry sand in Crashboat beach have the high spectral slope and in the 0.0 phi the dry sand of Guanica beach had the highest spectral slope.


Grain size 4.0 phi
Dry
Wet 4ml
Wet 8ml
Spectral slope
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Faro
Guanajibo
Crashboat
Mani
Guanica
Beaches


Grain size 3.0 phi
Dry
Wet 4ml
Wet 8ml
Spectral slope
0.14
0.12
0.1
0.08
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0.02
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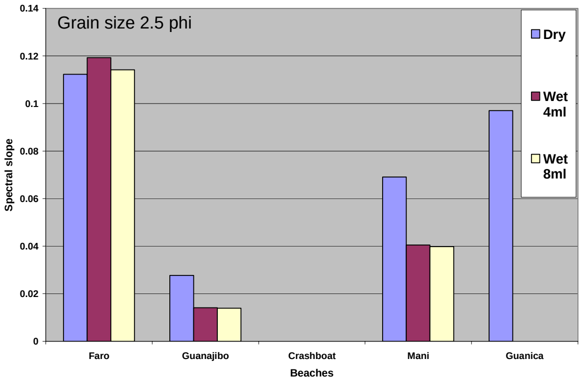
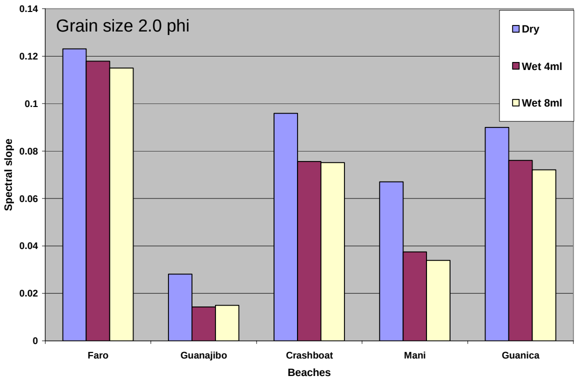
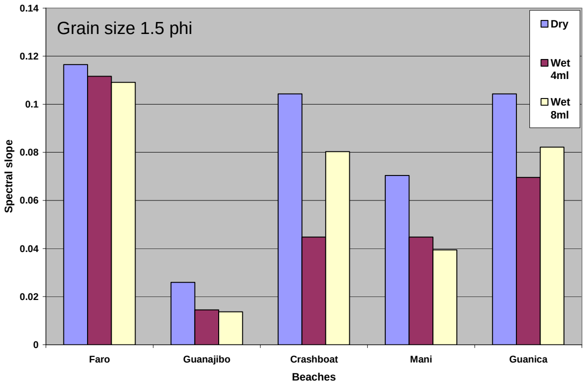
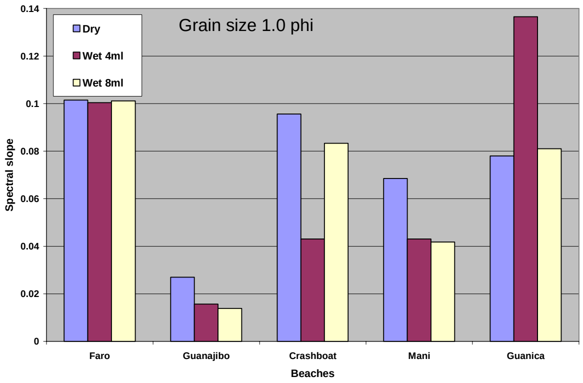
Faro
Guanajibo
Crashboat
Mani
Guanica
Beaches


Grain size 2.5 phi
Dry
Wet 4ml
Wet 8ml
Spectral slope
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Faro
Guanajibo
Crashboat
Mani
Guanica
Beaches


Grain size 2.0 phi
Dry
Wet 4ml
Wet 8ml
Spectral slope
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Faro
Guanajibo
Crashboat
Mani
Guanica
Beaches


Grain size 1.5 phi
Dry
Wet 4ml
Wet 8ml
Spectral slope
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Faro
Guanajibo
Crashboat
Mani
Guanica
Beaches


Grain size 1.0 phi
Dry
Wet 4ml
Wet 8ml
Spectral slope
0.14
0.12
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Guanica
Beaches

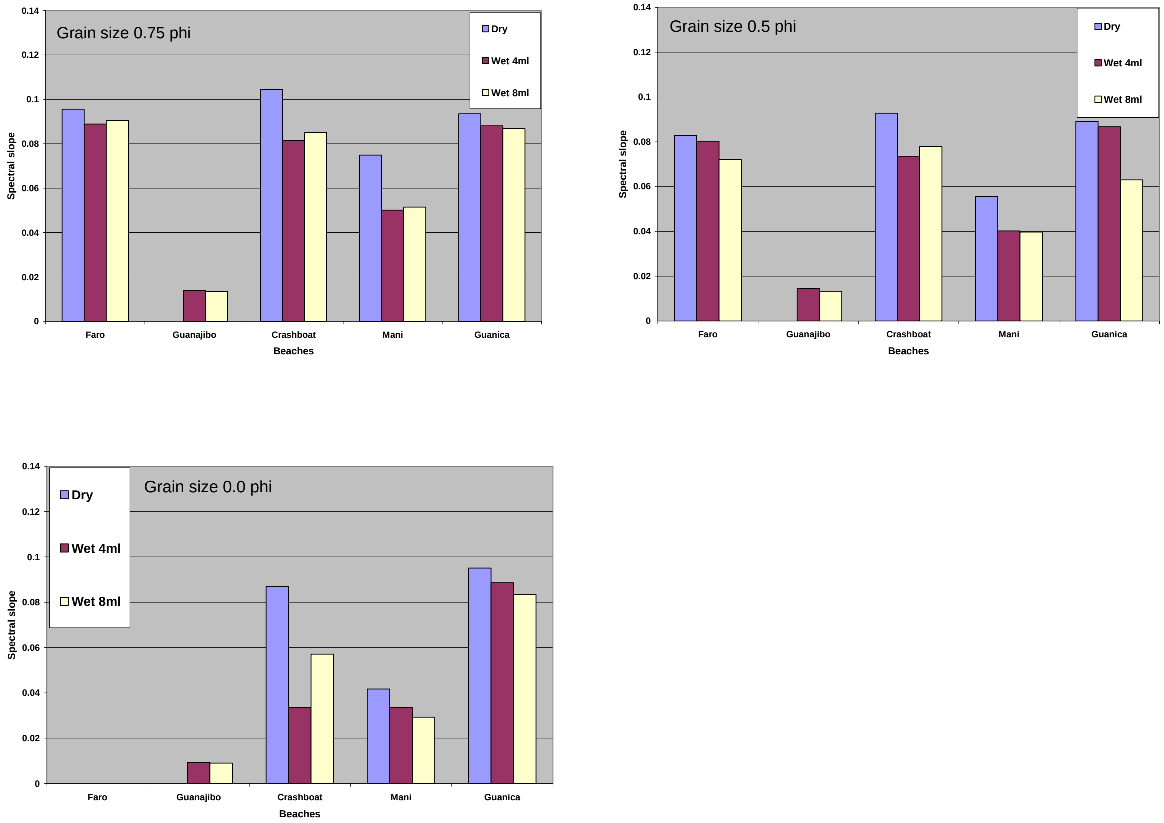

Figure 9: Spectral slope to all beaches with the same grain size.

The statistical analyses using SAS generated the understanding of the variability of the slope of the grain size and humidity of the different beaches (Table 3). The ANOVA analysis shows the significance in the variability with a probability less than 0.05. El Faro beach showed that the grain size had a significant difference ($p>0.0001$). In this beach the 1.5 and 2.0 phi grain size did not have difference because the analysis revealed $p> 0.784$. The Crashboat beach showed that the slope had significant difference $p>0.0001$. Guanajibo beach model showed significance in the grain size $p>0.0001$. El Mani beach also showed significance in the grain size $p> 0.0001$. These results demonstrate that the grain size in the reflectance curve and in the spectral slope have significant differences that affect the shape of the curves and therefore the detected reflectance. The only beach that had different results was Guanica, $p>0.7037$. No possible explanation was found for this and another study in Guanica beach is required.

Table 3: Analysis of Variance ANOVA as performed with SAS

Beaches	Overall values	Grain size	Humidity
Faro	0.0001	0.0001	0.0023
Crashboat	0.0001	0.0001	0.0001
Guanajibo	0.0001	0.0597	0.0001
Mani	0.0001	0.0001	0.0001
Guanica	0.7037	0.8112	0.3278

Discussion and Interpretation:

The changes in the spectral slope are caused by the grain size, composition and humidity. The major change in the visible range of the spectrum was found between 450 to 550 nanometers. Beaches composed of quartz, carbonates and light minerals have high spectral slopes and reflectance curves. Dark minerals and igneous material have lowest reflectance curves and spectral slopes. Other factor that changes the spectral slope and the reflectance curve is the particle size. Fine material produces high slope and reflectance in 4.0 phi grain sizes and lowest slope in 0.0 phi grain size. These results are produced because when the grain size is decreased the number of mirrors in which the light reflects are increasing (Vincent, 1997). The humidity analyses reveal that the dry sand reflects more and have a higher spectral slope than the wet sand; although these results no have correlation with the grain size and the composition.

The trend in the slope is consistent with those results showing a high slope for the dry sand and low slope for wet sand. Crashboat beach showed the highest difference in the slope between dry and wet sand. At 700nm it was 22%, at 550nm 19% and at 450nm 14%. EL Faro beach showed 13% at 700nm and 11% at 450 and 550 nm. Guanajibo beach showed 5% at 700 and 550nm, and 4% at 450nm. The SAS analyses supported the other data analyses of the reflectance curves because showed significant difference between the grain size and the humidity measurements.

Conclusions:

This research showed that the grain size have an important effect in the magnitude of the reflectance curve and in the spectral slope of sandy beaches. The finer materials increase the magnitude of the spectral slope and the larger materials reduce the magnitude. El Faro beach has a high magnitude in the spectral slope and reflectance measurements because its sand is very fine and have a large amount of materials that reflect light. The Guanajibo beach has a lower magnitude in the reflectance curve and spectral slope because the sand particles are bigger than in other beaches and the igneous composition of the particles reduces the reflection of light. The results of this study also showed that the water content of the sand affects the magnitude of the reflectance curve and the spectral slope. The wet sand will show lower magnitude in the reflectance curve and spectral slope than the dry sand. This has an important implication in remote sensing because it was proved that the signal detected by remote sensor will depend of the humidity of the sand. This aspect will have to be taken into consideration when developing algorithms to study sandy beaches using the visible range.

References:

Cameron, A., 2003, Spectral Analyses and Sedimentation of the West Coast Beaches of Puerto Rico: Mayaguez Campus, University of Puerto Rico, Department of Geology, Unpublished Undergraduate paper, 14p

Chiques, G., 2005, Spectral Characterization of Sandy Beaches in Western Portion of Puerto Rico: Mayaguez Campus, University of Puerto Rico, Department of Geology, Unpublished Graduate paper, 65p

Garcia, J., 2006, Effect of Grain Size and Moisture on the Reflectance of Beach Sand: Mayaguez Campus, University of Puerto Rico, Department of Geology, Unpublished Graduate paper, 26p

Morelock, J., 2000, Coastal Morphology and the Shoreline of Puerto Rico webpage http://geology.uprm.edu/Morelock/GEOLOCN_/cstln.htm

Vincent, R. K., 1997 Geological and Environmental Remote Sensing. Prentice Hall, Upper Saddler River, NJ, 357pp

Acknowledgment:

I would like to thank to my advisor, Dr. Fernando Gilbes for answering all my questions. I also thank to Patric Reyes a graduate student of the Marine Science Department for helping in the collection of reflectance measurements to all the samples. The support and advice of the Mathematical Department and Professor Pedro Torres Saavedra with the statistical analyses are very much appreciated.

Appendix:

Spectral slopes to all the beaches:

Faro (dry sand, 4.0ml y 8.0 ml)

Grain size	Dry sand	4.0 ml	8.0 ml
4 phi	0.1155	0.1108	0.1055
3 phi	0.1226	0.1141	0.109
2.5 phi	0.1123	0.1193	0.1142
2.0 phi	0.1231	0.1179	0.115
1.5 phi	0.1165	0.1116	0.1091
1.0 phi	0.1015	0.1004	0.1011
.75 phi	0.0956	0.0889	0.0889
.5 phi	0.0828	0.0803	0.072
0.0 phi	0	0	0

Crashboat (dry sand, 4.0ml, 8.0ml)

Grain size	Dry sand	4.0 ml	8.0 ml
4.0 phi	0.0708	0.0413	0
3.0 phi	0.0744	0.0565	0.0527
2.5 phi	0	0	0
2.0 phi	0.0959	0.0756	0.0751
1.5 phi	0.1043	0.0812	0.0803
1.0 phi	0.0956	0.0811	0.0833
0.75 phi	0.1044	0.0814	0.085
0.5 phi	0.0928	0.0735	0.0779
0.0 phi	0.087	0.0698	0.0571

Guanica (dry sand, 4.0ml, 8.0ml)

Grain size	Dry sand	4.0 ml	8.0ml
4 phi	0.0773	0	0
3 phi	0.1051	0	0
2.5 phi	0.097	0	0

2.0 phi	0.09	0.0766	0.0727
1.5 phi	0.1043	0.0696	0.0822
1.0 phi	0.078	0.1365	0.081
0.75 phi	0.0935	0.0881	0.0868
0.5 phi	0.0891	0.0867	0.063
0.0 phi	0.0951	0.0886	0.0835

Guanajibo (dry sand, 4.0 ml, 8.0 ml)

Grain size	Dry sand	4.0 ml	8.0 ml
4.0 phi	0.0272	0.0109	0.0085
3.0 phi	0.0278	0.0141	0.0141
2.5 phi	0.0277	0.0141	0.0139
2.0 phi	0.0281	0.0143	0.0149
1.5 phi	0.0259	0.0145	0.0137
1.0 phi	0.027	0.0157	0.0139
0.75 phi	0	0	0
0.5 phi	0	0	0
0.0 phi	0	0	0

Mani (dry sand, 4.0 ml, 8.0 ml)

Grain size	Dry sand	4.0 ml	8.0 ml
4.0 phi	0.0473	0.0251	0.0245
3.0 phi	0.0589	0.0327	0.0347
2.5 phi	0.0691	0.0405	0.0398
2.0 phi	0.067	0.0375	0.0339
1.5 phi	0.0704	0.0448	0.0394
1.0 phi	0.0685	0.0431	0.0418
0.75 phi	0.0749	0.0501	0.0515
0.5 phi	0.0555	0.0402	0.0397
0.0 phi	0.0417	0.0335	0.0293

Spectral slope to dry and wet sand:

Beaches	Dry	Wet
Faro	0.0294	0.0133
Crashboat	0.0247	0.0227
Guanajibo	0.0028	0.0018

Analyses of Variance with SAS

SITE = FARO
The GLM Procedure

Class Level Information		
Class	**Levels**	**Values**
humity	3	0 4 8
grain	8	0.5 0.75 1 1.5 2 2.5 3 4

Number of Observations Read	24
Number of Observations Used	24

SITE = FARO

The GLM Procedure

Dependent Variable: slope

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.00438909	0.00048768	49.71	<.0001
Error	14	0.00013735	0.00000981		
Corrected Total	23	0.00452643			

R-Square	Coeff Var	Root MSE	slope Mean
0.969657	2.973586	0.003132	0.105333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
grain	7	0.00419926	0.00059989	61.15	<.0001
humity	2	0.00018983	0.00009491	9.67	0.0023

Source	DF	Type III SS	Mean Square	F Value	Pr > F
grain	7	0.00419926	0.00059989	61.15	<.0001
humity	2	0.00018983	0.00009491	9.67	0.0023

SITE = FARO

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

grain	slope LSMEAN	LSMEAN Number
0.5	0.07836667	1
0.75	0.09113333	2
1	0.10100000	3
1.5	0.11240000	4
2	0.11866667	5
2.5	0.11526667	6
3	0.11523333	7
4	0.11060000	8

Least Squares Means for effect grain
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3	4	5	6	7	8
1		0.0055	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
2	0.0055		0.0487	<.0001	<.0001	<.0001	<.0001	<.0001
3	<.0001	0.0487		0.0152	0.0002	0.0019	0.0019	0.0598
4	<.0001	<.0001	0.0152		0.7846	1.0000	1.0000	1.0000
5	<.0001	<.0001	0.0002	0.7846		1.0000	1.0000	0.1969
6	<.0001	<.0001	0.0019	1.0000	1.0000		1.0000	1.0000
7	<.0001	<.0001	0.0019	1.0000	1.0000	1.0000		1.0000
8	<.0001	<.0001	0.0598	1.0000	0.1969	1.0000	1.0000	

SITE = FARO

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

humity	slope LSMEAN	LSMEAN Number
0	0.10873750	1
4	0.10541250	2
8	0.10185000	3

Least Squares Means for effect humity
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3

Least Squares Means for effect humity Pr > |t| for H0: LSMean(i)=LSMean(j) Dependent Variable: slope			
i/j	1	2	3
1		0.1562	0.0018
2	0.1562		0.1175
3	0.0018	0.1175	

SITE = CRASHBOAT

The GLM Procedure

Class Level Information		
Class	Levels	Values
humity	3	0 4 8
grain	8	0 0.5 0.75 1 1.5 2 3 4

Number of Observations Read	23
Number of Observations Used	23

SITE = CRASHBOAT

The GLM Procedure

Dependent Variable: slope

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.00528420	0.00058713	38.05	<.0001
Error	13	0.00020057	0.00001543		
Corrected Total	22	0.00548477			

R-Square	Coeff Var	Root MSE	slope Mean
0.963431	5.027402	0.003928	0.078130

Source	DF	Type I SS	Mean Square	F Value	Pr > F
grain	7	0.00304603	0.00043515	28.20	<.0001
humidity	2	0.00223817	0.00111908	72.53	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
grain	7	0.00332776	0.00047539	30.81	<.0001
humity	2	0.00223817	0.00111908	72.53	<.0001

SITE = CRASHBOAT

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

grain	slope LSMEAN	LSMEAN Number
0	0.07130000	1
0.5	0.08140000	2
0.75	0.09026667	3
1	0.08666667	4
1.5	0.08860000	5
2	0.08220000	6
3	0.06120000	7
4	0.05246190	8

Least Squares Means for effect grain
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3	4	5	6	7	8
1		0.2151	0.0014	0.0099	0.0034	0.1331	0.2151	0.0050
2	0.2151		0.4503	1.0000	1.0000	1.0000	0.0008	<.0001
3	0.0014	0.4503		1.0000	1.0000	0.7234	<.0001	<.0001
4	0.0099	1.0000	1.0000		1.0000	1.0000	<.0001	<.0001
5	0.0034	1.0000	1.0000	1.0000		1.0000	<.0001	<.0001
6	0.1331	1.0000	0.7234	1.0000	1.0000		0.0005	<.0001
7	0.2151	0.0008	<.0001	<.0001	<.0001	0.0005		0.8936
8	0.0050	<.0001	<.0001	<.0001	<.0001	<.0001	0.8936	

SITE = CRASHBOAT

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

humity	slope LSMEAN	LSMEAN Number
0	0.09065000	1
4	0.07005000	2
8	0.06958571	3

Least Squares Means for effect humity
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3
1		<.0001	<.0001

Least Squares Means for effect humity
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3
2	<.0001		1.0000
3	<.0001	1.0000	

SITE = GUANAJIBO

The GLM Procedure

Class Level Information		
Class	**Levels**	**Values**
humity	3	0 4 8
grain	6	1 1.5 2 2.5 3 4

Number of Observations Read	18
Number of Observations Used	18

SITE = GUANAJIBO

The GLM Procedure

Dependent Variable: slope

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.00078232	0.00011176	66.48	<.0001
Error	10	0.00001681	0.00000168		
Corrected Total	17	0.00079914			

R-Square	Coeff Var	Root MSE	slope Mean
0.978962	7.152667	0.001297	0.018128

Source	DF	Type I SS	Mean Square	F Value	Pr > F
grain	5	0.00002614	0.00000523	3.11	0.0597
humity	2	0.00075618	0.00037809	224.89	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
grain	5	0.00002614	0.00000523	3.11	0.0597
humity	2	0.00075618	0.00037809	224.89	<.0001

SITE = GUANAJIBO

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

grain	slope LSMEAN	LSMEAN Number
1	0.01886667	1
1.5	0.01803333	2
2	0.01910000	3
2.5	0.01856667	4
3	0.01866667	5
4	0.01553333	6

Least Squares Means for effect grain
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3	4	5	6
1		1.0000	1.0000	1.0000	1.0000	0.1554
2	1.0000		1.0000	1.0000	1.0000	0.5978
3	1.0000	1.0000		1.0000	1.0000	0.1070
4	1.0000	1.0000	1.0000		1.0000	0.2521
5	1.0000	1.0000	1.0000	1.0000		0.2145
6	0.1554	0.5978	0.1070	0.2521	0.2145	

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

humity	slope LSMEAN	LSMEAN Number
0	0.02728333	1
4	0.01393333	2
8	0.01316667	3

Least Squares Means for effect humity
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3
1		<.0001	<.0001
2	<.0001		0.9897
3	<.0001	0.9897	

SITE = GUANICA

The GLM Procedure

Class Level Information		
Class	**Levels**	**Values**
humity	3	0 4 8
grain	9	0 0.5 0.75 1 1.5 2 2.5 3 4

Number of Observations Read	21
Number of Observations Used	21

SITE = GUANICA

The GLM Procedure

Dependent Variable: slope

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	0.00195593	0.00019559	0.71	0.7037
Error	10	0.00276927	0.00027693		
Corrected Total	20	0.00472519			

R-Square	Coeff Var	Root MSE	slope Mean
0.413936	18.94418	0.016641	0.087843

Source	DF	Type I SS	Mean Square	F Value	Pr > F
grain	8	0.00126384	0.00015798	0.57	0.7810
humity	2	0.00069208	0.00034604	1.25	0.3278

Source	DF	Type III SS	Mean Square	F Value	Pr > F
grain	8	0.00117019	0.00014627	0.53	0.8112
humity	2	0.00069208	0.00034604	1.25	0.3278

SITE = GUANICA

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

grain	slope LSMEAN	LSMEAN Number
0	0.08906667	1
0.5	0.07960000	2
0.75	0.08946667	3
1	0.09850000	4
1.5	0.08536667	5

grain	slope LSMEAN	LSMEAN Number
2	0.07976667	6
2.5	0.09229444	7
3	0.10039444	8
4	0.07259444	9

Least Squares Means for effect grain
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3	4	5	6	7	8	9
1		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0000	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	1.0000	1.0000	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000		1.0000	1.0000	1.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	1.0000		1.0000	1.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000		1.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000		1.0000
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	

SITE = GUANICA

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

humity	slope LSMEAN	LSMEAN Number
0	0.09215556	1
4	0.09150556	2
8	0.07868889	3

Least Squares Means for effect humity
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3
1		1.0000	0.5739
2	1.0000		0.6354
3	0.5739	0.6354	

SITE = MANI

The GLM Procedure

Class Level Information		
Class	**Levels**	**Values**
humity	3	0 4 8
grain	9	0 0.5 0.75 1 1.5 2 2.5 3 4

Number of Observations Read	27
Number of Observations Used	27

The GLM Procedure

Dependent Variable: slope

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	0.00503807	0.00050381	30.29	<.0001
Error	16	0.00026615	0.00001663		
Corrected Total	26	0.00530423			

R-Square	Coeff Var	Root MSE	slope Mean
0.949822	8.913785	0.004079	0.045756

Source	DF	Type I SS	Mean Square	F Value	Pr > F
grain	8	0.00169179	0.00021147	12.71	<.0001
humity	2	0.00334629	0.00167314	100.58	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
grain	8	0.00169179	0.00021147	12.71	<.0001
humity	2	0.00334629	0.00167314	100.58	<.0001

SITE = MANI

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

grain	slope LSMEAN	LSMEAN Number
0	0.03483333	1
0.5	0.04513333	2
0.75	0.05883333	3
1	0.05113333	4
1.5	0.05153333	5
2	0.04613333	6

grain	slope LSMEAN	LSMEAN Number
2.5	0.04980000	7
3	0.04210000	8
4	0.03230000	9

Least Squares Means for effect grain
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3	4	5	6	7	8	9
1		0.2513	<.0001	0.0058	0.0046	0.1337	0.0132	1.0000	1.0000
2	0.2513		0.0292	1.0000	1.0000	1.0000	1.0000	1.0000	0.0506
3	<.0001	0.0292		1.0000	1.0000	0.0550	0.5533	0.0045	<.0001
4	0.0058	1.0000	1.0000		1.0000	1.0000	1.0000	0.5533	0.0013
5	0.0046	1.0000	1.0000	1.0000		1.0000	1.0000	0.4321	0.0010
6	0.1337	1.0000	0.0550	1.0000	1.0000		1.0000	1.0000	0.0269
7	0.0132	1.0000	0.5533	1.0000	1.0000	1.0000		1.0000	0.0028
8	1.0000	1.0000	0.0045	0.5533	0.4321	1.0000	1.0000		0.3439
9	1.0000	0.0506	<.0001	0.0013	0.0010	0.0269	0.0028	0.3439	

SITE = MANI

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Bonferroni

humity	slope LSMEAN	LSMEAN Number
0	0.06147778	1
4	0.03861111	2
8	0.03717778	3

Least Squares Means for effect humity
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: slope

i/j	1	2	3
1		<.0001	<.0001
2	<.0001		1.0000
3	<.0001	1.0000	