Computerized particle analyzer: the next generation of particle analysis

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Abstract

The characteristics of any substrate material can be attributed to its composition of particle characteristics. Sieve analysis is one of the most basic tests for fractioning particle sizes and the predominate method utilized for horticultural substrate characterization. However, sieve analysis is noted for its poor reproducibility and lack of valuable information. To better quantify particle shape and size, the Computer Particle Analyzer II (CPA) by W.S. Tyler Group was evaluated for its potential use in substrate science. The CPA was found to be approximately 97% accurate in both particle counts and dimensional measurements after calibration. Touching particles and particle oscillation across the measurement zone are believed to account for the error incurred during analysis. To validate the CPA's analysis, coarse, medium, and fine horticultural sands were analyzed and compared to traditional sieve analysis. Distribution error was calculated using the Chi-Square method, mean standard error, and a complex error term using the bin size and percent composition. Some error was recorded in the CPA's analysis of each sand. This highlights the variability that may occur when calculating particle volumes from 2-D image analysis. The 2-D characterization, accuracy, and customization of the CPA and its accompanying software can provide valuable data to more fully characterize substrate particle shape and size.

Keywords: image analysis, substrate, growing media, particle size distribution, physical properties

INTRODUCTION

The physical and hydrological properties of horticultural substrates are attributes of the size, shape, and distribution of its particles. In a general sense, more "coarse" particles are believed to increase air capacity while more "fine" particles increase water holding capacity (Handreck, 1983). This is due to particle size distribution (PSD) and resulting pore size and distribution (Jones and Or, 1998). Due to the influence of PSD in horticultural substrates, particle size analysis (PSA) is a common procedure utilized to evaluate substrate performance or ensure quality control.

Sieve analysis is one of the most basic tests for fractioning particle sizes of aggregate materials and is the predominate method of PSA with horticultural substrates (Allen 1997; Handreck, 1983; Nemati et al., 2009). Sieves are a unique tool that can sort a material solely based on particle size. However, sieve analysis is a rather crude method of PSA, noted for its poor reproducibility and lack of shape classification parameters (Allen, 1997; Carpenter and Deitz, 1950; Syvitski, 1991). Additionally, the screens, method of agitation, and material characteristics can affect the accuracy of data obtained by sieve analysis (Allen, 1997; Nemati et al., 2009; Syvitski, 1991). Standardization of sieving protocols for each material may increase the efficiency of sieve analysis, but this method should not be considered a good size descriptor of many non-spherical container substrate components (Syvitski, 1991). It is perhaps a more complete characterization of a material to use multiple techniques in combination (Syvitski, 1991).

Image analysis is a rapidly expanding technique due to the advances in modern

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Acta Hortic. 1266. ISHS 2019. DOI 10.17660/ActaHortic.2019.1266.14
Proc. Int. Symp. on Growing Media, Soilless Cultivation, and Compost Utilization in Horticulture
Eds.: J.E. Altland et al.

computer technology. In general, image analysis is a three-step process: 1) disperse a sample across a flat stage, making sure to separate individual particles; 2) use an image acquisition device to capture the sample digitally; and 3) utilize algorithms to process images and collect data. Although the technique can be labor intensive to prepare each sample, image analysis utilizes small sample quantities, provides a diverse range of characterization parameters (i.e., length to width ratio, sphericity, and Feret diameters), and delivers high repeatability (Fernlund, 2005; Vaezi et al., 2013). To further automate image analysis, some commercially available instruments can perform all three steps simultaneously with very little assistance required from the operator.

W.S. Tyler's parent company, Haver & Boecker, has developed a series of automated computerized particle analyzers (CPA) which differ slightly in size and preferable materials. The Computerized Particle Analyzer II (CPA II) is a self-contained device (87×19×57 cm) which houses an adjustable funnel, vibration feeder, conveyor, light source, line-scan camera, and sample catch basin (Figure 1). A computer and proprietary software accompanies the device, allowing the operator the flexibility to name the sample, determine which shape and size parameter(s) best characterize the material, and adjust the settings of the device before a sample is analyzed. Once the operator is ready, a sample can be loaded into the adjustable funnel. The height of the funnel will determine how much material is deposited on to the vibration feeder. The vibration feeder is 6.4 cm metal channel with a gentle, downward pitch to the conveyor. The feeder vibrates (operator-selected setting from 0 to 21) to separate the particles, orient them in the most stable position, and gently load them onto the conveyor. The conveyor belt is 45 cm long and moves at constant 1 m s^{-1} speed which propels each particle between a light source below the conveyor and a line-scan camera above the conveyor. The line-scan camera scans a line of 2048 pixels (each pixel is 34×34 μm) up to 20,000 times s^{-1}. As a particle passes across the light source, it is detected by a drop in light intensity along the line of pixels and a digital image of the particle is produced and analyzed instantaneously. Once scanned, the material is collected in the catch basin.

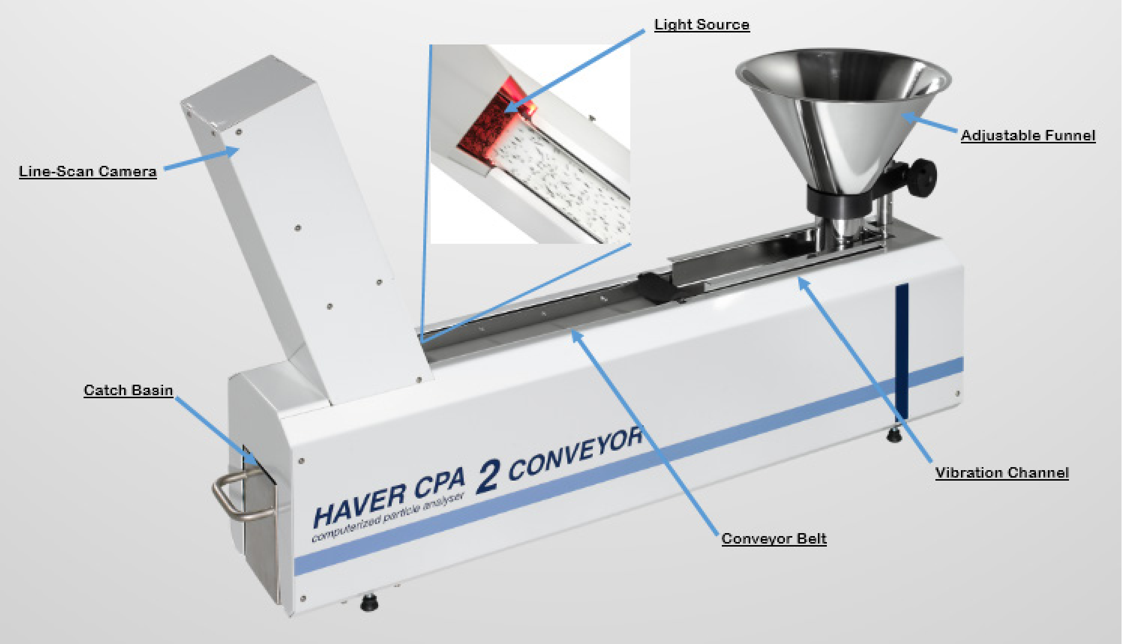

Figure 1. Tyler (Haver) Computer Particle Analyzer 2 Conveyor.

Data from a scanned sample is stored in .han and .ccd file format and can be viewed in two formats through the accompanying software. For each scanned sample, a particle library is created containing the identification number, image of each particle, and size parameters such as minimum and maximum Feret diameter (i.e., distance between the two parallel planes restricting the object perpendicular to that direction), length, width, length to width ratio, and equivalent diameter (diameter of a sphere of an equivalent parameter such as volume or surface area). The library also includes projected area, circumference, surface area, and volume calculated from each particle's equivalent diameter or segmented rectangles models. Shape parameters listed for each particle include circularity, sphericity, roundness, and symmetry. Features such as size, circularity, and length to width ratio can be used to filter the particle library to deconstruct a material or exclude particles like dust which tend to float along the line of scanning pixels creating large streaks which could possibly skew data. In the "Results Presentation" tab, a sample can be displayed according to size classes similar to standard sieve series sizes. The operator can custom-select any number of size classes to analyze a material or use any of the standard sieve sizes such as the ISO or ASTM sieve series available in the program. The data can be displayed in cumulative, passing or retaining, and differential distributions of the sample's length, area, and volume. Selecting multiple samples allows the operator to easily compare sample distributions. Additionally, if further analysis is warranted, the data from each sample can be exported via .csv or .xls file format.

With any new technical device, accuracy and precision studies must be conducted to evaluate the quality of the data. Data from image analysis varies from sieve analysis in that the data are weighted by particle count, not mass. Therefore, the CPA II's ability to accurately record the number of particles in a sample is paramount. Furthermore, since PSA data are typically viewed as a distribution of the percent composition across sieve sizes or size classes, the CPA II must also accurately measure each particle. It was the objective of this work to conduct a series of test to evaluate the CPA II with respects to particle counts and measurements.

MATERIALS AND METHODS

Particle size analysis by image analysis is weighted by particle count. Therefore, the device's accuracy counting particles is critical information. The accuracy of the CPA II to count particles is dependent upon two sources of error, touching particles and rejected particles. If particles are touching at the moment they are scanned, the particles will be considered one particle and measured as such. The CPA II uses a vibration feeder and conveyor system to reduce this source of error, but, to a degree, the source of error remains a concern. A rejected particle occurs when a particle passes outside of the measurement line. When the instrument detects that a particle was not scanned in its entirety, the particle is rejected and excluded from the analysis.

To evaluate the instrument's ability to separate particles without operator assistance, tall fescue seeds (*Festuca arundinacea*) were hand-counted in counts of 100, 500, 1,000, and 5,000 seeds and were analyzed. Each sample was evaluated five times. The data recorded for each replication included rejected particles and touching particles.

Since the goal of PSA is to sort a material on the bases of particle size, the ability of CPA II to accurately measure particles as the drop from the belt to the collection vessel is accomplished with the use of a line-scan camera which measures objects or changes within a line of pixels ≤20,000 times s^{-1}. However, the scan rate of the instrument should be properly calibrated to accurately scan the material(s) of interest based aerodynamics or density of the particle which may cause the particle to oscillate during digital evaluation. Proper calibration will allow the particle to travel ~34 µm, the height of each pixel, before the subsequent scan.

In order to evaluate the CPA II's measurement accuracy, two sources of error were considered: scanning calibration and particle oscillation. The best method to evaluate both sources of error was to measure a circular object. If the circular object is digitally elongated or shortened, the scan rate must be increased or decreased, respectively. A Feret diameter is a directional diameter measurement along the vertical axis which can be used to evaluate the scan rate. Particle oscillation error is a result of the particle tilting along the measurement line. A Martin diameter is a direction diameter measurement along the horizontal axis and can be used to evaluate the degree of error resulting from particle oscillation.

Metal washers with a diameter of 7.76, 11.79, and 17.70 mm were evaluated to determine the CPA II's accuracy to measure a particle. Each washer size was analyzed separately (n=100). The mean and standard deviation of the Feret and Martin diameters for each washer diameter were recorded. CPA II settings were held constant for all washer sizes.

RESULTS AND DISCUSSION

Touching particles and rejected particles were recorded in each of the fescue seed samples with one exception; no touching particles were recorded in the 100-count sample (Table 1). The accuracy of the CPA II to correctly count the number of particles in a sample ranged from 98 to 99%. However, these reported accuracies may only apply to samples with similar characteristics as fescue seeds.

Table 1. Accuracy of the Computer Particle Analyzer II with respect to particle counts of tall fescue seeds (*Festuca arundinacea*).

Seed count	Counted particles	Rejected particles[a]	Touching particles[b]	Accuracy (%)
100	98[c]	2	0	98
500	493	4	5	98.1
1000	991	5	5	99
5000	4943	38	37	98.5

[a] Rejected particles are those particles which were not scanned in their entirety.

[b] Touching particles consist of 2 or more particles counted as one and were excluded from the figures calculated in the column labeled "Counted particles."

[c] All numbers reported as means (n=5) and, therefore, the sum may not equal the true seed count.

Characteristics which may affect the accuracy of the CPA II are moisture content and surface texture. A moist sample will inherently aggregate, reducing the accuracy of the instrument to properly count particles. It is difficult to recommend an appropriate moisture content for sample preparation prior to image analysis because this may vary depending on the material and the objective of the study. Particle agglomeration may also be a result of the surface texture or shape of the particles. More fibrous materials may require the operator to tease apart aggregates for accurate characterization.

For each washer size, the CPA II reported a mean Feret and Martin diameter within 0.12 mm (approximately 4 pixels) difference from the true diameter (Table 2). These results indicate that the line-scan rate of the camera was properly calibrated for these materials. The mean Martin diameter for each washer size was consistently lower than the true diameter. These results indicate that the particles were oscillating across the measurement line resulting in a lower calculated diameter.

Table 2. Accuracy of the Computer Particle Analyzer II with respect to directional diameter measurements, Feret and Martin, of metal washers.

Washer diameter		Feret diameter	Martin diameter
7.76 mm	Mean[a]	7.85	7.69
	Stdv[b]	0.09	0.06
11.79 mm	Mean	11.79	11.69
	Stdv	0.11	0.11
17.70 mm	Mean	17.67	17.58
	Stdv	0.09	0.04

[a] For all reported means, n=100.

[b] Stdv = standard deviation.

Despite some error in the accuracy and precision of the CPA II to count and measure particles, every experiment resulted in an accuracy ≥98%. According the ASTM standards for sieve analysis of soils, up to 5% of the sample can be lost or irrecoverable and yet considered viable data (ASTM D6913). These results validate the accuracy of this computer particle analyzer to count and measure machined particles and seeds accurately. However, these results do not explicitly support the use of particle analyzers for the characterization of heterogeneous substrates but highlights the potential advantages of image analysis instruments for future work in substrate characterization. The combination of these two methods, image analysis and sieve analysis, may prove to be the most complete description of container substrates, lending valuable insight into the performance the substrates.

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