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Methods of Classifying Sand Shape and the Effects of Sand Shape on USGA Specification Rootzone Physical Properties

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Purpose:

Sand shape is composed of two components: sphericity and roundness. Sphericity describes how closely the sand grain assumes the form of a sphere. Roundness describes whether the grain has sharp or smooth edges on its surface. Sand shape may contribute to the physical properties of a rootzone mixture because shape can have an effect on bulk density, total porosity, air-filled and capillary porosity, and saturated hydraulic conductivity. Sand grain shape may also influence the stability of the playing surface because of its effects on how individual particles can lock together. Sand shape is currently determined by visual ratings. These ratings are difficult and quite subjective. The purpose of our project is to: 1) determine a non-subjective method for measuring sand grain shape; and 2) determine how sand shape influences rootzone mix physical properties.

Materials and Methods

Our methodology for determining sand shape involves visual and mechanical assessments. The visual method uses the Riley sphericity index and a Krumbein roundness chart. The sphericity index measures how globe-like a particle is by finding the ratio between the largest inscribing circle that can fill a magnified sand grain and the smallest circumscribing circle around that grain. A perfectly spherical grain will have an index of 1.0. Roundness, or smoothness, is a visual determination comparing the grain surface to a smoothness chart. A round grain may or may not be spherical and a spherical grain may or may not be round. Another way for determining sand shape may be through the use of the shape analysis software program ArcInfo. This software was developed for global information systems and land analysis. In this procedure sand grain images (35 mm slides) are scanned as Tiff images into a PC. The images are edited in Adobe Photoshop or Paintshop Pro to remove background differences. ArcInfo then determines the number and lengths of arcs required to outline the grain silhouettes, as well as determine perimeter length, volume and axis lengths. The ratio is then compared to standard sand grain values from USGA Specifications (Figure 1) and a sphericity and smoothness value assigned. This method will hopefully allow for the analysis of many grains at one time, thus giving a better estimate of the bulk sands shape.

Mechanical methods to be tested include: 1) Direct shear method - this determines the amount of sidewards force (shear force) required to cause the sand to slide over itself while a downward force is being applied. An angular material should require more shear force than a round material due to the frictional resistance of the individual grains towards sliding; 2) Rotatable drum method - this method determines the critical angle that an uncompacted sand can reach before it begins to avalanche. A less smooth and less spherical sand should have a greater critical angle than a smooth, spherical sand; 3) Dense soil angle of repose - In this technique the sand is compacted with a vibrator. The sand is then tilted until it fails at some critical angle. As in the rotatable drum method, the critical angle should be related to the surface characteristics of the sand; and 4) The cone penetrometer - The force required to push a cone shaped tip into a confined sand sample is measured. A spherical, round sand should offer less resistance than a non-spherical, non-round sand.

While these mechanical tests are being conducted on our sands we will also determine the physical properties of the sand materials as outlined by USGA specifications. At the end of our study we will be able to state if any of our methods can accurately determine shape and how shape relates to the physical properties of the rootzone mixes.

Results and Discussion:

Shape and Physical Properties:

The physical properties of a round (smooth) sand and angular (rough) sand having similar sphericities have been measured alone or in various combinations with peat and/or soil. The round sand had a higher bulk density (BD), lower total porosity (TP), lower air-filled porosity (AP), higher capillary porosity (CP), and lower saturated hydraulic conductivity (Ksat) than the angular sand. This is due to the round sand grains settling more easily than the angular sand.

Addition of fine or coarse peat to the two sands at 10%, 20% or 30% v/v lowered BD, but the decrease was slightly greater in the angular sand. The coarseness of the peat did not matter as much as would be expected in its influence on BD. Both sands behaved similarly when soil was added at 10% or 20% v/v. At 10% v/v both sands had an equal decrease in BD while at 20% v/v the soil increased the BD of both sands equally. When the soil was added at 30% v/v it caused the angular sand to have a greater increase in BD than the round sand.

Total porosity of both sands was increased by peat and a greater increase in TP occurred in round sand when peat was added at 20% or 30% v/v. Peat sizes used in this study did not seem important in its effect on the change in TP. Soil increased TP of the sands with one exception. When added at 10% v/v the soil slightly decreased the TP of the round sand.

The AP of both sands decreased with addition of fine peat or soil. Coarse peat increased AP. Response of the sand was affected by its shape. Angular sand had a greater decrease in AP than round sand when fine peat was added at 20% or 30% v/v. Round sand showed a much greater increase in AP than angular sand when coarse peat was added. Adding soil at 10% or 30% v/v decreased AP by about the same amount in both sands, but at 20% v/v there was a greater decrease in the angular sands AP. Peat and soil increased CP in both sands with a greater increase occurring in the angular sand. Fine peat increased CP more than coarse peat. Fine peat also had a greater influence on CP than the soil.

All amendments decreased Ksat and sand shape did not seem to have any effect. Soil caused a greater reduction in Ksat than fine peat which caused a greater reduction than coarse peat.

Peat plus soil additions resulted in a decrease in BD although not to the extent that peat alone did. Fine peat had a greater effect on decreasing BD in the peat/soil/sand mixes than coarse peat. Round sand was more affected than angular sand in all the combinations tested. The decrease in BD resulted, for the most part, in an increase in TP. When peat and soil were added to the mix at 5% v/v each there was a decrease in TP in the round sand and a slight increase in TP in the angular sand. When the percentages of the amendments increased to 10% v/v each, TP increased in both sands. More of an increase occurred in angular sand with fine peat, but coarse peat caused more of a change in the round sand. At 15% v/v each there was a greater increase in the angular sand with fine peat, but the change was equal when coarse peat was used. At 20% v/v each, the round sand had a greater percentage of change in TP than the angular sand. Peat size was not important in this mix ratio.

Air-filled porosity decreased with peat/soil addition even though TP increased in most instances. At 5% v/v each of the mix, AP decreased more in round sand with fine peat/soil. Coarse peat/soil at this rate caused an equal decrease in both sands. When peat/soil increased to 10% v/v each, fine peat caused a greater decrease than coarse peat and more of a change occurred in the round sand. A larger decrease in AP occurred when the peat/soil was 15% v/v each of the mix, especially with the fine peat and the round sand. However at 20% v/v each of peat/soil the trend reversed itself with the angular sand having a greater decrease than the round sand.

Because of the decrease in AP, CP porosity increased when amendments were added to either sand. This increase became greater as percentage of the amendments added to the sands increased. A greater increase in CP always occurred in the angular sand mixtures than in the round sand mixtures.

Saturated hydraulic conductivity was decreased by the addition of amendments to the two sands, but the percentage of decrease was equal, for the most part, in both sands. Although we would expect differences in Ksat because of the measured changes in BD and TP it appears that the redistribution of AP and CP had the net effect of canceling out the influence that sand shape may have had on Ksat.

To summarize these findings, shape did have an impact on the response of sand to the addition of various amendments. The round sand typically showed a greater decrease in bulk density (BD) than the angular sand as a result of a greater increase in total porosity (TP), but TP increased because of an increase in capillary porosity(CP), not aeration porosity(AP). The angular sand had similar trends, but TP increased less than for the round sand plus CP increased more in the angular sand. These results make sense because of the initial differences observed for the physical properties of the unamended sands. The round sand had a higher BD initially, a lower TP, a lower AP, higher CP and lower saturated hydraulic conductivity (Ksat). Therefore the addition of amendments to a round sand was more likely to lower BD, increase TP and cause less of an increase in CP than for an angular sand. However, any effect of the previous changes on Ksat were very minor.

Dense Soil Angle of Repose:

Work is being conducted to determine if DSAR can be used to separate sand samples based on their shape. In DSAR the sample (about 200 g.) is compacted using a vibrator at voltages ranging from 30 v to 80 v. After vibration at a particular voltage the sand, which is contained in a small box, is tilted until the surface of the sand fails (slides). The angle of failure is determined. Four sands, previously characterized for their sphericity and roundness, are being tested either as mixtures of sizes (0.05 to 1.0), or as uniform sizes. The DSAR produces reproducible results for mixtures of sand or uniform sand. Forty volts gives separation of the four differently shaped mixtures. Sand strength increases with the round sand mixture as voltage increases and round sand can increase in strength until 80 volts is applied after which the sand can no longer be compacted. Up to 50 volts the angular, sub-angular, and sub-rounded sand mixtures have greater strength than the round sand mixture. Unlike the round sand mixture, these other sands tend to lose strength beyond 40 volts. Angular and sub-angular sand can no longer be compacted at voltages greater than 50 volts. Sub-rounded sand can no longer be compacted after 60 volts.

When the sands are sieved into their 0.25 mm size range and tested we find that 40 volts is useful for separating the four sand shapes. From 45 volts to 65 volts the round sand (lowest DSAR) and angular sand (highest DSAR) can be separated from each other. The sub-angular and sub-rounded sands tend to have the same intermediate DSAR values. Tests are being conducted on the 0.05, 0.15, 0.33, and 0.5 mm fractions to determine which voltage provides the best separation.

Cone Penetrometry:

The resistance of different shaped sands is being tested using a hand held cone penetrometer after the sands have been compacted according to USGA specifications. Round and sub-rounded sands can be separated from sub-angular and angular sands. The former two sands yield readings <5 while the latter two sands yield readings of >8. However, it has not yet been possible to separate a round sand from a sub-rounded sand, or a sub-angular sand from an angular sand.

Direct Shear Strength Method:

It was often observed that the response of the sands to increasing normal stress was not always a linear one. Response curves were sometimes concave or convex and the response could not be related to surface texture. Therefore, further work has been done to: 1) to confirm previous friction angles; and 2) test for the linearity of the response curve to normal stress. Two sands, Wedron #430 and Stancill's bunker sand, were re-examined because of their similar sphericities but different surface smoothnesses. They were placed under normal stresses ranging from 10 lbs to 120 lbs. in 10 lb. increments. As previously mentioned, normal stresses of 30, 60 and 90 lbs. are usually used to determine friction angles of non-cohesive soils. However, if one of these three points is high or low then it is difficult to determine the true shape of the curve. Twelve data points allows us to determine if the shape of the curve is linear, convex or concave.

Using the 0.25 mm or 0.5 mm fraction of an angular, sub-angular, sub-rounded and rounded sand revealed a fairly linear response of each sand to increasing normal stress. Developing best fit lines through the data yielded equal friction angles for all the sands, even though some lines were more sigmoidal in shape. It was determined that linearity decreased as the angularity of the sand increased. Angular materials appear to weaken in strength at certain normal stresses.

Friction angles obtained by using 12 data points per sand were lower than when only three data points were used. The use of three data points often resulted in lines having steeper slopes that tended to accommodate the position of the 30 and 90 lb. normal stress points. The 60 lb. data point was often lower than the line. Taking this middle data point into consideration would lower the steepness of the line and decrease the slope.

Using sand size mixtures described previously we have found that the internal friction angle of either a round or angular sand changes only slightly. However, the angular material has a greater amount of change in internal friction angle than a rounded material. We assume this is because the different sized angular sand grains cause some locking and, therefore, a greater amount of frictional resistance to movement. Smoothness of the round grains allows them to continue to move even if grain size varies. This is an expected observation, but the change in internal friction angle, about 5 degrees, is not as great as expected.

As mentioned in the mid-year report, it seems that the direct shear strength method may not be a suitable method for separating sand according to surface roughness. However, the plan is to continue testing this method to learn more about why these differently shaped sands do not behave as predicted.

Computer Imaging

This method was not part of our original proposal, but after several discussions with Dr. Rick Day, Director of the Penn State Land Analysis Laboratory, it seemed that procedures used to analyze land shape from digitized topographical maps and satellite images might be suitable for quantifying the shapes of sands. The advantages would be that many more sand grains can be quantitatively analyzed for sphericity and roundness. Slides generated from microscopic views of the sand grains are scanned to raster TIFF format images, edited to create uniformly colored backgrounds and remove objects not of interest, and converted to an ArcInfo vector format where each sand grain is represented by a polygon. A series of shape parameters are then calculated for each grain. Shape parameters include, but are not limited to: (a) number of line segments defining the polygon perimeter, (b) polygon area, (c) average length of line segments, (d) perimeter length, (e) average angle of deviation formed by two connected line segments, and (f) major and minor axis lengths. Combinations of parameters, such as area/perimeter length ratios, will also be calculated. Algorithms will be applied to "generalize" the shape of each sand grain with pre-determined tolerances that force the graphical appearance to be preserved after generalization. The value of calculated shape parameters will be compared for the ungeneralized and generalized images and should provide an index of grain angularity. Correlations between graphical shape parameters and sand grains of pre-determined shape class will be calculated to determine if the shape parameters can be used to effectively classify sand shape.

To date, we have determined the photographic exposure time and magnification size necessary to produce scannable slides having the least amount of required editing. We have also scanned in the 18 sand images from Figure 1 of the USGA Specifications Manual. These images will be used to test the ability of ArcInfo to quantify shape differences and to test which shape parameters are best for distinguishing between shapes. Once this is determined we will begin quantifying the shapes of our test sands. A graduate student from the Land Analysis Laboratory has been hired to test ArcInfo and other image analysis programs.