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This Week's Citation Classic

Newman E I. A method of estimating the total length of root in a sample. *J. Appl. Ecol.* **3**:139-45, 1966. [Dept. Botany, Duke University, Durham, NC]

The paper proposes a method in which roots are laid out on a flat surface and a count is made of the number of intersections between the roots and random straight lines. The total root length is then calculated by a simple formula. The paper describes tests showing the accuracy of the method and the length of time taken for samples of different size. [The *SCI*® indicates that this paper has been cited over 170 times since 1966.]

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"The basic idea for this method came to me while I was working for my PhD at Cambridge University in the late 1950s. A species I was studying, *Rumex acetosella,* spreads by horizontal roots. I wanted to estimate the total length of these roots without excavating them completely, and it occurred to me that I could do this by counting the number crossing a trench. Subsequently I dropped *Rumex* to concentrate on other species, and never used these results.

"In 1964-1965, while I was working with Paul Kramer at Duke University on root growth and water uptake, I wanted to determine the total length of the root systems of plants. Most plants have great lengths of root, making direct measurement very time-consuming, so some quick method of estimation was needed. It occurred to me that the method I had devised for *Rumex* could be modified for any root system once washed out of soil: the roots would be spread out on a flat surface (of area A) on which there were sample lines (total length H), and the number of intersections (N) between roots and lines would be counted. I could see intuitively that an estimate of the length of root, R, would be given by

$$R = k\frac{NA}{H}$$

where k is a constant, but I was not enough of a mathematician to know what the value of k would be. I consulted my father, a professor of mathematics at the University of Manchester; he referred me to Moran in Canberra, who in turn told me that the answer had been known since the nineteenth century: $k = \pi/2$. Using this constant, I checked my line intersection method against direct measurement, with roots from several different species, and found very good agreement.

"My paper describing the method was rejected by two journals, but fortunately Kramer encouraged me to try again. In the paper originally submitted, the method used regularly arranged sample lines. The referee of the *Journal of Applied Ecology,* a statistician, objected to this and I therefore modified the method to use random lines. Subsequently, several papers, e.g., Marsh,[1] pointed out that it is quicker to use regularly arranged lines and the loss of accuracy is small.

"I have not spent any further time developing root measuring techniques, but papers have been published by other people who tested and modified the method. Many of these are cited by Böhm.[2] The method has been automated using either mechanical movement of the roots past a photoelectric counter, or an electronic scanner, but neither of these methods has been widely used. I think a crucial feature in the popularity of my original method is that it uses only simple apparatus available in any laboratory."

1. **Marsh B a' B.** Measurement of length in random arrangements of lines. *J. Appl. Ecol.* **8**:265-7, 1971.
2. **Böhm W.** *Methods of studying root systems.* Berlin: Springer-Verlag, 1979. 188 p.