Determination of Attenuation Coefficient and Water Content of Broccoli Leaves using Beta Particles

Komal Kirandeep
Department of Mathematics, Statistics and Physics, Punjab Agricultural University Ludhiana, India-141004

Parveen Bala
Department of Mathematics, Statistics and Physics, Punjab Agricultural University Ludhiana, India-141004

Amandeep Sharma
Department of Mathematics, Statistics and Physics, Punjab Agricultural University Ludhiana, India-141004

ABSTRACT
In present investigation water content in the leaves of Broccoli has been determined using their attenuating characteristics to beta particles of ^{204}Tl. The mass attenuation coefficient is obtained as the slope of leaf thickness versus logarithm of relative transmission intensity. As the water content in the leaves varies, these parameters also vary. The transmission intensity decreases with increase of water amount in plant leaves. Beta attenuation is a fast, reliable and non-destructive method that provides continuous monitoring of plant water status.

Keywords
Mass attenuation coefficient, Water content of leaves, Beta particle transmitted intensity, Non- destructive inspection

1. INTRODUCTION
Mass attenuation coefficient is the capability of a material to absorb or scatter radiations as they pass through them. The attenuation studies in matter have helped the researchers in solving variety of problems in physical sciences, bio-sciences, agricultural science and medical physics [1]. Beta particle attenuation yields fundamental information on material composition such as thickness, water content etc. Nathu Ram et al. [2], Thontadarya [3], Batra et al. [4] have witnessed the measurement of mass attenuation coefficients through different materials as a function of energy, atomic number of the absorber and experimental geometries. Mahajan [5] measured attenuation coefficients for some elements and found to be in agreement with empirical relation.

On large scale, water content of the leaves and vegetation is an important variable in physiological plant activities. It maintains their vitality, photosynthetic efficiency and hence is an important production limiting factor. Actual water content of the leaves and plants varies with its type and the environmental conditions. When leaves dry up, they mainly lose their water content and hence it is found to be a strong indicator of vegetation stress also. Mederski [6] introduced beta radiation gauge for measuring relative water content in leaves of soyabean plant. Jarvis and Slatyer [7], Obrigewitsch et al. [8] made an attempt to calibrate the beta gauge for determining the leaf water status using cotton leaf as absorber. The calibration requires the fully turgid leaf in addition to completely dry and fresh leaves. Beta gauging technique makes the method little awkward due to the loss of organic matter. However, in present work the technique is modified by estimating the absolute water content through fresh leaves using Geiger Muller counter.

Some spectroscopic methods have also been used to determine water content in leaves. Xiangwei et al. [9] used parameters such as leaf reflectance, correlation coefficients and spectral index for determining crop water content. Ullah et al. [10] estimated leaf water content from the mid to thermal infrared (2.5–14.0 μm) spectra, based on continuous wavelet analysis. Yi et al. [11] used hyperspectral indices to estimate water content in cotton leaves. It aimed on the relation between water content and hyperspectral reflectance. It aimed at identifing an index for remote water content estimation and correlated field spectral measurements to leaf water content. Recently, Giovanni et al. [12] detected crop water status in mature olive groves using vegetation spectral measurements and regression. However, this technique requires the availability of full spectra with high resolution, which can only be obtained with handheld spectro-radiometers or hyper-spectral remote sensors.

A more reliable beta attenuation technique overcomes the sophistication of instruments/techniques used in spectroscopic methods and measures the water content in a convenient way. Although the beta-gauging technique has been explored in the past for several applications, yet the direct use of measured mass attenuation coefficient has not been utilized successfully for the purpose. To the best of our knowledge there is no study of this type, plotting moisture content versus transmitted intensity, for Broccoli leaves using beta particles using ^{204}Tl radioactive source.

2. THEORY
Water constitutes the major portion in a plant leaf. Thus changes in water content of plant leaves are reflected by changes in the absorber thickness. The attenuation of beta radiation through a plant leaf depends upon mass per unit area of the leaf. The intensity of transmitted beta radiation through a plant leaf , is given as;

$$I = I_0 exp^{-\mu t} \quad (1)$$

Where I_0 is the intensity of the unattenuated beta radiation, t and μ are the thickness and mass attenuation coefficient respectively of leaf (organic matter and water). From this equation mass attenuation coefficient (μ) can be calculated by knowing the other quantities. Rewriting equation (1) for a fresh leaf as

$$t_f = \frac{1}{\mu_f} \ln \left(\frac{I_0}{I_f}\right) \quad (2)$$

And for a completely dry leaf

$$t_d = \frac{1}{\mu_d} \ln \left(\frac{I_0}{I_d}\right) \quad (3)$$

Where t_d, I_d and μ_d are the mass per unit area, intensity and mass attenuation coefficient respectively of completely dry leaf (organic matter).

Since leaves contain organic matter and water, we can write

$$t_w = t_f - t_d \quad (4)$$

Where t_w is the mass of water per unit leaf area. Using equations (2), (3) and (4), we get,

$$t_w = \frac{1}{\mu_d} \ln \left[\left(\frac{I_0}{I_f}\right)^n X \left(\frac{I_0}{I_d}\right) \right] \quad (5)$$

And $n = \mu_d/\mu_f$; the ratio of mass attenuation coefficients of completely dry leaves to those of fresh leaves. Thus, using the experimental values of μ_d, μ_f and I_d/I_0 and measuring the ratio I_f/I_0 for a fresh leaf, equation (5) provides the absolute water content. For direct weighing measurements of leaf, the percentage water content is given by the following formula [8]:

$$\% \text{ water content} = \left[\frac{fresh\ leaf\ mass - dry\ leaf\ mass}{fresh\ leaf\ mass}\right] x100 \quad (6)$$

3. EXPERIMENTAL

The picture of experimental arrangement used in present investigations is shown in Fig. 1. Radioactive source ^{204}Tl

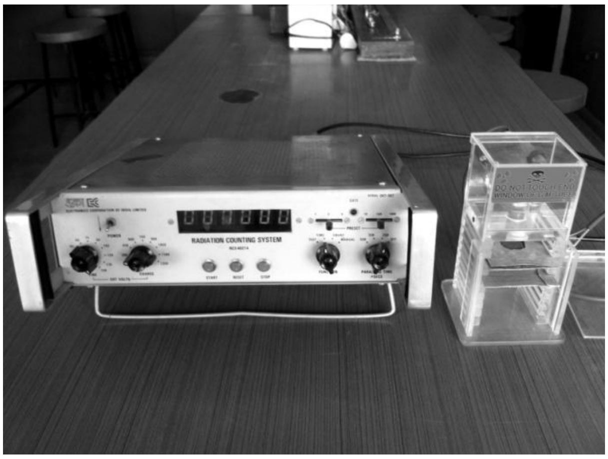

Fig 1: Experimental set-up for measurements

with end point energy 0.766 MeV, has been used as a source of beta particles. The Geiger Muller counter is used for intensity measurements of experimental study. The plant leaves of broccoli that act as attenuating medium are held between two rectangular equal sized aluminum sheets, having 2.5 cm diameter matching holes. The distance between beta source and GM window is kept 4.3 cm while placing leaf sample almost at the middle of this gap. The source-absorber-detector geometry is centrally aligned. This geometry is kept same during the experiment that results in non-varying scattering and air absorption effects. A Geiger Muller tube operating at the middle of the beta plateau i.e. at 450 Volt, is used for measuring the beta intensity. The output of the tube is amplified and fed to the discriminating and scaling units of a counter.

The leaves of Broccoli are taken from fields of Punjab Agricultural University, Ludhiana. Leaves to be investigated are washed with water and then soaked for a few minutes in layers of blotting paper. Circles of radius 3.1 cm were cut from the leaves and mass of each circular leaf is determined by weighing with an electrical balance having an accuracy of 10^{-4} gm. The transmission studies of beta particles are made through these fresh leaf circles. The observation time chosen for each absorber thickness is 200 sec and statistical error in observed counts remains below 2%. The stability of the apparatus was checked by keeping it on for sometimes and also by taking three or more readings for the selected plant leaf.

After doing the transmission study of one fresh leaf circle, another leaf circle was placed exactly above this leaf circle and transmitted intensity was noted. Likewise leaf circles are placed one above the other and their transmission study was done. The counts are noted for the increasing leaf circles till they showed sensitivity to the beta particles and the apparatus. In second part of this work, for variation in water content of leaves, one circular leaves is selected for investigations. The circular leaf is kept under an IR lamp for one minute. This evaporates some amount of water from the leaf and reduces its thickness (mg/cm^2). Transmission of beta particles is measured through this leaf and counts are noted. The same leaf sample is again exposed to one minute IR radiation, which causes further drying and reduction in thickness. The transmitted intensity is measured again for this dried leaf. This process is repeated till it shows sensitivity for transmission intensity.

4. RESULTS AND DISCUSSION

The data for broccoli leaf thickness and logarithm of relative transmission intensity has been shown in Table 1. The column 2 in data table contains the values for thickness of leaf. This thickness (mass per unit area) includes water content and organic matter of selected leaf. The column 3 shows the logarithmic values of relative transmission through leaves with different thickness.

The plot for this data of leave thickness versus logarithm of relative transmission intensity has been shown in Fig.2. The equations for the best fitted regression lines is linear one and

Table 1: Thickness versus counts of Broccoli with ^{204}Tl

Sr. No.	Thickness (mg/cm^2)	$-\ln(I/I_0)$
1.	28.62	0.713
2.	66.60	1.433
3.	100.80	2.060
4.	138.92	3.005
5.	174.58	3.730
6.	209.63	4.598

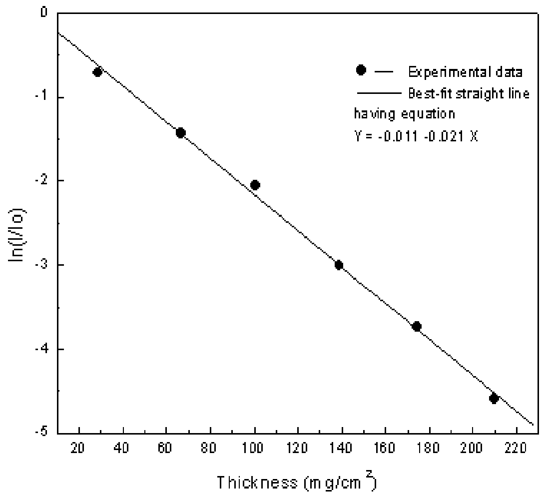

Fig.2.: The relative transmission (logarithmic) as a

function of leaf thickness

have been shown in the plot. This plot shows that relative transmission intensity decreases linearly with increase of leaf thickness. The slope of this fitted line gives the mass attenuation coefficient (as per equation 1) and determined value of μ is 0.021 cm^2/mg. A small value of attenuation coefficient indicates that the material in question is relatively

Table 2: Data for Broccoli leaf and ^{204}Tl beta source. The errors in count rate indicate statistical uncertainties only

Thickness of leaf (mg/cm^2)	Absolute moisture content t_w	Moisture content (%)		Transmitted intensity
		Beta attenuation	Direct weighing	
34.47	9.87	28.63	28.22	5027±71
32.38	7.71	23.81	23.59	5228±72
30.88	6.27	20.33	19.88	5652±75
29.66	4.93	16.62	16.58	5844±76
28.50	3.81	13.36	13.19	6205±79
27.51	2.83	10.29	10.06	6429±80
26.52	1.99	6.37	6.71	6673±82
25.63	0.98	3.82	3.47	6879±83

transparent, while larger values indicate greater degrees of opacity. Table 2 shows variation of water content with the exposure of leaf to IR heat radiation, and corresponding change in transmitted intensity. The column 2 of this table shows decreasing values for the thickness of water content (calculated by using 5) and is also known as the absolute moisture content. The percentage moisture content of the leaf by beta attenuation method and by direct weighing (calculated by equation 6) has been shown in columns 3 and 4 respectively. A comparison and close agreement of measured values by two methods provides authenticity of beta attenuation technique. Column 5 shows the transmitted intensity values, for different leaf thickness, increases with decrease in water content of leaves which must be obvious too. The errors quoted (less than 2%) in count rate indicate statistical uncertainties only. The slope of fitted lines (Fig.3) is negative because increase of water content causes more absorption of beta particles and hence decrease of transmitted intensity. The best-fit straight line serving as calibration curves provide an alternative way to measure moisture content. We believe that the present experimental findings with regard to agricultural fields will be quite useful to other investigators in improving their design for field instruments.

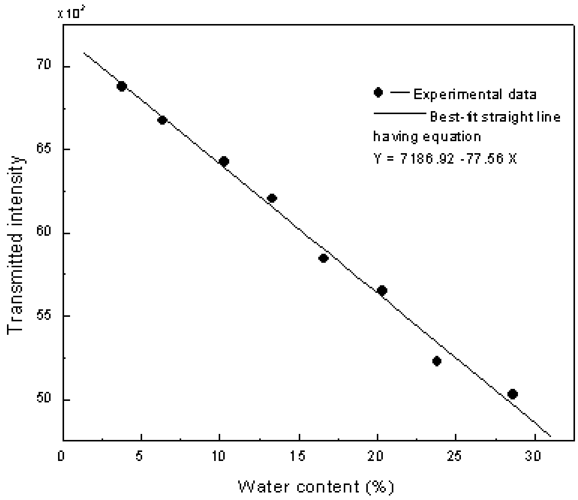

Fig3: Variation of transmitted intensity as a function of water content of broccoli leaf

5. CONCLUSION

The mass attenuation coefficient values are useful for quantitative evaluation of interaction of radiations with leaves of plants. Measuring leaf water content can build knowledge of the soil moisture status aiding in effective irrigation water management. The beta attenuation method overcomes the sophistication of techniques used in spectroscopic methods. Moreover, the method is fast, non-destructive, an easy-to-handle and hence can be utilized for planted leaves. Investigations based on beta transmission methods are rarely available for selected vegetable leaves that are grown in seasonal conditions of this region. It will lay an important foundation for sustainable development and modern agricultural technology. There is also a need to simulate the present experiment with some suitable Monte Carlo Simulation code for better understanding of present work to prototype the method in field practice.

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