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Measurements for water retention calculations and physical characterization were made on skeletal and non-skeletal soils in southwest Oregon. A new bulk density sampler was designed for the physical characterization of the steep, skeletal soils commonly encountered in this area. The new sampler and the techniques required for the measurement and calculation of physical properties and available water are presented.

The bead cone bulk density sampler is a modification of the sand cone excavation technique. The design allows a sample volume (1.5×10^7 mm^3) large enough to include rock fragments up to 160 mm in diameter which is important due to the large spatial variability of rock fragments. The bead cone is also designed to be easily portable and operate effectively on slopes up to 100 percent.

A field test was conducted to compare bead cone and sand cone sampling techniques and results. Total soil density, fine soil density, rock fragment content and volumetric water content were measured or calculated with no statistical difference observed between the results obtained with the two samplers. On soils where slope or rock fragment size are not limiting for the sand cone both samplers work well: beyond these limits the bead cone is the preferred technique.

Measurements of total soil density, fine soil density and rock fragment content using the bead cone and a 76 mm diameter, 76 mm length corer were compared on 30 soils in southwest Oregon. The core method compared well for rock fragment contents below 15 percent. There was, however, little agreement in soils with higher rock fragment content due to physical impedance and the small volume of the corer.

The bead cone sampler was used to aid in the characterization of the physical properties of southwest Oregon. Soils were assessed at forty sites covering nine parent materials. The sites were sampled for total bulk density, particle size distribution, dry season water content and field capacity water content. The physical properties of the rock fragments significantly influence the calculation of seasonal water content and total available water. The porosity of the rock fragments ranges from 10 to 50 percent and contributed an average 15 percent of the total available water. The porosity of rock fragments must also be included in the calculation of rock fragment volume and fine soil density. The fine soil averaged over 12 percent organic matter with 50 percent of mineral soil being sand.

Linear models using these soil physical properties were then used to predict water content at field capacity, seasonal low and total available water. The use of probablistic prediction models to estimate available water content may be valuable for long range management planning but appear to be of little value in management of specific sites. It was concluded that, using the methods presented, direct measurements of available water would be easier and more accurate than the models used for prediction.

Soil Physical Properties and Available Water Capacity of Southwest Oregon Forest Soils

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SOIL PHYSICAL PROPERTIES AND AVAILABLE WATER CAPACITY OF SOUTHWEST OREGON FOREST SOILS

INTRODUCTION

In the western United States, reforestation success is often limited by a physical environment which is too harsh for germinating or transplanted seedlings. More specifically, in the Mediterranean climate (hot, dry summers) of southwest Oregon it is often the availability of water for seedling transpiration which limits seedling growth and survival. Water availability is particularly important in situations where the soil resource is limited. The Bureau of Land Management (USDI) classified approximately 60 percent of the forest soils they manage in southwest Oregon as skeletal, with twenty five percent of the total land mapped as lithic (Wert, Pomerening, and Gibson, 1977; deMoulin, Pomerening and Thomas, 1975). These shallow, rocky soils often have inadequate soil water for seedling establishment. In addition, the presence of rock fragments in these soils increases the difficulty of reforestation management. Rock fragments cause a dilution of the fine soil and can significantly affect soil fertility, root growth and heat transfer. The dilution effect, which can cause a reduction in total available water, is more significant than just a reduction in water available for seedling transpiration. The soil water required for establishment of transplanted seedlings includes not only water for transpiration but also water for evaporative cooling of the soil surface and maintenance of a nonlethal heat transfer regime. The available water supply importance in such situations is, therefore, the total amount of water available in the soil. For this study, available water supply was defined as the quantity of water stored in the soil root zone after drainage has reached a negligible rate minus any water which remains in the soil root zone at the driest part of the year, which is usually late summer.

The first part of this research was to design a bulk density sampler that would sample total soil density and rock fragment content on the steep, skeletal soils of southwest Oregon. The bead cone sampler, a modification of the sand cone excavation technique, was designed with a sample size large enough to accurately measure total soil density and rock fragment content in soils with high variability. It is also simple enough in operation to quickly and easily characterize large soil units. The development of the bead cone facilitated enabled the second part of this research: a survey of the physical properties in southwest Oregon, for the purpose of characterizing the soil environment that is commonly encountered.

For this characterization, forty soil locations were selected to collectively sample for their physical properties and available water capacity. The sites were selected to include those soils representative of large areas of southwest Oregon as well as the most commonly found parent materials. Field and laboratory measurements were required to best describe the physical nature of these soils. Once measured or calculated, the physical properties were used to develop models based on soil physical properties for use in prediction of available water capacity.

These models, based on several physical properties, were useful in examining which factors most influence available water in skeletal soils. There were two types of models used, deterministic and probablistic. The relationships between the physical properties and available water capacity are deterministic in nature. The calculation of water content using the deterministic models requires several physical measurements and is specific and accurate for the soil on which the measurements are taken. For a more general view, probablistic models were developed and used as predictive models. These models are less accurate and require more physical measurements. Their advantage is, however, that they are not specific to any one management unit and can be easily used for planning purposes on units which cover several soil types.

CHAPTER 1

DEVELOPMENT AND CALIBRATION OF AN IRREGULAR HOLE BULK DENSITY DEVICE

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DEVELOPMENT AND CALIBRATION OF AN IRREGULAR HOLE BULK DENSITY SAMPLER[1]

Alan L. Flint and Stuart Childs[2]

ABSTRACT

A sampler was developed for measurement of both rock fragment content and soil bulk density. The sampler utilizes an irregular hole excavation technique which is particularly suited for measurements on skeletal soils. The sampler is designed to sample rock fragments up to 160 mm in diameter and an irregular hole volume of 1.5×10^7 mm^3. The sampler is also designed to operate on steep slopes and to be easily portable. The combination of direct volume measurement and surface calibration before measurement allows determination of sample volume to one percent accuracy.

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In addition to the sampler design and operation, results of two field comparisons are presented. The sampler compares well with sand cone and core sample measurements in situations where those samplers can be used. In soils where rock fragment content is less than 15% there is good agreement between measurements made with this sampler and those from a core sampler. At higher rock fragment contents, the two measurement techniques give differing results. It is probable that in these cases the core sampler is less accurate.

INTRODUCTION

As forest practices become more site specific and intensive, soil characterization for management becomes increasingly important (Geist and Strickler, 1978). Bulk density, the dry mass of a unit volume of soil (SSSA, 1978), is an important characterization parameter because it gives an indication of soil compactness. As density increases, there is progressively greater restriction of root growth, aeration, infiltration, and hydraulic conductivity. All these factors affect soil productivity. A second important use of density information is in the conversion of laboratory measurements of fertility, water content, and biological activity from a mass basis to a volume or areal basis.

Several common characteristics of forest soils in the Pacific Northwest make the accurate determination of soil bulk density difficult. These include the occurrence of appreciable quantities of rock fragments and large roots, lack of areal uniformity in properties, and steep slope. The presence of rock fragments (material > 2 mm in diameter) generally leads to a field measured soil bulk density that is higher in value than the fine soil density (material <2 mm in diameter) alone. The difference between fine and whole soil bulk density in cultivated soils with few rock fragments is of minor importance (Elonen, 1971), but with increasing rock fragment content, it becomes significant in many forest soils (Childs, 1982; Terry et al., 1981). The difference is important to recognize because fine soil density is known to have a close relationship with root growth (Keisling and Smittle, 1981; Minore et al., 1969), soil aeration

(Keisling and Smittle, 1981), volumetric soil water content (Flint et al.[3]), and soil water release properties (Childs, 1982).

Spatial variability of soil density and rock fragment content is particularly important in forest soils. The common range of reported variability is represented in Table 1.1 by coefficients of variation. Although variability in total bulk density is low for the soil units shown, rock fragment variability can be much higher. This variability is of major concern for calculating volumetric soil properties. Therefore, density measurements in variable environments such as these must include enough information to calculate both total density, fine soil density, and rock fragment content.

The overall objective of this study was to design, calibrate, and test a bulk density sampler appropriate for forest soils of the Pacific Northwest. Design considerations included: 1) ease of portability, 2) ability to collectively sample bulk density and rock fragments, 3) the need to sample on steep slopes, and 4) the need to sample a large enough volume to achieve suitable measurement accuracy.

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[3] Flint, A. L., S. W. Childs, and D. H. McNabb. 1981. Effect of rock fragments and sieving on soil water release curves. In Agron. Abstracts, Am. Soc. Agron., Atlanta, GA. December, 1981.

Table 1.1. Coefficients of variation of % rock fragments and bulk density, various sampling units.

Sample unit	Coefficient of Variation in % Rock fragment	Bulk density	Author
Soil series	18-35	10-19	Irby,† 1967
Flood plain	309	10	Mollitor et al., 1980
Soil map unit	77-79	9-14	Wicherski,‡ 1980
Seedling nursery		12-27	Terry et al., 1981
Blue Mountains		8-10	Geist & Strickler, 1978
Red pine stand		4	Alban, 1974
Red pine stand		8	Mader, 1963

†Irby, John Ferman, Jr. 1967. A study of the sampling variability of total nitrogen, bulk density, and gravel content in two forest soils. M.S. Thesis, University of Washington. Seattle, Wash., 52 pp.

‡Wicherski, B. P. 1980. Analysis of variability of some forest soils of southwestern Oregon. M.S. thesis. Dept. of Soil Sci., Oregon State Univ., Corvallis, Or. 151 pp.

CURRENT TECHNIQUES

The measurement of bulk density and rock fragment content usually may be accomplished by using one of four general techniques: clod, core, radiation, and excavation methods (for detailed methodology see Blake, 1965a). Each of these is quite useful in certain soils and situations, but all have limitations if universally applied (Shipp and Matelski, 1965). The limitations can be severe if both bulk density and rock fragment content are measured using only one method, particularly when measurements are made on gravelly or skeletal soils (Blake, 1965a; Shipp and Matelski, 1965; Terry et al., 1981).

Density measurements with the clod method use mass and volume of a natural clod or large ped. This method often yields a high bulk density value because the measurement excludes the natural pore space between clods and between clods and rock fragments (Blake, 1965a; Shipp and Matelski, 1965). Values may also be higher because of bias towards firm, compact clods capable of withstanding disturbance during measurement. Although the clod can be broken up and sieved to determine rock fragment content, this measured value is often low (Shipp and Matelski, 1965).

The core method uses the mass of the soil removed from the volume of a hammer driven core cylinder (Blake, 1965a). The core method may not adequately estimate the soil bulk density of rock fragment content in forest soils because of impedance of the core cylinder by rock fragments and large woody roots (McClintock, 1959; Shipp and Matelski, 1965). An advantage of the core method, however, is that it provides an "undisturbed" sample which, in preserving natural structure, can be useful for other laboratory measurements. The spatial variability of rock fragments, even in skeletal soils, allows a core sample to be taken by finding areas of low rock fragment content. This type of sampling is less representative because it prevents proper random sampling, but does provide an undisturbed sample.

The radiation method of measuring bulk density (Blake, 1965a) employs either of two techniques: scattering or transmission of gamma radiation. The scattering technique using a single probe samples a spherical soil sample around the probe. The diameter of the sphere of measurement changes from 200 to 750 mm depending on the probe, soil, and water content. The transmission technique, typically using two probes, measures the fraction of radiation transmitted through a single, thin layer of soil, and also is dependent on the probe, soil, and water content (Blake, 1965a; Vomocil, 1954). Both techniques must be corrected for rock fragment content and water content since they average the density of the fine earth (including organic matter), rock fragments, and water content. A correction for water content and rock fragments using the scattering technique in nonhomogeneous soils is difficult due to the large, variable sample size.

In the excavation method, density is determined by dividing the mass of soil excavated from an irregular hole by the volume of that hole. The volume of the hole is determined by filling it with a material of known density or volume, usually water or sand.

Use of water requires that the hole be lined with an impermeable, flexible liner (A.S.T.M, 1982a; Shipp and Matelski, 1965; Howard and Singer, 1981), which may be subject to rupture in gravelly soils. Since these techniques require the surface to be level, a bench must be cut into soils on sloping terrain. Since soil horizons generally form parallel to the soil surface, proper sampling becomes difficult, if not impossible, for shallow surface horizons on sloping terrain (Alexander, 1977).

The sand cone excavation technique, which was designed specifically for gravelly soils (Blake, 1965a) was used extensively in the development of the new sampler. In the sand cone procedure the soil is excavated and a weighed sand dispenser inverted over the irregular hole. A valve is opened, and sand is allowed to flow freely until the hole and calibrated funnel covering the hole are filled. The dispenser is reweighed and the weight of sand used is converted to volume by dividing the weight by the bulk density of the sand. The volume of the calibrated funnel is subtracted giving the volume of the irregular hole. A significant problem with this technique is compaction of sand during the measurement. The ASTM procedure (A.S.T.M., 1982b) specifies the use of sand that varies in bulk density by less than one percent. Merriman (1958), however, found a 2% error in volume caused by sand compaction. Tavenas et al. (1973), in a review of test procedures for measuring maximum and minimum densities of sand, found coefficients of variation to be 2.2 and 2.0% respectively and concluded that variation of 2.5% would be an acceptable standard for the measurement of maximum (compacted) or minimum (free flowing) density. Gravimetric conversions to volume using the weight and bulk density of sand used are also subject to errors of scale resolution and stability in the field. The sand cone technique is limited to moderate slopes because of the natural angle of repose for free flowing sand and the instability of the apparatus. Level benches may be dug, but this leads to the aforementioned sampling problems. A final limitation for sand cone measurements is sample size. ASTM specifications in the procedure acknowledge the small size of the irregular hole and limit sand cone measurements to soils with rock fragments <50 mm in diameter.

SAMPLER DESIGN

The "bead cone" design, which is a modification of the sand cone, was derived while considering the limitations of the other four bulk density measurement techniques. The major needs for improvement were to remove slope limitation, and increase the sample volume and rock fragment size that could be sampled. To further improve accuracy a direct reading volume determination and surface calibration were incorporated in the design. A comparison of the features of the sand cone and the bead cone is summarized in Table 1.2.

The bead cone apparatus (Fig. 1.1) is constructed of 10 mm thick clear plexiglass. All critical points are attached with machine screws with some smaller pieces welded with plexiglass cement. The four major components of the bead cone apparatus are the beads, the bead reservoir, the sloping reservoir bases, and the base plate. The beads are light- weight epoxy spheres (Eccospheres, size EP-404, Emerson and Cumming, Canton, Mass.), ranging from 3.0 to 6.3 mm in diameter with a bulk density of .24 Mg m^{-3}. The bead reservoir is 500 mm tall with a volume of 1.125 x 10^7 mm^3. A scale is attached to the bead reservoir for direct measurement of the volume of beads used.

Three base reservoirs and adaptor plates allow for measurement on shallow to steep slopes. The reservoirs are attached to the bead reservoir with eye bolts and wing nuts which allow for easy transit and on-site reassembly. The three reservoirs are constructed with the same basal area of 5.75 x 10^4 mm^2, which allows for equal sample size (up to 1.5 x 10^7 mm^3) at the same depth when using different bases on various slopes. The base plate anchors and houses the respective adapter plate for each base reservoir. In order to retain loose soil or beads when measurements are taken on steeper slopes, the base plate has four sides 80 mm tall. On steep slopes the base plate can also be anchored to the soil with large spikes to increase stability.

Table 1.2. Comparison of measurement characteristics of the sand cone and bead cone.

Factor	Sand Cone	Bead Cone
Slope	0-40%	0-100%
Sample volume	$3.0 \times 10^6 mm^3$	$1.5 \times 10^7 mm^3$
Rock fragment size	Up to 50 mm in diameter	Up to 160 mm in diameter
Volume determination	Gravimetric conversion	Direct reading
Surface calibration	None specified	Recommended
Fill material	Disposable sand	Recycled beads
Portability	Can become heavy	Bulky but light

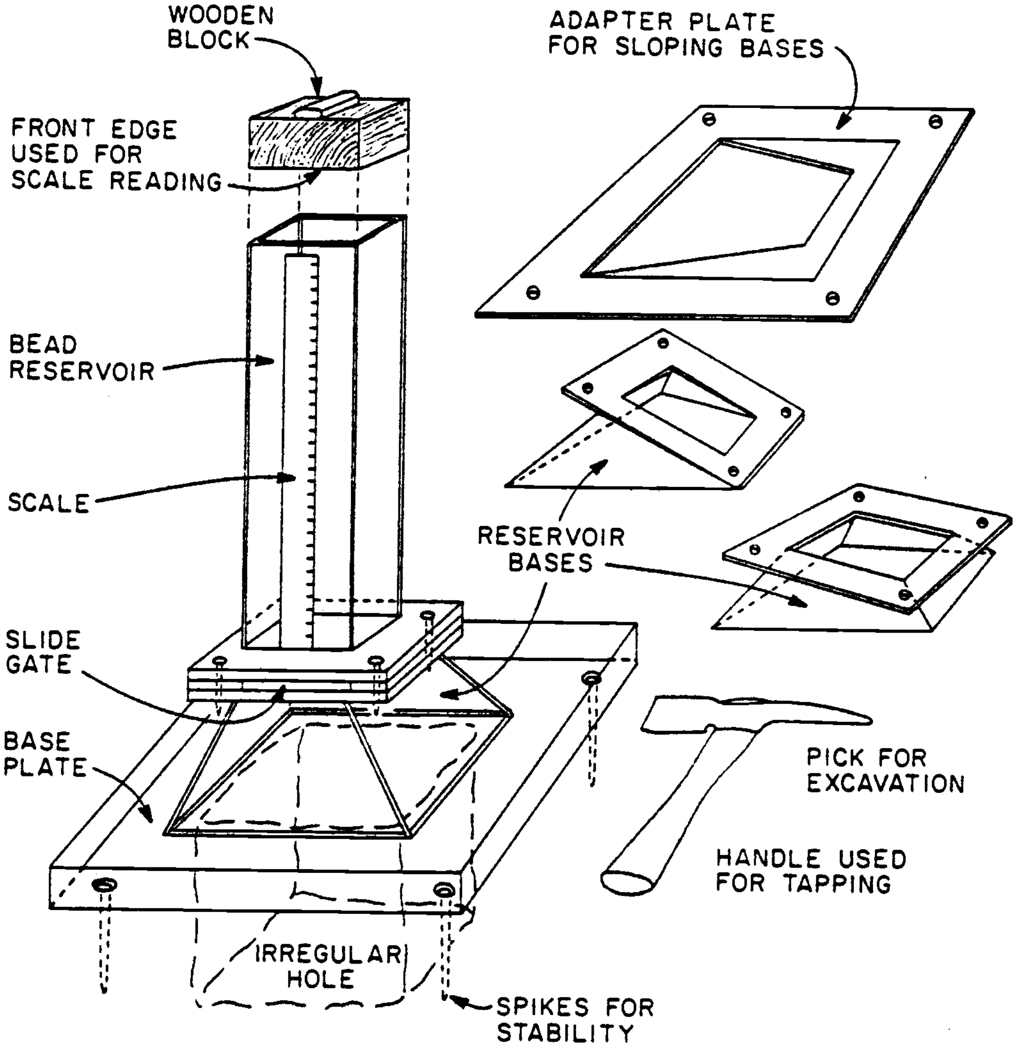

Figure 1.1. Bead cone device used for measuring the volume of an irregular hole.

BEAD CONE CALIBRATION AND MEASUREMENT PROCEDURE

The beads, as with sand, are subject to compaction when jarred. To determine the measured volume errors, a wooden box was constructed using the approximate dimensions of a sample hole. The bead cone apparatus was then run through a series of trials using different compactive efforts. Actual compaction was accomplished by tapping the sides of the apparatus before taking each reading. A similar compactive technique was successfully used by McLintock (1959) to calibrate the packing density of sand.

When there is no tapping or jarring of the apparatus during the measurement, the calculated volume is in error by less than 1% (Fig. 1.2). If, however, the sides of the bead chamber and base reservoir are tapped after the beads have fallen into the box but before the second volume reading is taken, there could be an error of up to 6%. The calibration was then rerun with the sides of the bead chamber being tapped before the first reading and before the second reading. Tapping the apparatus 10 times before the first reading and 10 times before the second reading gave the best results, with less than .5% error in volume (Fig. 1.2).

Field operation.

Based on field trials and calibration, the following is a procedure recommended for making bead cone density measurements. The procedure can be divided into two parts: steps 1-5 determine the

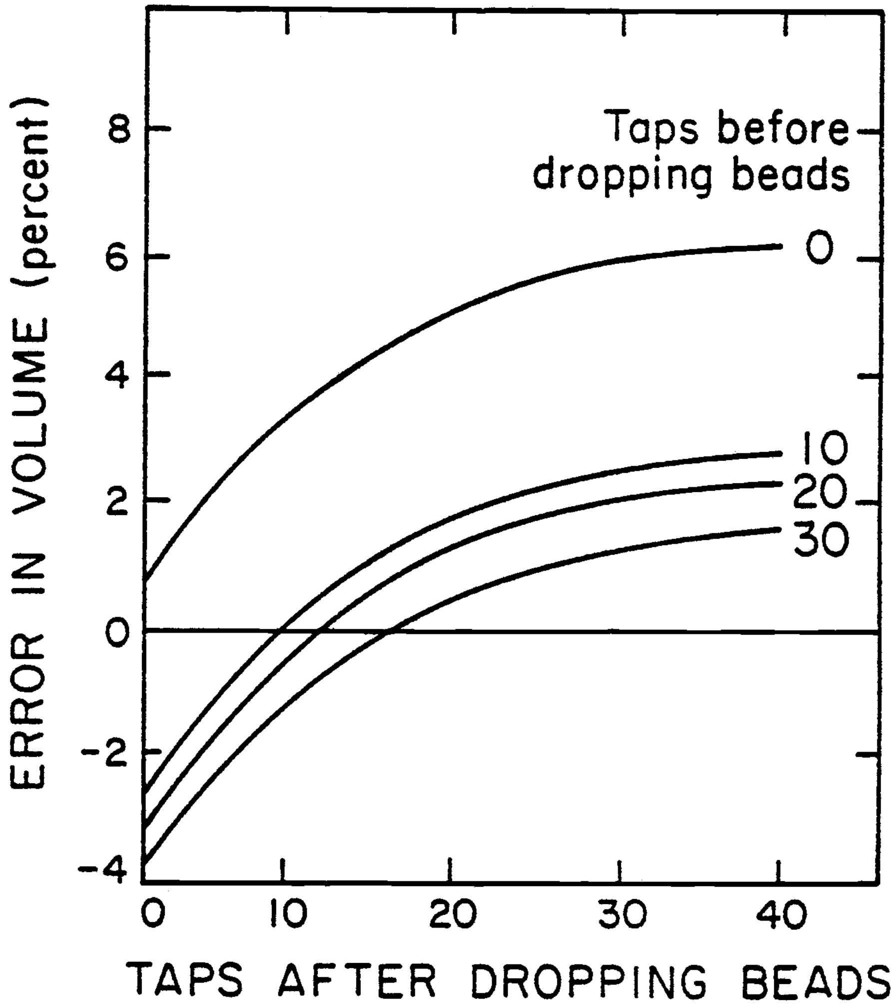

Figure 1.2. Error in measurement of fixed volume using different compactive efforts. Fixed volume is $8.5 \cdot 10^{-3} m^3$.

volume of the base reservoir and the irregularity of the soil surface, while steps 6-8 determine the volume of the irregular hole.

1. Prepare a relatively planar soil surface that maintains the natural slope and allows the anchored base plate to sit flush with the soil surface.
2. Select and attach the appropriate base reservoir and adapter plate to the bead cone.
3. Fill the bead reservoir and tap the sides 10 times to compact the beads. Read the volume from the scale on the bead reservoir and then pull the slide gate, allowing the beads to flow into the base pyramid on top of the soil surface.
4. Recompact the beads by tapping the sides 10 times and read the new volume. The difference in volumes is the volume of the base pyramid, as well as any irregularity of the planar surface. A truly planar surface is difficult to obtain. During our field experiments on 25 forest soils we found the surface calibration to vary ±3.6 mm^3/mm^2.
5. Once the surface calibration is complete remove the apparatus and the beads from the soil surface leaving the anchored base plate in place. A light weight portable vacuum cleaner was used to pick up the beads for reuse. Once vacuumed up the beads were placed in a mesh bag and shaken to remove any loose soil particles from the beads.
6. (a) Excavate the hole, store the soil removed, and place the bead cone on the base plate.

(b) The soil removed can be weighed in the laboratory or in the field. The soil weight approached 1.5 Mg in our study and required a scale resolution of 0.002 Mg to maintain greater than 0.5% accuracy.

7. Fill the bead reservoir, tap the sides to compact the beads, and take a new reading. Pull the slide allowing the beads to flow into the hole. Under most circumstances the entire bead chamber will empty into the hole. Replace the slide, refill the bead chamber, recompact the beads, and read the volume. Pull the slide again, allowing the beads to fill the remainder of the hole and the base reservoir. Recompact the beads and read the final volume.
8. The volume of the irregular hole is determined by summing the total volume of beads required to fill the excavation and base reservoir and subtracting the surface calibration.

FIELD TESTS

Two field experiments to test the bead cone were conducted during the summer of 1980. In the first, the bead cone and sand cone were compared on the Price-Ritner complex (fine Dystric Xerochrept, clayey- skeletal Dystric Xerochrept) on 20-30% slopes in the MacDonald Experimental Forest near Corvallis, Oregon. In the second study, bead cone measurements were compared with data from 76 mm length, 76 mm diameter cores for 35 soil types in Southwest Oregon. To compare the beadcone and sand cone ten points were selected in a 0.2 ha plot. Total density, fine soil density, and volumetric rock fragment content were measured or calculated and statistically analyzed. The volumetric rock fragment content was determined from the gravimetric content of and rock fragment bulk density, which is the actual volume per unit weight rock fragments would displace in the soil. Rock fragment bulk density was determined from rock fragment particle density and porosity, which were determined by water pycnometry (Blake, 1965b). Porosity was determined on the same samples by measuring water content of rock fragments after saturating the samples in water under a vacuum. On soils with high rock fragment contents, cores were difficult to obtain. Often, they could only be collected after several attempts, usually when an area was found with fewer rock fragments.

Total soil density, fine soil density, and volumetric rock fragment content measured using the sand cone appear to be more variable but were not statistically different from results obtained with the bead cone apparatus (Table 1.3). Coefficients of variation

Table 1.3. Means and coefficients of variation for the beadcone and sandcone on the Price-Ritner complex.

	Beadcone		Sandcone	
	$\overline{X}$	C.V.	$\overline{X}$	C.V.
Total soil density Mg m^{-3}	1.28	8.8	1.40	11.9
Fine soil density Mg m^{-3}	.97	7.4	1.04	8.5
Volumetric rock fragment percent	18.9	43.5	23.0	47.0
Volumetric water content percent	30.4	9.9	32.6	10.8

There is no significant difference between the beadcone and sand cone. There is a significant difference ($.05 > p$) between total and fine soil density using either technique.

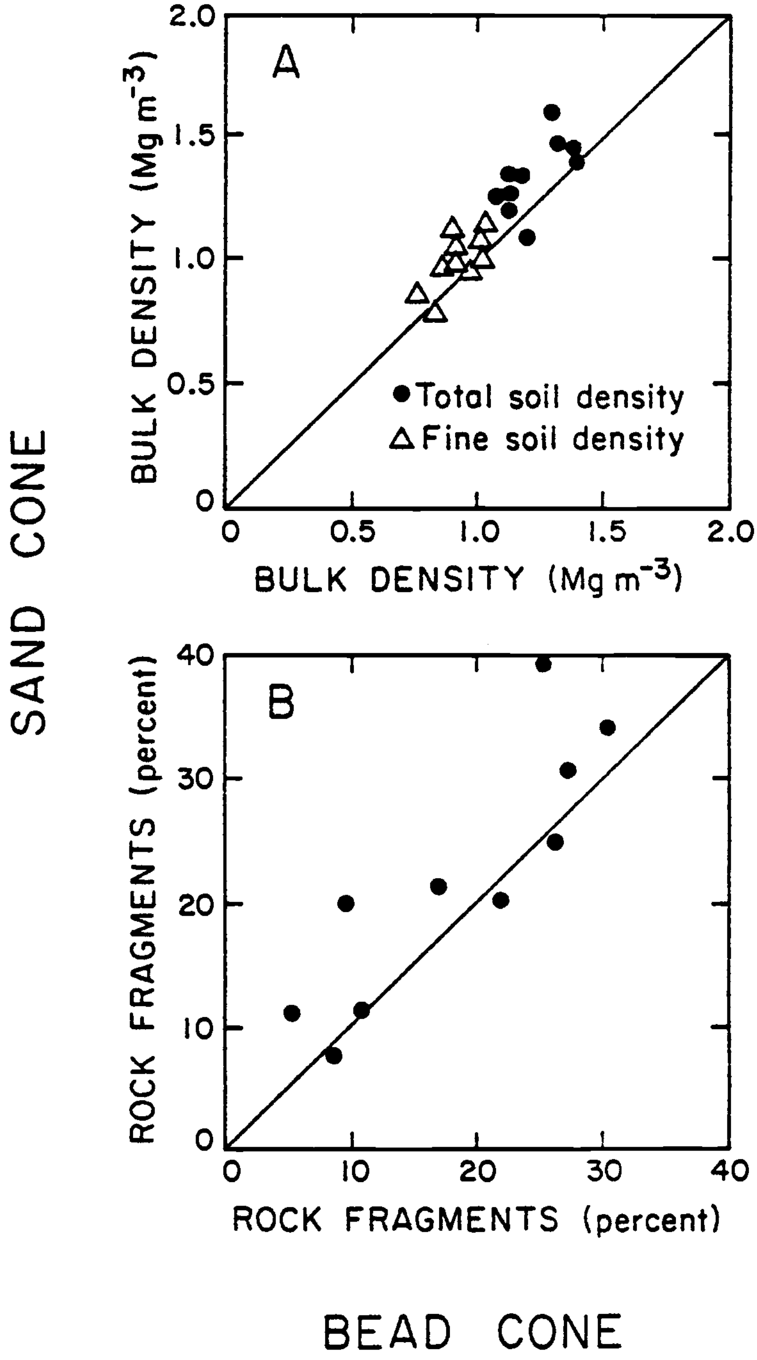

Figure 1.3. Sand cone measurements versus bead cone measurements for bulk density and rock fragment percentage for the Price-Ritner complex.

measured for the various properties are similar to other literature values (Table 1.1). Our data do show that correction of total density to a fine soil basis (Table 1.3) has a large effect which may well be important in interpretations based on density data.

The results of the second experiment (Fig. 1.4) show that the bead cone and core sampler data are quite different and do not correlate well (r^2 values of 0.43, 0.52, and 0.53 for total soil density, fine soil density, and rock fragment content, respectively). Since core samples became more difficult to obtain on soils with high rock fragment contents, we felt that the core samples might be in error beyond some rock fragment content value. Because the core sampler and bead cone should give the same results in soils with few rock fragments, we attempted to separate the data where soils with increasing rock fragment content would cause a failure in the core sample measurement. Figure 1.5 shows the results of a succession of regression calculations using soils with increasing rock fragment content. The value of 15% best separates the data set because it maximizes the sum of 1) the coefficient of determination relating fine soil densities measured with the two samplers, and 2) the coefficient of determination relating the total soil densities. Correlation between total bulk density and fine bulk density was improved (r^2 = .81 and .79 respectively) when only those soils with less than 15% rock fragment content were considered. It was assumed that the corer was sampling accurately in soils with rock fragment contents up to 15% and inaccurately above that point. This assertion seems reasonable given the small sample size of the corer and the known large variation in rock fragment distribution within a given soil type.

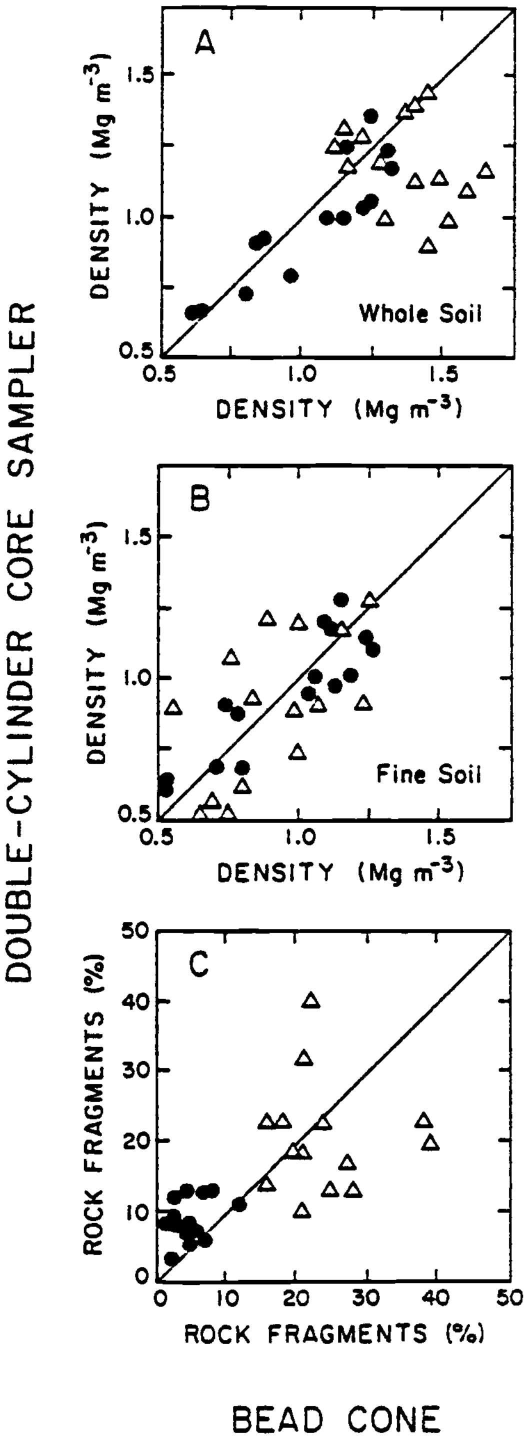

Figure 1.4. Soil measurements determined by 76 mm diameter core versus that by the bead cone for 30 locations in southwestern Oregon. The soils are stratified into two groups, those with <15% rock fragments (●) and those with >15% rock fragments (△) by volume.

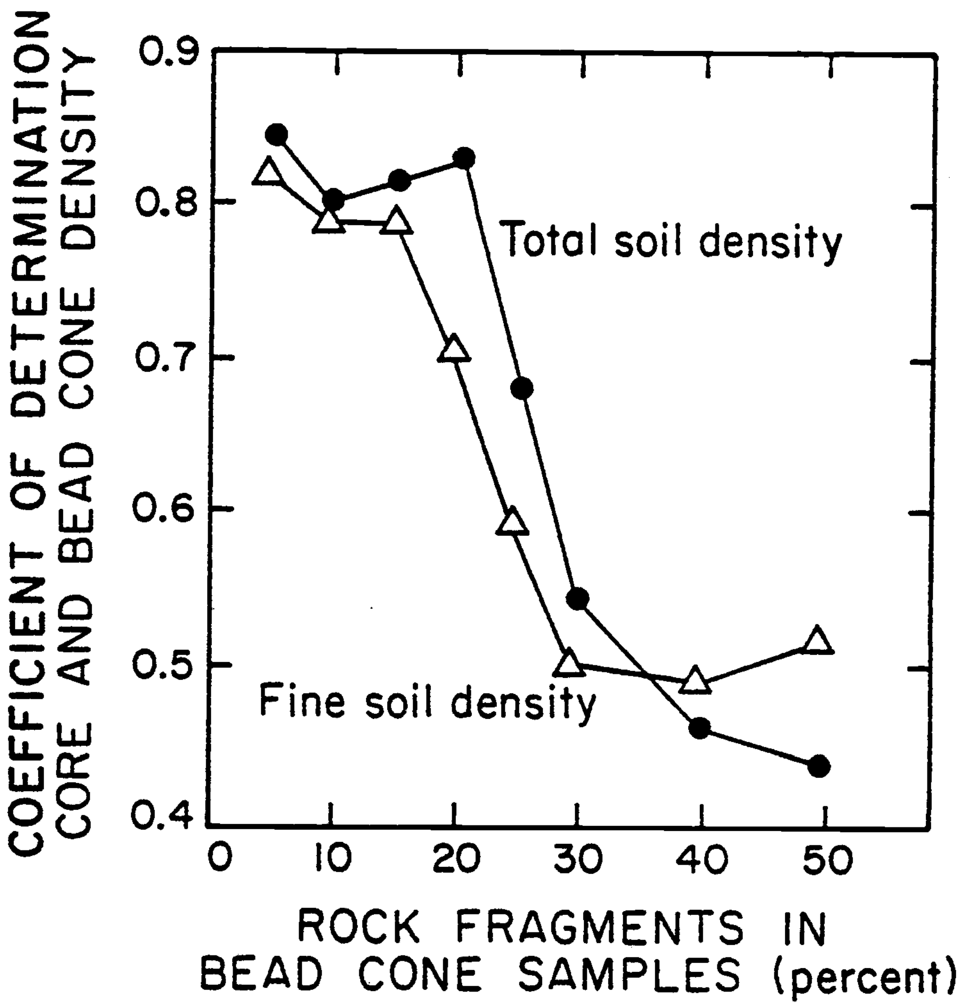

Figure 1.5. Correlations between soil density determined by core samples and bead cone apparatus versus rock fragment content in bead cone sample.

CONCLUSIONS

The bead cone method outlined in this report is a modification of the sand cone irregular hole excavation technique used for measuring soil bulk density. The technique has been devised so that it can be employed on steep, remote sites with appreciable rock fragment contents. The bead cone apparatus was designed to measure the volume of an irregular hole with an accuracy of 1%. It also samples a large enough volume to allow measurement of rock fragments up to 160 mm in diameter. The sampler requires initial calibration in order to establish its exact dimensions and the packing behavior of the epoxy spheres used to measure volume. Once this calibration is established, the sampler can be used without daily calibration since calibration constants do not change with time.

Two field experiments were conducted to compare the bead cone with a sand cone and a 76 mm length, 76 mm diameter corer. Sand cone experiments were performed in a situation where both samplers could be used and both gave similar results. It can therefore be concluded that, when slopes are sufficiently gentle and rock fragments are less than 50 mm in diameter, either sampler can be used. In an experiment comparing bead cone and corer measurements, it was found that corer measurements compared well with bead cone results only when the rock fragment content was less than 15%. We conclude that the bead cone is a useful sampler for density measurements in situations where rock fragment content is high and slopes are steep. The sampler can be used in less severe conditions but may be less convenient than the corer when rock fragment contents are low.

CHAPTER 2

PHYSICAL PROPERTIES OF ROCK FRAGMENTS AND THEIR EFFECT ON AVAILABLE WATER IN SKELETAL SOILS

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Physical Properties of Rock Fragments and Their Effect on Available Water in Skeletal Soils[1]

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ABSTRACT

Water retention was measured in skeletal and nonskeletal forest soils at forty locations in southwest Oregon on nine parent materials. The net effect of rock fragments is a reduction or dilution of the total water holding capacity because of the net reduction in total porosity. The amount of available water was, however, found to be significantly influenced by the quantity and physical properties of the rock fragments contained in the soil. Particle density, porosity, bulk specific gravity, and water release characteristics of rock fragments were examined to quantify their effect on water retention. Rock fragment porosity ranged from 12 to 60%, supplied 15% of

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the total available water on the average, and accounted for 2 to 52% of the measured variation in whole soil available water.

Linear regression models, developed to predict water content based on soil physical properties, proved to be of little value when applied to the large range of parent materials encountered. Furthermore, the parameters needed to predict available water content were more difficult to obtain than the direct measurement itself. In order to use the direct measurement technique, an estimate of the variability of total soil density and volumetric rock fragment content is required for skeletal soils.

INTRODUCTION

Extensive research is currently being conducted to quantify the physical environment for reforestation in southwest Oregon. The majority of soils in this region are skeletal with limiting moisture regimes. This paper presents results of an investigation into the measurement and estimation of soil physical properties and available soil water. Available water supply per unit volume is defined as that water stored in the root zone after drainage has reached a negligible rate minus any water which remains in the soil root zone at the driest part of the year.

Available water becomes quite important in the skeletal soils of this region for two reasons. During the characteristically long, dry summers, seedling survival depends on spring and early summer water use for growth and budset before midsummer dormancy to withstand late summer heat stress events and eventual winter cold. Lower water holding capacity in skeletal soils due to large rock fragment contents can be deleterious if a water supply adequate for seedling budset is not available. The second important factor is the ameliorating effect water can have on heat stress events. The higher heat capacity of water allows wet soils to receive higher radiation loads without greatly increasing soil surface temperature. This can be particularly beneficial during short or diurnal heat stress events.

Although slope, aspect and ground cover directly affect seasonal timing of water use, the most important factors affecting total water retention are related to soil properties. We studied these properties in two phases. First, the physical properties important in predicting water retention were identified and their range and variation determined. Second, techniques were developed for adequate sampling of these properties on soils derived from nine common parent materials in the region.

The major objectives of this research were to:

1. Quantify available water supply for transplanted seedlings in 40 skeletal and nonskeletal soils in southwest Oregon.

2. Quantify the soil physical properties of the root zone for these same soils.

3. Identify field and laboratory techniques for measurement of water supply for specific sites or estimation of water supply for planning purposes.

Measurement and prediction of available water is the focus of the work reported here but it should be remembered that measurements of soil density, rock fragment percentage, and water supply have a number of uses in the quantification of forest site quality. Available water supply is a good first measurement because it is important to both the heat and moisture budgets for a site. In reforestation planning, water supply should be measured first and then the need for site modifications (e.g. soil mulches, artificial shade, vegetation control) can be considered for water conservation. Our definition of available water supply, which is consistent with this management approach, allows available water supply to increase beyond what we measure if summer rains occur. For planning purposes, rainfall input should be accompanied by a suitable probability figure.

The effects of soil layering are also of considerable importance in skeletal soils. In addition to the commonly observed effects of genetic or depositional layers increasing water retention (Clothier, Scotter, and Kerr, 1977), skeletal soils have irregular layers, voids, and weathering rinds around individual fragments which affect water flow and storage. These factors and the known spatial variability of rock fragments in skeletal soils (Flint and Childs, 1983) indicate that field measurement of available water may be easier than the detailed procedures required for accurate estimation.

A final facet of available water is the specification of the soil volume a given seedling can use. Once this decision is made, total water supply can be calculated and compared with expected demand to determine the adequacy of the supply. It is of note that this approach does not include any treatment of water use rate or timing effects on availability.

MATERIALS AND METHODS

A major factor to consider in designing an experiment with skeletal soils is the relative fragility of their structure. Although mechanical strength may be quite high, excavation of undisturbed soil monoliths or cores is quite difficult. For the soils of southwest Oregon, Flint and Childs (1983) found that cores 76mm in length and diameter provided accurate measurement of rock fragment content and fine soil density when rock content was less than 15% by volume. In rockier soils, excavation techniques which sample larger volumes were required. As a result, effects of soil structure on soil water retention are difficult to assess with laboratory measurements.

For this study, we felt it was important to do the following:

1. Develop a simple field method to measure available soil.

2. Use a technique to measure rock fragment content with sample volume large enough to include fragments up to 160mm in effective diameter.

3. Separate soil water content into two fractions: water retained in the fine earth and water retained in the rock fragments. This separation allows correction of small volume samples to reflect the average site proportions of fine earth and rock fragments.

4. Distinguish between fine and total soil density, for assessment of the soil's available water capacity.

5. Assess the range in rock fragment properties (particularly porosity and density) for the dominant rock types of southwest Oregon.

Forty sampling locations were selected in southwest Oregon covering nine soil parent materials and rock fragment contents ranging from 3 to 57%. Fourteen of the sampling sites were located near the modal profiles of the soil series. Parent materials were selected to cover the range found in southwest Oregon. These included granite, basalt, meta-sediment, alluvium, and volcanic ash with pumice. At each location three representative points were selected and sampled for field bulk density (BD_t) and rock fragment content. Samples were taken from the surface to 250mm depth to provide information about the seedling root zone. In most cases, this was not the taxonomic control section. A large volume bulk density sample ($0.001m^3$) was collected using a bead cone (Flint and Childs, 1983), with the excavated soil placed in a plastic bag for laboratory analysis. Duplicate moisture can samples were also taken at each point for laboratory analysis. The sampling was done in late August and early September, which would yield the lowest seasonal water content.

A separate sampling site was selected in close proximity to the other three points to estimate field capacity water content. A plastic cylinder was placed over a $0.65m^2$ area and filled with water to a depth of 0.15m. After the water infiltrated into the soil, the cylinder was removed and the soil surface was covered with plastic to prevent evaporation. Between 2 and 3 days later duplicate "field capacity" moisture samples were taken for laboratory analysis (Salter and Williams, 1965).

In the laboratory, bulk density samples were sieved through a 2mm screen to measure gravimetric rock fragment content (R_m). A sample of the rock fragments between 2 and 4.75mm was used to determine particle density using a water pycnometer (Blake, 1965). Air bubbles were removed from the rock fragment pores by placing the rock fragment particles in water and under a vacuum. The saturated samples were removed from the pycnometer and rolled in a damp towel to remove surface water, leaving the pores saturated (ASTM, 1977). The oven dry weight loss of the sample is a measure of the volume of water in pores, which, at saturation, is the pore volume. The bulk specific gravity of the rock fragments ($BD_{>2}$) is then calculated using their particle density ($PD_{>2}$) and porosity ($P_{>2}$).

$$BD_{>2} = (1-P_{>2}) \cdot PD_{>2} \qquad (1)$$

The volumetric rock fragment content (R_v) was then calculated for the bulk soil samples:

$$R_v = BD_t \cdot R_m \,/\, BD_{>2} \qquad (2)$$

The bulk specific gravity ($BD_{>2}$) is used rather than the particle density to calculate volumetric rock fragment content in order to include the volume of the pores within the volume of rock fragments. The exclusion of the pores by using particle density would yield an artificially low volumetric rock fragment content and an underestimate of fine soil density. Fine soil density ($BD_{>2}$) was calculated using equation (3):

$$BD_{<2} = BD_t(1-R_m)/(1-R_v) \tag{3}$$

The soil moisture samples were oven dried and sieved to determine rock fragment content. The water removed from the sample was partitioned into two different components, water contained in <2mm soil and water contained in rock fragments (Berger, 1976). Water retention of rock fragments is distinctly different from the <2mm soil and given the high variability of rock fragment content in the small moisture samples it was critically important to separate the two components. Ideally the rock fragments should be sieved and measured separately; however, this can be quite difficult if samples are wet or clayey. There could also be considerable water loss, especially for the "field capacity" sample, during the the process of sieving. If the soil could not be sieved then an estimate of water held by the rock fragments was made using an alternate procedure. Using data from several authors (Cochran[3]; Coile, 1953; Hanson and Blevins, 1979), a water release curve for rock fragments was developed to predict pore saturation percentage (S) of the rock fragments depending on their water potential (Fig. 2.1). The pore

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[3] Cochran, P. H. 1966. Heat and moisture transfer in a pumice soil. Doctoral Dissertation. Dep. Soil Science, Oregon State University, Corvallis, OR 97331.

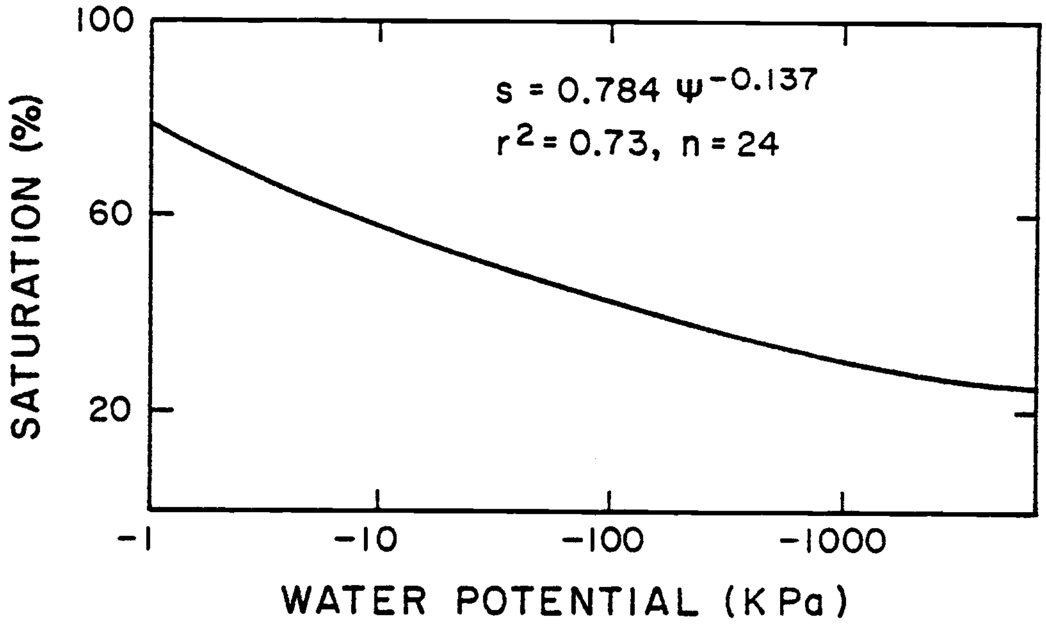

Figure 2.1. Water release characteristic curve for rock fragments 2.00 to 4.75 mm in diameter.

saturation percentage multiplied by the total porosity of the rock fragments ($P_{>2}$) yields the volumetric water content of rock fragments ($W_{>2}$). The water release curve for rock fragments was used in conjunction with a measurement or estimate of water potential to estimate the rock fragment water content at the time of sampling.

Once rock fragment water content was determined using one of the techniques above, the fine soil gravimetric water content ($W_{m>2}$) was determined from the moisture can samples using equation (4):

$$W_{m<2} = (W_{mt} - W_{>2} \cdot R_{ms})/(1-R_{ms}) \qquad (4)$$

where W_{mt} is the total sample gravimetric water content and R_{ms} is the gravimetric rock fragment percentage of the moisture sample can.

The volumetric water content of the whole soil (W_{vt}) was calculated using the two partitioned water contents from the moisture samples and rock and fine soil fractions obtained from the large volume bulk density sample:

$$W_{v<2} = W_{<2} \cdot BD_{<2} \cdot (1-R_v) \qquad (5)$$

$$W_{v>2} = W_{>2} \cdot R_v \qquad (6)$$

$$W_{vt} = W_{v<2} + W_{v>2} \qquad (7)$$

The two fractions are added together in equation (7) to give total volumetric water content. Average rock fragment content and fine bulk density of the large bulk samples were used to calculate total water content rather than the small moisture cans. This technique allows the higher variability of rock fragment content in small moisture cans to be ignored (Reinhart, 1961).

On 19 of our 40 locations, a tensiometer was used to measure water potential at field capacity when early spring water samples were collected. These measurements showed the water potential at field capacity to vary from -3 to -14.5 kPa (Table 2.1). On the other 21 samples we assumed the water potential at field capacity to be -10 kPa in order to calculate water content of the rock fragments from the equation in Figure 2.1. On all forty samples the seasonal low water potentials were assumed to be -3000 kPa. These assumptions were reasonable to use as the difference in volumetric water content with water potentials between our values of -3 kPa and -12 kPa for the rock fragment field capacity estimate varied by ±6% and an estimate between -1500 and -6000 kPa for the seasonal low would vary by only ±2.5%.

The technique outlined above was used to calculate volume average available water. The data gathered were analyzed to determine the importance of each physical measurement on the estimate of available water, and to determine if some parameters could be predicted knowing the values of others.

RESULTS

A summary of the physical properties used for calculation of soil water content for the 40 soil locations in southwest Oregon is given in Table 2.1. These values represent means of several measurements taken at each sample location. The correlations drawn from these data therefore relate soil types rather than individual soil samples. The data set has considerable range with coefficients of variation for rock fragment content, rock fragment porosity, clay content, and organic matter content greater than 40%. There are some expected trends relating various properties to parent materials. The ash soils are low density and have large rock fragment porosity whereas granitic soils are relatively high in density with low rock fragment porosity. It is noteworthy that the available water measurement shown in Table 2.1 is not highly correlated with any one column in the table; the relationship between water retention and soil properties is not straightforward in skeletal soils.

Linear correlations were performed for all measured variables (Table 2.2) to determine the relationships among various soil properties. These results show a number of low correlations. This was expected due to the range of parent materials and the fact that the data set consists of means rather than individual data points. It is of interest that total bulk density has a low correlation with rock fragment content ($r^2 = 0.18$, Table 2.2). At best total density was only marginally correlated with rock fragment bulk sensity, rock fragment porosity, and particle density ($r^2 = 0.54$, 0.48, and 0.36 respectively, Table 2.2). Apparently, the porosity of the rock

Table 2.1. Soil physical properties of southwest Oregon forest soils.

					Rock fragment properties			<2mm soil properties			Volumetric water content				
Soil name	Parent material	Total bulk density	Fine soil bulk density	Volumetric rock fragments	Particle density	Porosity	Bulk density	Organic matter	Clay	Sand	Seasonal low	Field capacity	Available water capacity	Percentage available water contained in rock fragments	Field capacity water potentials
		---$\mathrm{Mg\ m^{-3}}$----		--%--	$\mathrm{Mg\ m^{-3}}$		$\mathrm{Mg\ m^{-3}}$	-----gravimetric %----			-----------%---------			--%--	kPa
Illinois Valley	Serpentine	1.51	1.24	35.5	2.65	27.2	2.04	19.1	27.1	43.3	--	--	--	--	--
Prospect Sand	Alluvium	1.45	1.28	19.3	2.51	14.8	2.14	2.9	3.5	87.8	8.3	19.3	11.0	8.7	-5.0
M.U. 27	Breccia	1.19	0.88	25.5	2.64	25.6	2.10	12.3	11.5	62.9	10.3	19.1	8.8	18.2	--
M.U. 27	Breccia	1.14	0.70	40.8	2.52	43.7	1.75	11.0	10.8	63.4	12.3	22.4	10.1	42.8	--
M.U. 27	Breccia	1.21	0.97	22.6	2.75	34.0	2.05	16.3	15.9	50.7	12.0	23.6	11.6	15.2	--
M.U. 27	Breccia	1.14	0.79	36.7	2.56	47.5	1.74	10.9	15.3	54.7	15.1	28.5	13.4	39.2	--
M.U. 27	Breccia	1.15	0.81	33.9	2.54	39.4	1.82	11.0	12.9	58.1	12.8	28.4	15.6	23.6	--
M.U. 27	Breccia	1.24	0.92	27.2	2.63	26.6	2.08	10.1	12.4	61.1	9.2	27.3	18.2	9.7	--
Dumont Series	Andesite	1.02	0.90	16.2	2.46	31.8	1.68	12.1	16.2	46.8	15.9	26.9	11.0	14.7	--
Dumont Series	Andesite	1.25	1.05	22.5	2.50	23.1	1.92	12.0	19.1	45.9	--	42.8	--	--	-6.0
Laurelhurst Series	Andesite	1.18	1.16	3.5	2.51	32.5	1.83	9.3	30.8	34.6	20.7	37.3	16.7	2.1	--
Straight Series	Andesite	0.97	0.83	18.0	2.43	33.8	1.61	27.6	15.7	46.9	--	36.5	--	--	--
M.U. 51	Andesite	1.03	0.62	28.4	2.63	28.3	2.05	11.5	14.5	57.6	10.4	16.1	5.7	52.1	--
M.U. 51	Andesite	0.92	0.68	22.1	2.55	39.9	1.82	16.9	13.4	54.3	8.5	17.2	8.7	22.5	--
M.U. 51	Andesite	1.06	0.80	22.4	2.61	31.2	1.99	12.7	19.5	51.8	14.7	26.2	11.5	20.6	--
M.U. 51	Andesite	1.41	0.79	49.2	2.61	27.9	2.04	15.3	19.1	53.4	11.5	24.8	13.3	24.9	--
M.U. 51	Andesite	1.06	0.92	16.0	2.55	35.5	1.77	8.7	16.1	48.5	--	--	--	--	--
M.U. 51	Andesite	1.30	1.07	35.8	2.53	41.7	1.71	9.5	12.8	53.9	--	--	--	--	--
Vermisa Series	Metasediment	1.33	0.60	40.0	2.72	11.8	2.3	10.0	14.2	61.5	4.6	11.5	6.8	27.2	--
Vermisa Series	Metasediment	1.42	0.99	31.2	2.74	16.8	2.28	8.8	12.0	40.8	9.4	26.1	16.7	15.3	-2.0
Beekman Series	Metasediment	1.53	1.20	25.7	2.87	14.4	2.46	6.5	6.8	47.6	7.1	20.1	13.0	8.4	--
Beekman Series	Metasediment	1.34	0.89	37.9	2.59	20.8	2.05	9.1	19.5	45.2	9.4	24.7	15.2	11.7	-12.0
Kanid Series	Metasediment	1.13	0.80	23.5	2.61	17.1	2.16	12.1	13.7	57.3	8.0	22.6	14.6	16.8	-3.0
Tishar Series	Metasediment	1.37	1.23	17.7	2.61	18.5	2.13	8.4	12.5	55.6	12.1	25.7	13.5	6.7	-14.5
McGinnis Series	Metasediment	1.05	0.78	27.7	2.51	34.5	1.64	16.6	16.1	50.3	12.5	28.1	15.5	22.2	-5.5
Pollard Series	Metasediment	1.27	1.01	24.5	2.56	18.3	2.09	10.5	9.9	58.8	6.4	22.2	15.8	11.9	-5.0
Pollard Series	Metasediment	1.08	0.99	10.5	2.50	28.5	1.79	9.2	21.4	45.9	13.7	30.5	16.7	5.7	-13.0

Table 2.1, continued.

					Rock fragment properties			<2mm soil properties			Volumetric water content			Percentage available water	Field
Soil name	Parent material	Total bulk density	Fine soil bulk density	Volumetric rock fragments	Particle density	Porosity	Bulk density	Organic matter	Clay	Sand	Sea-sonal low	Field capacity	Available water capacity	contained in rock fragments	capacity water potentials
		---Mg m^{-3}	----	--%--	Mg m^{-3}		Mg m^{-3}	-----gravimetric	%----		-----------%	---------		--%--	kPa
Pollard Series	Metasediment	1.29	1.15	14.3	2.56	19.7	2.06	10.2	24.9	43.1	13.8	32.3	18.4	5.3	-6.5
M.U. 82	Metasediment	1.38	0.81	40.2	2.67	17.9	2.24	11.5	8.7	38.1	4.7	21.9	17.2	18.3	--
M.U. 82	Metasediment	1.22	0.82	31.8	2.74	23.9	2.09	12.7	11.8	42.9	6.8	26.0	19.2	12.8	--
Turkey Creek	Metasediment	1.42	1.17	23.5	2.62	13.8	2.26	7.8	10.0	46.6	3.6	22.9	19.3	6.3	-4.0
Limestone Creek	Granitic	0.98	0.88	6.9	2.78	16.5	2.35	19.1	5.2	71.8	8.6	23.0	14.4	4.1	--
Siskiyou Series	Granitic	1.32	1.23	10.0	2.62	17.3	2.17	5.1	7.1	67.9	4.2	19.5	15.2	4.1	-8.5
Holland Series	Granitic	1.32	1.27	5.5	2.62	16.5	2.19	4.4	7.1	70.0	4.0	22.5	18.5	1.6	-3.5
M.U. 42	Tuff and Breccia	0.87	0.80	11.5	2.51	58.1	1.46	17.2	13.0	49.5	17.2	30.9	13.7	12.4	-6.5
M.U. 42	Tuff and Breccia	0.95	0.91	5.1	2.64	40.4	1.72	17.5	21.4	37.1	18.2	36.8	18.5	4.8	-6.0
Mt. Mazama	Pumice and Ash	0.69	0.63	12.3	2.33	52.2	1.11	22.6	4.3	50.8	10.5	22.6	12.1	16.2	-10.5
Mt. Mazama	Pumice and Ash	0.72	0.66	32.2	2.13	60.3	0.84	6.8	3.4	57.6	13.8	34.0	20.2	24.7	-8.0
Geppert Series	Basalt	1.42	1.07	55.7	2.60	37.1	1.75	20.1	11.6	53.4	12.6	28.2	15.6	36.3	-4.5
Witzel Series	Basalt	1.65	1.31	40.8	2.66	23.3	2.14	6.6	25.1	31.3	10.2	32.9	22.7	21.1	-5.5
	Means	1.20	0.94	25.1	2.58	29.1	1.94	12.1	13.9	52.5	10.7	26.0	14.5	15.1	-7.0
	Standard Deviation	.21	.20	12.3	.12	12.2	.32	5.1	6.0	10.8	4.1	6.4	3.8	10.2	-3.4
	Range	.96	.71	52.2	.74	48.5	1.62	24.7	27.4	56.5	17.0	31.4	17.0	40.3	-13.0

Note: M.U. 51 and M.U. 27 are soil map units from the Umpqua National Forest, M.U. 42 is from the Rogue River National Forest and M.U. 82 is from the Siskiyou National Forest.

Table 2.2. Correlation matrix for soil physical properties and water content; r values are given to indicate positive or negative correlation.

Variable	BD_t	$BD_{<2}$	R_v	$PD_{>2}$	$P_{>2}$	$BD_{>2}$	Clay	Sand	OM	WP	FC	AWC
BD_t	40	0.688	0.428	0.596	-0.690	0.737	0.094	-0.071	-0.449	-0.440	-0.176	0.217
$BD_{<2}$	40	40	-0.209	0.274	-0.482	0.433	0.106	-0.044	-0.426	-0.142	0.196	0.456
R_v	40	40	40	0.118	0.029	0.068	-0.055	-0.081	0.014	-0.186	-0.190	-0.061
$PD_{>2}$	40	40	40	40	0.648	0.873	0.048	-0.057	-0.101	-0.339	-0.399	-0.086
$P_{>2}$	40	40	40	40	40	-0.902	0.029	-0.127	0.397	0.651	0.363	-0.049
$BD_{>2}$	40	40	40	40	40	40	0.013	0.112	-0.354	-0.574	-0.439	-0.055
Clay	40	40	40	40	40	40	40	-0.598	0.184	0.613	0.489	0.058
Sand	40	40	40	40	40	40	40	40	-0.218	-0.422	-0.537	-0.422
OM	40	40	40	40	40	40	40	40	40	-0.230	0.205	-0.230
WP	35	35	35	35	35	35	35	35	35	35	0.733	-0.001
FC	37	37	37	37	37	37	37	37	37	37	37	0.679
AWC	35	35	35	35	35	35	35	35	35	35	35	35

† r's in upper triangle, N's in diagonal, contingent N's in lower triangle.

‡ BD_t = field bulk density, $BD_{<2}$ = fine soil bulk density, R_v = volumetric rock fragment content, $PD_{>2}$ = particle density of rock fragments, $P_{>2}$ = porosity of rock fragments, $BD_{>2}$ = bulk density of the rock fragments, Clay = gravimetric percentage clay in <2mm mineral soil, Sand = gravimetric percentage sand in <2mm mineral soil, OM = organic matter percentage in <2mm soil, WP = volumetric water content percentage at the seasonal low, FC = volumetric water content percentage at field capacity, AWC = volumetric available water capacity percentage (FC-WP).

fragments is as important as the total volume when the population consists of soils high in rock fragments. Fine soil density also correlated marginally with total soil density ($r^2 = 0.48$, Fig. 2.2). These two results are not surprising, since the theoretical relationship between fine soil density and total bulk density is as follows:

$$BD_t = BD_{<2} + (BD_{>2} - BD_{<2}) \cdot R_v \qquad (8)$$

which shows a complex interrelationship rather than a single important factor.

A significant factor in total bulk density and water content is the bulk specific gravity of the rock fragments. The bulk specific gravity, which is related to particle density with a positive correlation $r^2 = 0.77$ (Fig. 2.3), accounts for the effect of natural porosities included in rock fragments. An increase in particle density yields an increase in bulk specific gravity and therefore a decrease in rock fragment porosity.

Rock fragment porosity is also important to water retention and total available water of most soils measured. Rock fragments contributed an average of 15% of the total available and ranged from 1.6 to 52.1% (Table 2.1). Water content was, however, difficult to predict by any one factor (Table 2.2). There are several factors that work in conjunction with each other to determine the water content at any particular time. Multiple regressions were used to determine which factors were most useful for estimating water retention at the seasonal low and field capacity (Table 2.3).

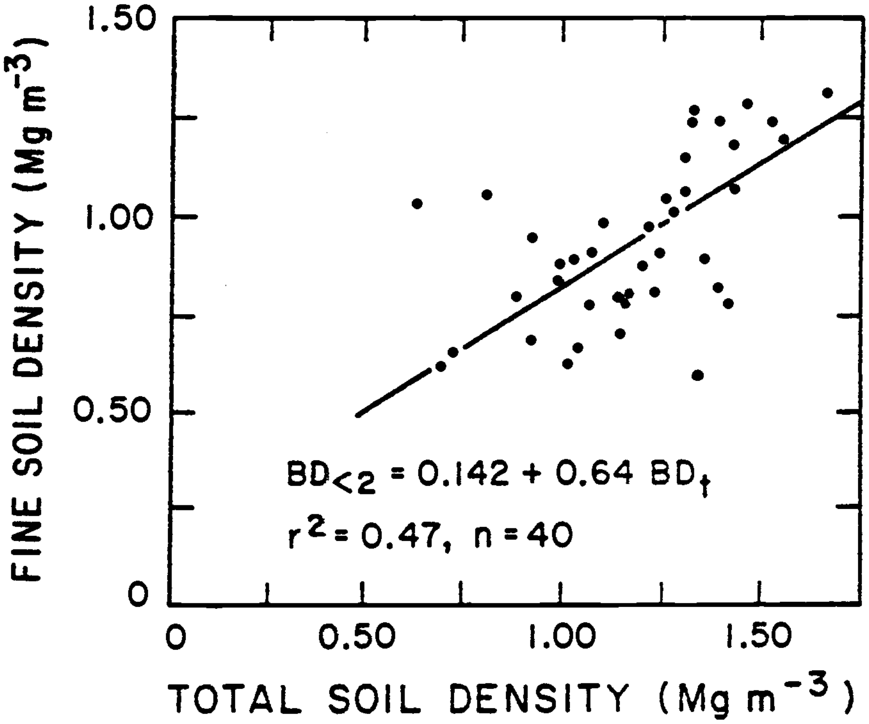

Figure 2.2. Fine soil density versus field bulk density for forty forest soils in southwest Oregon.

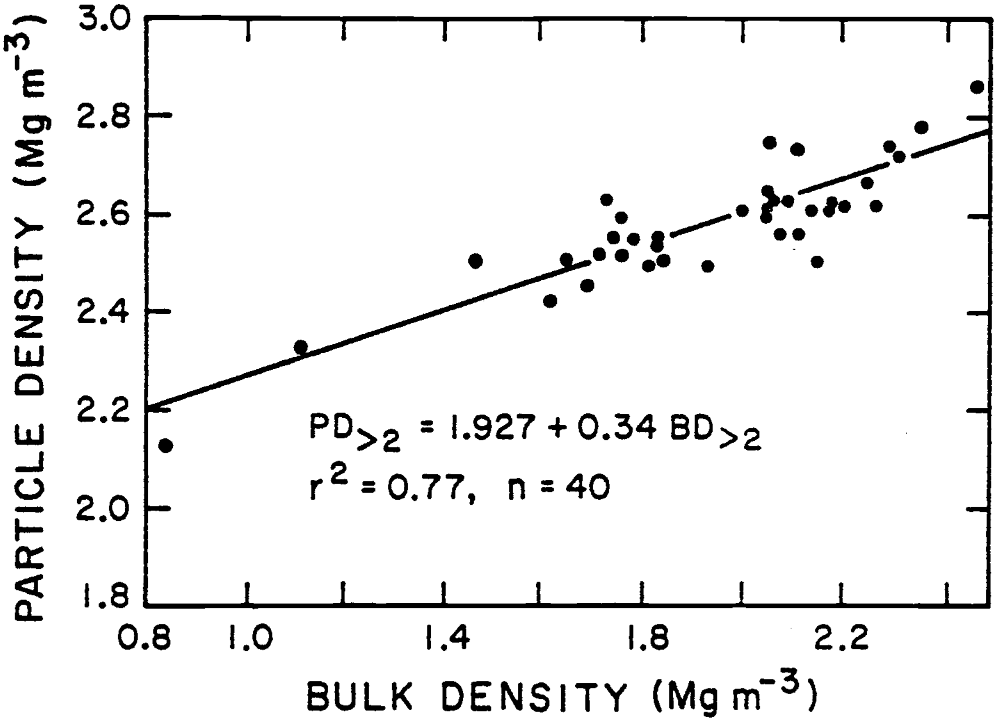

Figure 2.3. Particle density versus bulk density for rock fragments 2.00 to 4.75 mm in diameter.

The rock fragment porosity and clay content gave an r^2 of .76 for predicting seasonal low while the rock fragment porosity and sand content gave an r^2 of .38 for predicting field capacity. These two parameters made the most significant contribution of any two parameters to their respsective water contents and indicate the importance of clay in holding water at low potentials (seasonal low) and its lesser importance at high potentials (field capacity). The addition of total bulk density, fine bulk density, bulk specific gravity, volumetric rock fragment content, organic matter content, and sand or clay increased the r^2 for the seasonal low to 0.82 and the field capacity to 0.70. In soils where the rock fragment porosity is low, the effect of rock fragment content should be quite important since a primary factor affecting water supply would be the decrease in water storage volume, however, in soils with increasing rock fragment porosity, the total rock fragment content becomes less important than knowing rock fragment porosity.

Table 2.3. Multiple regression of soil physical properties† to predict available water capacity (AWC), water content at field capacity (FC), and water content at the seasonal low (WP).

$WP = .405 \cdot CL + .202 \cdot P_{>2} - .480$	$r^2 = .76$
$WP = .452 \cdot CL + .192 \cdot P_{>2} - 6.158 \cdot BD_t + 8.52 \cdot BD_{<2} + .037 \cdot R_v + .040 \cdot OM + .038 \cdot SA - 4.824$	$r^2 = .82$
$FC = .288 \cdot SA + .153 \cdot P_{>2}$	$r^2 = .38$
$FC = .264 \cdot CL + .302 \cdot P_{>2} + 11.077 \cdot BD_t - .179 \cdot R_v - .188 \cdot SA + 14.941$	$r^2 = .51$
$FC = .414 \cdot CL + .007 \cdot P_{>2} - 38.611 \cdot BD_t + 39.645 \cdot BD_{<2} + .351 \cdot R_v + .064 \cdot OM - .173 \cdot SA + 29.411$	$r^2 = .70$
$AWC = -.199 \cdot CL - .098 \cdot P_{>2} - 21.773 \cdot BD_t + 22.266 \cdot BD_{<2} + .211 \cdot R_v - .164 \cdot OM - .207 \cdot SA + 31.894$	$r^2 = .54$

†Symbols: CL = gravimetric percentage clay in <2mm mineral soil, $P_{>2}$ = porosity of rock fragments, BD_t = field bulk density (Mg m^{-3}), $BD_{<2}$ = fine soil bulk density (Mg m^{-3}), R_v = volumetric rock fragment content, OM = organic matter percentage in <2mm soil, SA = gravimetric percentage sand in <2mm mineral soil, AWC = volumetric available water content percentage, FC = volumetric water content percentage at field capacity, WP = volumetric water content percentage at seasonal low.

CONCLUSIONS

To properly quantify available soil water for a skeletal soil there are several measurements or estimates which must be made: total bulk density, rock fragment content, water content at the driest part of the season, water content at field capacity, rock fragment particle density, and rock fragment porosity. From this data set available water can be calculated using the equations in this paper. This is a preferred method since it accounts for soil variability and profile layering, which can be of considerable importance in skeletal soils. There are several simplifications that can be used if only general information is needed for a soil.

Bulk density measurements for skeletal soils require sampling a large volume and making several determinations in order to estimate variability. The total bulk density samples are also used to calculate rock fragment content and fine soil density. If measurement of all quantities is not possible, estimates may be made with limited accuracy. Two approaches are possible. The first approach is to estimate those soil properties that cannot be easily measured. These estimates should be based on some knowledge of the soil in question; personal experience or soil survey information would be the most valuable. The measured and estimated values can then be used in the various deterministic equations presented to calculate water retention. The second approach is to use some type of regression equation, such as those reported here (Table 2.3). These regression equations also require several estimated or measured soil properties. The regression equations are based on probabilistic relationships rather than the deterministic relationships shown throughout the text. This difference make regression equations well suited for accurate estimates of average values. Probabilistic estimates may therefore be quite appropriate for planning efforts but measurements are preferred for management of specific sites.

The measurement of water content should be expressed on a whole soil basis by correcting small moisture can samples to field basis using the techniques described. Field capacity water content can be measured by using a wetting procedure in the summer, at the same time that the dry season measurement is made. The site should be wet up and allowed to drain. It may be wet up a second time to reduce lateral water loss and hysteresis effects. Summer measured field capacity estimates are useful for planning but measurements taken in early spring give a better estimate because they would include water held in the profile due to layering that may not be easily seen from the summer wet-up (Salter and Williams, 1965; Clothier, Scotter, and Kerr, 1977).

Bulk specific gravity can be estimated from Figure 2.3 if particle density is known or estimated based on parent material. If particle density is measured by using a water pycnometer, it is convenient to measure porosity with the same sample. These two values allow calculations of rock fragment bulk density. In our study, field capacity water content depended considerably on rock fragment porosity and sand content. Since the sand fraction is usually derived from the same material as the rock fragments, natural porosity of these fractions may be closely related. Therefore this porosity may contribute to the water holding capacity of the sand as well as the rock fragments.

Measurement of soil water supply in skeletal soils is complicated by the fact that rock fragments hold water. Since it is likely the smaller fragments are more porous than larger (Coile, 1953; Hanson and Blevins, 1979), less weathered fragments, it may be that increasing the upper size limit of the "fine soil fraction" may be a reasonable way to simplify soil water measurement procedures. By including all soil particles up to 5mm in diameter in soil water measurements, i.e. fine soil density and gravimetric water content, the significance of the water holding capacity of the remainder of the larger, less porous rock fragments may be reduced. This shift in the arbitrary break between fine and coarse soil material would, however, increase the variability of properties of the fine soil fraction.

SUMMARY

The physical characterization of southwest Oregon forest soils required the development of the bead cone sampler. The sampler, designed to measure both rock fragment content and total soil density, has proved valuable in providing an accurate measurement of the physical properties with a minimum number of samples. The design allows for accurate sampling on steep, skeletal soils which comprise a large percentage of the manageable forest land in southwest Oregon. The bead cone sampler worked well when compared to the sand cone and a 76 mm diameter, 76 mm length corer ON SOILS where those samplers could be used. The corer did not work as well when rock fragment content was greater than 15 percent due to physical impedance and small sample size.

There are two soil density values of interest in skeletal soils: total density, which includes rock fragments, and fine soil density, which excludes rock fragments. It is the fine soil density which may be most important in managing soils. The exclusion of rock fragments for fine soil density calculations is based on effective rock fragment volume. The volume determination of rock fragments is not straightforward when weathering rinds, fractures and other natural pores are included. It was determined that rock fragment bulk density, which averaged 2.0 Mg m^{-3}, is more appropriate in calculations of volume than the particle density, which averaged 2.6 Mg m^{-3}.

The dilution effect of rock fragments may have contributed to the high concentration of organic matter in the fine soil, which averaged 12 percent. On a whole soil basis the organic matter would be lower (6 percent), but this number would be misleading since its importance is in the fine soil. The fine soil, in addition to its high organic matter content, was dominated by sand. This becomes important in considering soil chemical properties and fertility management since most biological activity, such as root growth and decomposition is occurring there. It should be kept in mind that the soil resource has many interactive properties. Soil resource managers, whether evaluating fertility, chemical processes, water flow, heat flow, soil classification or forest tree growth and yield should be aware of the current measurement techniques and methods of calculating and using physical properties for skeletal soils.

Linear models, which are commonly used to predict available water content (Alexander, 1982), were developed from the data presented. These models are useful for some management applications but cannot be used to predict reforestation success on specific sites. The modeling analysis showed that the nature of the rock fragments contributed greatly to prediction of water retention. Rock fragment porosity is the most influential property affecting dilution of available water with increasing rock fragment content. The total reduction is not as severe in soils where the rock fragment porosity is high and contributes significantly to total available water.

Clay content was most influential in predicting water content at the seasonal low whereas the sand was more influential in predictions of field capacity. The inclusion of fine soil texture and organic matter content, however, was of minor importance in predicting total water retention in skeletal soils. Soil texture and organic matter percentage are more important in other areas of investigation, such as cation exchange and organic matter cycling.

The information presented here can be used in several ways to aid in managing skeletal soils. For specific sites, the measurement procedures outlined can be used for accurate determination of total available water and soil density. The equations presented also allow for the conversion of gravimetric data to a volume basis. Volume conversions are appropriate for many measurement applications, such as fertility, microbial activity, and available water supply. The volume conversion technique presented here properly account for rock fragment volume by including their natural porosity. The use of a large bulk sample for the original characterization of a site allows small, more variable subsamples to be used for subsequent measurements. Finally, the data and models presented can be used to estimate available water or other physical parameters on specific sites if direct measurement is not possible. It is recommended that measurements be taken for most sites since the data presented here are only averages. The data can, however, be used as a reference for estimating other physical properties.

REFERENCES

Alban, David H. 1974. Soil variation and sampling intensity under red pine and aspen in Minnesota. U.S. Dept. of Agric., Forest Service North central Forest Exp. Stn. Research Paper NC-106, 10 pp.

Alexander, E. B. 1977. Measurement of soil depth and horizon thickness. Soil Survey Horizons, Spring 1977.

Alexander, E. B. 1982. Available water capacities of California soils in relation to water retention at different matric potentials. Earth Resources Note 2, Region 5, U. S. Forest Service.

A.S.T.M. 1977 Absorption and bulk specific gravity of natural building stone. American Society For Testing and Materials. ANSI/ASTM R 97-47 Annual Book of ASTM Standards, Part 19.

A.S.T.M. 1982a. Density of soil in place by the rubber-balloon method. Amer. Soc. for Testing and Materials, ANSI/ASTM D2167-66, Annual Book of ASTM Standards, Part 19.

A.S.T.M. 1982b. Density of soil in place by the sand cone method. Amer. Soc. for Testing and Materials, ANSI/ASTM D1556-64, Annual Book of ASTM Standards, Part 19.

Berger, E. C. 1976. Partitioning the parameters of stony soils, important in moisture determinations into their constituents. Plant and Soil 44, 201-207.

Blake, G. R. 1965a. Bulk density. In C. A. Black (ed.) Methods of soil analysis, Part 1. A. S. A. Monograph 9:374-390. Am. Soc. Agron., Madison, Wis.

Blake, G. R. 1965b. Particle density. In C. A. Black (ed.) Methods of soil analysis, Part 1. A. S. A. Monograph 9:371-373. Am. Soc. Agron., Madison, Wis.

Childs, S. W. 1982. The nature of skeletal soil in steep terrain. In Proc. Reforestation of Skeletal Soils Workshop, OSU Forest Intensified Research Program, Medford, OR. Nov. 17-19, 1981.

Clothier, B. E., D. R. Scotter and J. P. Kerr 1977. Water retention in soil underlain be a coarse-textured layer: Theory and field application. Soil Sci. 123: 392-399

Coile, T. S. 1953. Moisture content of small stone. Soil Sci. 75:203-207 deMoulin, L. A., J. A. Pomerening and B. R. Thomas. 1975. Soil inventory of the Medford District. U.S.D.I. Bureau of Land Management. Medford, OR.

Elonen, Paavo. 1971. Particle size analysis of soil. Acta Agracia Fennica, Univ. of Helsinki. 122pp.

Flint, A. L. and S. W. Childs. 1983 Development and calibration of and irregular hole bulk density device. Submitted to the Soil Sci. Soc. Amer. J.

Geist, J. Michael, and Gerald S. Strickler. 1978. Physical and chemical properties of some Blue Mountain soils in northeast Oregon. U.S. Dept. of Agric., Forest Service, Pacific Northwest Forest and Range Exp. Stn. Research paper PNW-236, 19 pp.

Hanson, C. T. and R. L. Blevins. 1979. Soil water in coarse fragments. Soil Sci. Soc. Amer. J. 43:819-820

Howard, R. F., and Singer, M. I. 1981. Measuring forest soil bulk density using irregular hole, paraffin clod, and air permeability. Forest Sci. 77:316-322.

Keisling, T. C., and D. A. Smittle. 1981. Soil bulk density corrections for providing a better relationship with root growth in gravelly soil. Commun. in Soil Sci. and Plant Anal. 12(1):91-96.

Mader, D. L. 1963. Soil variability--a serious problem in soil-site studies in the Northeast. Soil Sci. Soc. Am. Proc. 27:707-709.

McLintock, T. F. 1959 A method for obtaining soil sample volumes in stony soils. J. Forestry, p. 832-834.

Merriman, J. 1958. Laboratory evaluation of the volumeter no. 770 for field density test volume determinations, Laboratory Report REM-2, U.S. Bureau of Reclamation.

Minore, D., C. E. Smith, and R. F. Woolard. 1969. Effects of high soil density on seedling growth of seven northwestern tree species. U.S.D.A. Forest Service Research Note PNW-112.

Mollitor, A. V., A. L. Leaf, and L. A. Morris. 1980. Forest soil variability of northeastern floodplains. Soil Sci. Soc. Am. J. 44:617-620.

Reinhart, K. G.. 1961 The problem of stones in soil-moisture measurement. Soil Sci. Soc. Proc. 1961 268-270

Salter, P. J. and J. B. Williams. 1965. The influence of texture on the moisture characteristics of soils. I. A critical comparison of techniques for determining the available-water capacity and moisture characteristic curve of a soil. Journal of Soil Sci. 16:1-15

Shipp, R. F., and R. R. Matelski. 1965. Bulk density and rock fragment determinations on some Pennsylvania soils. Soil Sci. 99:392-397.

Soil Science Society of America. 1978. Glossary of soil science terms. S.S.S.A., Madison, Wis. 36pp.

Tavenas, F. A., R. S. Ladd, and P. La Rochell. 1973. Accuracy of relative density measurements: results of a comparative test program. p. 18-60. In ASTM STP 523, Evaluation of relative density and its role in geotechnical projects involving cohesionless soils, American Society for Testing and Materials.

Terry, T. A., D. K. Cassel, and A. G. Wollum II. 1981. Effect of soil sample size and included root and wood on bulk density in forested soils. Soil Sci. Soc. Am. J. 45:135-138

Vomocil, J. A. 1954. In situ measurement of soil bulk density. Agric. Engr. 35:651-655.

Wert, S. R., J. A. Pomerening and T. S. Gibson. 1977. Soil inventory of the Roseburg District. U.S.D.I. Bureau of Land Management. Roseburg, OR.