THE NEUTRON METHOD OF MEASURING THE MOISTURE CONTENT OF FLORIDA SOILS

L. C. HAMMOND
Associate Soil Physicist
Florida Agricultural Experiment Station
Gainesville

The feasibility of using the neutron (part of the atomic nucleus) to measure the moisture content of soils was shown in 1950 (1) and commercial instruments became available in 1954 (6). Advantages claimed for the neutron method are particularly attractive for field research involving soil moisture-plant relationships. This paper presents the results of calibration and moisture measurement studies on sandy soils with a neutron meter.

Theoretical principles are reviewed in detail by van Bavel (7). In summary the method is based upon the fact that hydrogen, which is part of the water in the soil, interacts with fast neutrons to a greater extent than any other element found in significant quantities in most mineral soils. The fast neutron, after several collisions with hydrogen, loses sufficient energy to become a slow or thermal neutron. The number of these slow neutrons around a given source of fast neutrons placed in the soil is directly proportional to the amount of hydrogen (and water) per unit volume of surrounding soil. The instrumentation consists of a fast neutron source, a slow neutron detector, and a counting device. In practice the fast neutron source and the detector tube are lowered into an access tube in the soil and connected by cable to a portable scaler above ground. The slow neutron count during a fixed time is checked on a calibration curve to give the soil-water content in percent by volume.

Experimental Procedure

The Nuclear-Chicago d/M Gauge with a 5 millicurie source of fast neutrons was used in these studies. The calibration curve supplied with the instrument and covering a moisture content range of 10 to 50 percent by volume, was checked by field sampling. Additional calibration points were needed for the less than 10 percent moisture range found in many well-drained sandy soils in Florida. Six calibration points ranging from 5.5 to 24 percent moisture were obtained from 3 soil series: Lakeland, Arredondo, and Leon. A steel tube (1 21/32 inches O.D., 1 9/16 inches I.D.) 3 to 4 feet in length was driven into the soil at the selected sampling site, withdrawn, emptied of soil and re-introduced into the sample hole. Neutron counts were obtained with the fast neutron source centered at least 12 inches below the soil surface. From 4 to 9 soil core samples 3 inches in diameter and 3 inches long were collected with a Uhland type sampler immediately adjacent to the tube and at various depths within 12 inches of the neutron source. The moisture content of the soil cores was determined gravimetrically with drying at 110°C, and the results were expressed on a per unit volume basis.

The calibration curve resulting from the above procedure was used to compare the gravimetric and neutron methods of estimating the moisture content of Arredondo soil profiles under 20-year Hamlin orange trees in the College citrus orchard. The soil profile in this 2-acre site consists of seven to eight feet of fine sand to loamy fine sand underlain by sandy clay. Four trees were selected in a single row across the orchard and two steel access tubes (91 inches long) per tree were placed at random points on a circle 3 to 4 feet from the tree trunk. Neutron counts were taken every six inches to a depth of 84 inches. On three dates, in addition to the neutron counts, soil cores (3X3 inches) were collected from 2 profiles per tree at 6, 12, 24, and 36-inch depths. The profiles were located at random points on the same circle as the access tubes, but not closer than 18 inches to them. The soil was oven-dried at 110°C, and the moisture content expressed on a per unit volume basis. The moisture data obtained by the two methods on three dates at four depths were subjected to an ordinary analysis of variance.

Results and Discussion

The straight line fitted by least squares to five of the six neutron calibration points is...
given in Figure 1. The equation of the line is: 
\[ y = -2.20 + 40.83x \]  
where \( y \) is the estimated percent moisture by volume and \( x \) is the ratio of neutron counts in the soil and in the standard shield. The standard deviation from regression is 0.76 percent. A segment of the calibration curve supplied with the neutron instrument is also shown in Figure 1. The equation for the straight line is \( y = 2.65 + 30.84x \) and the standard deviation from regression is 0.63 percent. The latter calibration was obtained with steel tubing 1.625 inches O.D. and 1.555 inches I.D. while the steel tubing used in the present study was 1.630 inches O.D. and 1.560 inches I.D. This difference in access tubing size probably contributed very little to the discrepancy between the two calibration curves.

The calibration data from the three sandy Florida soils indicate that the calibration curve accompanying the neutron meter can be used on these soils only at soil-moisture contents greater than about 15 percent. At lower moisture contents a different straight line segment is suggested by the data. A curvilinear relationship in the low moisture range and in the same direction as the above deviation was obtained by others (1, 2). One would expect a positive rather than a negative count ratio at zero moisture content because of the presence of soil elements, other than hydrogen, which have a slight moderating effect on fast neutrons. In addition, small amounts of hydrogen are found in clay and other secondary minerals.

### TABLE 1. Gravimetric and neutron estimates of the soil-moisture content of Arredondo fine sand profiles under Hemlin orange trees on three dates

| Depth (inches) | February 19, 1959 | April 9, 1959 | April 30, 1959 | Average 3 dates
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<tbody>
<tr>
<td></td>
<td>Gravimetric</td>
<td>Neutron</td>
<td>Gravimetric</td>
<td>Neutron</td>
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<tr>
<td>6</td>
<td>8.65</td>
<td>5.41</td>
<td>9.42</td>
<td>6.06</td>
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<tr>
<td>12</td>
<td>8.27</td>
<td>8.10</td>
<td>8.69</td>
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<td>18</td>
<td>8.15</td>
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<td>8.38</td>
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<tr>
<td>24</td>
<td>7.96</td>
<td>8.06</td>
<td>8.34</td>
<td>8.20</td>
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<td>30</td>
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<td>7.79</td>
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<td>36</td>
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<td>42</td>
<td>-----</td>
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<td>48</td>
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<td>-----</td>
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<td>54</td>
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<td>7.29</td>
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<td>10.80</td>
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<td>-----</td>
<td>19.80/4</td>
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<td>76</td>
<td>-----</td>
<td>8.44</td>
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<tr>
<td>84</td>
<td>12.40</td>
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1/ Average of eight profiles except for the gravimetric method where samples were lost as follows: two at 12 inches and one each at 24 and 36 inches on February 19th and one at 12 inches and two at 36 inches on April 9th.
2/ Neutron values averaged only where gravimetric averages were available.
3/ Water table at average depth of 80 inches.
4/ Water table at average depth of 90 inches.
The results of the field test of the new calibration curve are given in Table 1. Rainfall of approximately 2 inches occurred 12 days before the February 19th sampling and eight days before each of the April samplings. Thus, in all cases the moisture content of the top three feet of soil was less than field capacity determined 48 hours after a rainfall (3).

The error mean squares were 0.9797 and 0.7949 for the gravimetric and neutron methods, respectively. The respective standard errors for the means of eight samples were 0.35 and 0.32 percent moisture by volume. The two methods provided estimates of the moisture content with about equal precision. The standard errors of estimates were in the range of those previously found in sampling the College citrus orchard at nearly comparable soil moisture conditions (3). Two factors may have caused the neutron results to be slightly less variable than the gravimetric. First, the sample size was larger for the neutron than for the gravimetric method. The data for the 6-inch depth clearly indicate that the radius of the sphere of influence of the neutron method was greater than six inches. Second, the neutron samplings on subsequent dates were made on the same soil sample while the gravimetric method resulted in a destruction of the sample. Thus, there was a tendency for neutron measurements to respond alike from date to date as was found for tensiometers by Richards (4).

The moisture content at the six-inch depth was significantly (0.05% level) higher than at the other depths for the gravimetric method and significantly (0.001% level) lower for the neutron method. This discrepancy resulted in an overall significant (0.001% level) difference in methods. However, it is clear from the data in Table 1 that there were no significant differences between methods at depths of 12, 24 and 36 inches. The under estimate of the moisture content at six inches by the neutron method was due to the loss of neutrons through the soil surface. A study of the spatial sensitivity of this equipment in sandy soils is in progress.

For both methods, date and tree were the only other significant (0.05% level, except 0.001% level for date with gravimetric method) sources of variation.

The two-minute counting time resulted in total counts of approximately 2000 and 3600 at moisture contents of 5 to 10 percent respectively. The ratio of counts in the soil to counts in the standard shield minimized errors due to instrument drift (7). Approximately one in every ten readings were made in the shield. The standard error of the above respective total counts would be 45 and 60 counts or 2.25 and 1.67 percent of the counts per two minutes. These standard errors in terms of the moisture content, using the new calibration curve, would be approximately 0.15 and 0.20 percent moisture by volume. In view of the fact that the standard deviation from the regression curve is 0.76 percent moisture by volume there is no reason to increase the counting time in order to reduce the counting error. The calibration error should be reduced by additional sampling. However, the mean of eight neutron moisture samples was estimated with the present calibration curve within ± 9 percent of the mean. Estimates of the soil-moisture content in the field with a better precision than this are difficult to obtain and are not necessary for most field work (3, 5). Thus, advantages such as time and labor savings, non-destructive sampling and a single calibration curve valid for most mineral soils, can be realized for the neutron method in soil moisture determinations in sandy Florida soils.

**Summary**

The neutron and gravimetric methods of determining the soil-moisture content of Arredondo fine sand were compared on three dates utilizing a calibration equation established for the low range of moisture contents found in sandy Florida soils. The two methods were about equal in precision and the moisture estimates did not differ significantly except at the 6-inch depth where the neutron estimate was low due to the loss of neutrons through the soil surface. The data showed that the neutron meter and the calibration equation were satisfactory for the measurement of the moisture content in a narrow range of values on a sandy Florida soil. Some characteristics, advantages and limitations of the neutron method were indicated.

**Acknowledgements**

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LITERATURE CITED


THE PRODUCTION AND FUTURE OF HYBRID VEGETABLES

J. R. Wall

In general terms a hybrid is an off-spring from the mating of parents of different genetic makeup. The differences may be minor or they may be large. However, to the farmer or seedsman, a hybrid is the result of crossing inbred strains of a particular crop. The maximum degree of hybrid vigor is to be found in the first generation (F₁) following the cross, with reduced hybrid vigor in each subsequent generation. For this reason the term hybrid may be misleading unless it is qualified by the terms F₁ or F₂ generation.

To the average person a magical quality is associated with hybrids, whether they be in flowers, vegetables, or animals. Apparently some breeders have been impressed by this magic, for they have at times introduced poorly adapted hybrids poorer in performance than good standard varieties. It should be emphasized that not all hybrid plants show hybrid vigor, even though the general public is often led to believe that all do.

Hybrids which do well under some conditions or in some localities may do poorly in others. As in conventional variety breeding, the breeder who wishes to utilize hybrid vigor must have specific aims and purposes. The performance of a hybrid depends upon its genetic constitution, and therefore is a result of the hereditary makeup of its parental inbreds. The plant breeders' major task is the development or selection of suitable inbred lines to use as parental material. In the development of these lines, the effectiveness of selection for particular characteristics, the accurate measurement of these characters, and the extent of their heritability are highly important. There are no short cuts for this complex job.

The secret of the success of good adapted F₁ hybrids is that all the plants of a given hybrid are good producers. In open-pollinated varieties a few plants which may be superior to a good hybrid can be found, but many are inferior. Uniformity of production makes the big difference between performance of good hybrids and open-pollinated varieties.

Hybrid Vigor

Hybrid vigor and what it is have puzzled man for centuries. He has used it even though he could not explain it. The hybrid vigor of the mule was known to ancient man. The mule has been called an animal without pride of ancestry or hope for posterity. Darwin (2) was an early observer of hybrid vigor in plants and noted that the progeny of two individuals were frequently more vigorous than either parent. Darwin stated that nature abhors continued self-fertilization since she has made many provisions to insure cross-fertilization.

In 1909 Shull (15) stimulated great interest in the possible use of F₁ hybrid seed when he advanced his hypothesis for the production and utilization of F₁ single-cross hybrids in corn. Shull had noticed that when two inbred lines of corn are crossed, the vigor of their progeny increased greatly. He suggested that the term heterosis be given to the physiological stimulus of heterozygosis.

Even today, 50 years after Shull's paper describing hybrid vigor was published, the causes of heterosis are not fully understood. An explanation of hybrid vigor resides in the fundamental chemistry of the plant, with the hybrid being more able to synthesize needed metabolites for growth and reproduction.

As is often the case, there was a considerable time lag between the demonstration of hybrid vigor in corn and its practical application, Fol-